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ABSTRACT

The central topic of this dissertation is environmental policy. Using a supply side approach to the problem of anthropogenic emissions of carbon dioxide the first essay studies the effect of backstop technology research on the speed at which fossil fuels are depleted. The key insight is that backstop technology research encourages fossil fuel owners to supply more of their resource in the near future because they anticipate that their resource will become obsolete before it is depleted. Thus, while backstop technology research offers the promise of an eventual decrease in carbon dioxide emissions, it creates a higher near future cost of climate change due to the increase in near future carbon dioxide emissions. The paper shows that even if backstop technology research was costless, for a large enough discount rate on the cost of global warming no backstop technology research can be optimal.

The following chapters study carbon abatement policy instruments from a political economy perspective. They illustrate some problems with both traditional cap and trade systems and carbon taxation and then proceed to propose an alternative policy instrument with significant advantages over these systems. The key feature of the proposed carbon securities is that they entitle their owners to a fixed proportion of ex ante unknown total emissions. The total level of carbon emissions is set by the political process after the carbon securities have been sold. In contrast to a traditional permit system, in which a government's choice of emissions quota is influenced by one lobby which represents industries that consume significant amounts of carbon-based energy, a system based on carbon securities creates an additional group of stakeholders with a strong incentive to get organized and influence the government's choice of an emission level. The advantages over existing systems include stronger commitment to abatement policy, an equilibrium carbon price closer to the social optimum, a more predictable environmental policy in the presence of either climate or political uncertainty, and higher investment in abatement technology.

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1 Introduction

Mounting scientific evidence suggests that the increase in atmospheric greenhouse gases has played a central role in raising the average surface temperature of the earth since the industrial revolution. Global warming is expected to cause the sea level to rise, increase the intensity of extreme weather events, change agricultural yields, increase the ranges of disease vectors, and lead to glacier retreat and species extinctions. In February 2007 the United Nations scientific panel on climate change declared that the evidence of a warming trend is "unequivocal," and that human activity is "very likely" the driving force in that change.[1] This added new momentum to a debate that these days seems centered less over whether humans are warming the planet, but instead over what to do about it.

The central theme of this dissertation is the question what are the effects of climate policy and which policy instruments are most promising for addressing the problem of global warming. The next chapter looks at research towards a backstop technology and its effect on the speed at which fossil fuels are depleted. It shows that fossil fuel depletion is accelerated by an increase in the research intensity of backstop technology research. I show that this effect should be considered before increasing research spending towards developing a backstop technology. The key insight is that backstop technology research encourages fossil fuel owners to supply more of their resource in the near future because they anticipate that their resource will become obsolete before it is depleted. Thus, while backstop technology research offers the promise of an eventual decrease in carbon dioxide emissions, it creates a higher near future cost of climate change due to the increase in near future carbon dioxide emissions. The paper shows that even if backstop technology research was costless, for a large enough discount rate on the cost of global warming no backstop technology research can be optimal.

The third chapter proposes a new carbon abatement policy instrument, carbon securities. Carbon securities are a financial instrument that enti-

[1] Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (2007-02-05).

tles its owner to a fixed proportion of ex ante unknown future emissions. The total level of carbon emissions is set by the political process after the carbon securities have been sold. In contrast to a traditional permit system, in which a government's choice of emissions quota is influenced by one lobby which represents industries that consume significant amounts of carbon-based energy, a system based on carbon securities creates an additional group of stakeholders with a strong incentive to organize and influence the government's choice of an emission level. The advantages over existing systems include stronger commitment to abatement policy, an equilibrium carbon price closer to the social optimum, a more predictable environmental policy in the presence of either climate or political uncertainty, and higher investment in abatement technology.

The fourth, fifth and sixth chapter consider extensions of the carbon securities model. The fourth chapter addresses the questions what effect the quantity of carbon securities that are bought by carbon-using firms has on the equilibrium. The fifth chapter studies what happens if the lobbying game is described as a Tullock game and then provides a number of reasons why a common agency lobbying model is a better choice than a Tullock model. The sixth chapter considers the practical implementation of carbon securities or more generally pollutant securities. It looks at the question how the current SO_2 allowance system in the United States could be changed into a SO_2 securities system.

2 Backstop Technology Research and the Depletion of Fossil Fuels

2.1 Introduction

Among the suggestions what to do about global warming one idea seems particular promising: developing an alternative, climate-friendly energy source, a backstop technology, in order to make fossil fuels obsolete. Such a technology would allow uncut energy consumption while not having a negative impact on the climate.

This paper studies the effect of backstop technology research on the depletion of fossil fuels. The key insight is that backstop technology research encourages fossil fuel owners to supply more of their resource in the near future because they anticipate that their resource will become obsolete before it is depleted. Thus, while backstop technology research offers the promise of an eventual decrease in carbon dioxide emissions, it creates a cost in the form of higher present day greenhouse gas emissions.

I apply methods of the theory of optimal extraction of exhaustible resources to study the effect of backstop technology research on the problem of global warming. The moment of development of the backstop technology is assumed to be an uncertain function of research effort. I show that an increase in backstop technology research effort leads to more planned near future fossil fuel extraction and thus higher near future carbon dioxide emissions. This change in the distribution of carbon dioxide emissions over time affects the cost of global warming for two reasons: First, planned extractions of the resource may never happen if a backstop technology has already been developed by that time. Second, a more gradual global warming is likely to be associated with lower cost since it makes adaptation easier. I show that the research intensity which minimizes the expected cost of global warming decreases with the discount rate used for global warming related costs. The final section of this paper illustrates the implications of the model by means of a numerical example. For this I use data published by the International Energy Agency (IEA, 2007).

This paper contributes to the literature on global warming, in particular on the effects of energy demand reducing policies such as backstop technology research. The supply side approach taken here complements the majority of the economic literature on global warming which has taken a demand side approach to this market failure. Typically the demand side literature has advocated demand reducing policies. A prominent example of this demand side perspective is Nordhaus' DICE model (1993, for a summary), an empirical Ramsey model of optimal economic growth with the addition of a climate sector. It studies the consumers' choice between consumption, investment in capital and greenhouse gas abatement without taking the energy suppliers into account. One of its main results is that the optimal carbon tax rises steadily over time. The basic structure of the DICE model has been used for a significant number of models including the RICE model (Nordhaus and Yang, 1996), a regional version of DICE, and the ENTICE model (Popp, 2004), which incorporates some endogenous technological change aspects. Another example of a much talked about study on global warming is the voluminous Stern Review (Stern et al, 2006), which also takes a demand side perspective and mentions the energy markets only in passing.

This paper is closest related to those papers that consider the problem of global warming within a framework that uses the methods of the literature on the optimal extraction of exhaustible resources. Sinn (2007a) compares the Pareto optimal extraction in a world with global warming to the extraction path that resource suppliers will choose. He looks at the effects of several demand reducing policies but does not consider backstop technology research. Hoel and Kverndokk (1996) study the optimal depletion of fossil fuels in the presence of a backstop technology in a world with global warming. They do not, however, unlike the paper at hand, consider the phase in which research towards a backstop technology occurs, but instead assume that a backstop technology already exists.

2.2 The Model

I consider a continuous time model of an economy with n identical suppliers of fossil fuels. The amount of fossil fuel resources owned by firm j at time 0 is $S_j(0)$ where $S_j(0)$ is an aggregate of different types of fossil fuels, summed with respect to their carbon content. So if the entire stock is consumed, the amount of carbon dioxide released is $S_j(0)$. Given the resource stock, a firm j chooses for each point in time t an amount of resource $R_j(t)$ to be extracted and sold. The profit of the firm at time t is $R_j(t)\,[P(R(t)) - c(S_j(t))]$ where P denotes the price of the fossil fuel, S the stock of the resource, $c(\cdot)$ is a cost function, and $R = \sum_{j=1}^{n} R_j$ the sum of the extractions of the n firms. The firm's decision problem is to find a sequence of extractions that maximizes profits. In the following R_j is used as short notation for $R_j(t)$, similarly S and P are to be understood as variables that may take different values at different points in time.

While the economy depends at the present time on fossil fuels for its energy needs, there is ongoing research to develop an alternative, climate-friendly energy source, henceforth referred to as backstop technology.

Definition 2.1 *A backstop technology is a technical process that can satisfy all energy needs of the economy at a cost lower than or equal to the cost of fossil fuels and that does not produce any greenhouse gas emissions. This implies that once the backstop technology has been developed there is no demand anymore for fossil fuels.*

I make the following assumption about the research process that leads eventually to the development of a backstop technology:

Assumption 2.1 *The probability that no backstop technology has been developed until time t is $e^{-\rho t}$, where ρ is the instantaneous probability of the development of a backstop technology which may change with time t.*

The probability ρ can also be understood as research intensity. The society can affect the choice of ρ via providing public funds for research on backstop technology or by giving subsidies to private companies active in the alternative energy field. The choice of ρ, which is given exogenously, and the cost of research function will not be explicitly considered in this paper. The question of interest is how fossil fuel owners react to a given research intensity.

All firms know the instantaneous probability that a backstop technology is developed, ρ. They are also aware of the strategies of all of their rivals which implies that they know the price path. At each point in time the firms play a Cournot game in the sense that they compete in quantities and firm j optimizes under the assumption that the other $(n-1)$ firms do not change their strategies if firm j changes its strategy.

I make the following assumptions about the demand for fossil fuels and the extraction cost:

Assumption 2.2 *Demand for fossil fuels can be described by an inverse isoelastic demand function $P(R)$ with $P'(R) < 0$ and an absolute price elasticity $\epsilon > \frac{1}{n}$. Additionally, $2P'(R) + P''(R)R_j < 0$. This is equivalent to requiring that the firm's revenue function is strictly concave.*

Assumption 2.3 *Unit extraction cost, $c(S_j)$, depend on the stock of the resource that firm j has at its disposal. The cost function is differentiable with $c'(S_j) < 0$ and bounded from above.*

The resource owner j maximizes the discounted sum of profits subject to some feasibility constraints:

$$\max_{\{R_j\}} \int_0^\infty (P[R] - c[S])R_j e^{-it} e^{-\rho t} dt \tag{2.1}$$

subject to

$$\dot{S}_j = -R_j$$

$$S_j(0) > 0$$

$$R_j, S_j \geq 0.$$

The first constraint is the equation of motion for the stock of the resource. The second constraint requires that the initial stock of firm j is positive. Finally, neither the amount extracted nor the stock are allowed to be negative.

Proposition 2.1 *Under assumptions 1 to 3, the solution to the optimal control problem in (2.1) is characterized by the following two conditions:*

$$(\rho + i) = \frac{\dot{P}(R)}{P(R) - \frac{\epsilon R}{\epsilon R - R_j} c(S_j)} \tag{2.2}$$

$$\lim_{t \to \infty} e^{-it-\rho t} \lambda(t) S_j(t) = 0 \tag{2.3}$$

Proof. The second condition of the proposition is a standard transversaltity condition for this type of optimal control problem. To derive the first condition, consider each firm's Hamiltonian

$$H_j = (P[R] - c[S_j])R_j - R_j \lambda_j.$$

An interior solution to (2.1) has to satisfy

$$\frac{\partial H_j}{\partial R_j} = P'(R)R_j + P(R) - c(S_j) - \lambda_j = 0. \tag{2.4}$$

Note that this is indeed a maximum because $\frac{\partial^2 H_j}{\partial R_j \partial R_j} = 2P'(R) + P''(R)R_j < 0$ by Assumption 2. Using the absolute price elasticity, $\epsilon = -\frac{\partial R}{\partial P}\frac{P}{R}$, equation (2.4) can be written as

$$\frac{P(R)R_i}{\epsilon R} + P(R) - c(S_j) = P(R)\left(1 - \frac{R_j}{\epsilon R}\right) - c(S_j) = \lambda_j.$$

Differentiating λ_j with respect to time yields

$$\dot{\lambda_j} = P(\dot{R})\left(1 - \frac{R_j}{\epsilon R}\right) - c'(S_j)\dot{S_j} \tag{2.5}$$

since the assumption that the n firms are identical implies that $\frac{R_j}{\epsilon R}$ is constant over time. This is a consequence of the symmetry of a Nash equilibrium in such a setup. The solution to (2.1) also has to satisfy

$$\frac{\partial H_j}{\partial S_j(t)} = -c'(S_j(t))R_j = (\rho + i)\lambda_j - \dot{\lambda}_j. \tag{2.6}$$

Plugging (2.5) in (2.6) yields

$$(\rho + i) = \frac{\dot{P}(R)}{P(R) - \frac{\epsilon R}{\epsilon R - R_j} c(S_j)}$$

proving the first condition of the proposition. ■

The R_j, $R = nR_j$, and S_j in Proposition 1 are sequences of planned *equilibrium* quantities. They are *planned* in the sense that if no backstop technology has been developed at time t, then extraction will be the $R(t)$ described by equations (2.2) and (2.3). If a backstop technology has been developed when time t is reached then the amount extracted from time t onwards will be 0. In the following this paper will focus on these equilibrium sequences.

If there are no extraction cost and no backstop technology research, equation (2.2) reduces to Hotelling's (1931) condition that the percentage rate of price increase equals the rate of interest. Backstop technology research with its implicit threat that the resource becomes worthless encourages a resource owner to discount with $\rho + i$ rather than i.

Note that with positive extraction cost the market structure affects the optimal extraction condition. If the market is competitive, n is large, then R_j is small compared to ϵR. This implies that for a competitive market equation (2.2) simplifies to

$$(\rho + i) = \frac{\dot{P}(R)}{P(R) - c(S_j)}$$

while for a monopoly, $n = 1$, it is

$$(\rho + i) = \frac{\dot{P}(R)}{P(R) - \frac{\epsilon}{\epsilon - 1} c(S_j)}.$$

Note that there are two key assumptions in the model outlined above: the supply of fossil fuel is fixed and backstop technology research is exogenous. While actual supply is fixed - there is only so much fossil fuel currently available on earth and the natural production of new fossil fuels takes several hundred millenia - one could also think of supply as the currently known fossil fuel stock, which may increase over time as new stocks are discovered. Backstop technology research is thought of as being independent of fossil fuel extraction and therefore also of the price of fossil fuel. This is a simplifying assumption that makes the model mathematically more tractable. However, one might also think that research effort towards developing a backstop technology increases if fossil fuel prices increase: an alternative to fossil fuels is potentially more profitable if fossil fuel prices increases. The nature of this relationship between fossil fuel prices and profitability of research critically depends on whether the developer of the backstop technology is able to act as monopolistic owner of the backstop technology or not.

If research intensity of the privat sector increases with the price of fossil fuels, there are some interesting dynamics. Suppose the government increases its spending for backstop technology research and thereby increases ρ. An increase of ρ encourages fossil fuel owners to extract more of their resource today. As a consequence, the price of fossil fuels falls. If private sector backstop technology research responds to fossil fuel prices, then this fall of the price of fossil fuel may decrease research intensity.

2.3 Analysis

2.3.1 The Extraction Path

The conditions characterizing the optimal resource extraction, equations (2.2) and (2.3), can be studied by means of an extraction-stock diagram. This method was first used in Sinn(1982). The definition of the absolute price elasticity, ϵ, implies that the slope of the equilibrium extraction path of the economy in an stock-extraction diagram is

$$\frac{dR}{dS} = \frac{\dot{R}}{\dot{S}} = \epsilon \frac{\dot{P}}{P}$$

where S and R are aggregate equilibrium quantities with $R = nR_j$ and $S = nS_j$. Equations (2.2) and (2.3) state that the slop of the extraction path is

$$\frac{dR}{dS} = \epsilon(\rho + i) \left(1 - \frac{c\left(\frac{1}{n}S\right)}{P(R)} \left[\frac{\epsilon R}{\epsilon R - R_j} \right] \right). \tag{2.7}$$

The assumption that the cost function is bounded from above implies that the equilibrium extraction path for the economy passes through the origin of the S-R diagram.[2]

Proposition 2.2 *An increase in research towards a backstop technology causes a steepening of the extraction path and therefore higher near-future carbon dioxide emissions.*

Proof. The Proposition follows immediate from equation (2.7). To see this note that the expression for the slope of the extraction path can be written as

$$\frac{dR}{dS} = \epsilon(\rho + i) - \epsilon(\rho + i)\frac{c\left(\frac{1}{n}S\right)}{P(R)} \left[\frac{\epsilon n}{\epsilon n - 1} \right]. \tag{2.8}$$

[2] The first optimality condition, $P(R) + P'(R)R_j - c(S_j) - \lambda_j = 0$, implies that if $c(\cdot)$ is bounded, $\lambda \to \infty$ as $R \to 0$ since with an isoelastic demand function the price of the resource tends to infinity for $R \to 0$. Then the second optimality condition, equation (2.6), implies that for $R \to 0$ it has to hold that $i + \rho = \hat{\lambda}$. Therefore the transversality condition, equation (2.3), implies that $\lim_{t\to\infty} S(t) = 0$.

and consider how for a fixed level of S the slope changes in response to a change in ρ. Figure 1 illustrates extraction paths for different research intensities. ■

Note that the market structure affects the slope of the extraction path. The slope of the extraction path for a competitive market is

$$\frac{dR}{dS} = \epsilon(\rho + i)\left(1 - \frac{c(S)}{P(R)}\right)$$

while it is

$$\frac{dR}{dS} = \epsilon(\rho + i)\left(1 - \frac{c(S)}{P(R)}\left[\frac{\epsilon n}{\epsilon n - 1}\right]\right)$$

for a monopolist. So an increase in ρ has a smaller effect on the slope of the extraction path of a monopolist than on the extraction path of a large number of competitive firms. This is in line with the familiar result that a monopolists depletes the resource more slowly if faced with an isoelastic demand curve (Stiglitz, 1976).[3]

Figure 1 sketches the extraction paths for three different research intensities under the assumption that the number of firms n is large and that extraction cost are negligible.

First, consider a baseline case with no research towards a backstop technology, $\rho = 0$. The extraction path passes through the origin and its slope is

$$\frac{dR}{dS} = \epsilon i$$

The economy starts at time $t = 0$ at the right-hand side of Figure 1 with a stock $S_0 = \sum_{j=1}^{n} S_j(0)$. The larger the extraction R the faster the economy moves along the curve towards the origin.

Second, suppose that there is a positive probability that a backstop technology will be developed. Equation (2.7) shows that an increase in research effort makes the extraction path steeper.[4] The intuition for this

[3]Note that this statement hinges on the assumption of iso-elastic demand. Lewis et al (1979) show that if the demand elasticity increases with quantity consumed a monopolist depletes the resource more quickly than a group of competitive firms.

[4]While the constant probability case has initially a higher extraction than the baseline case with no research, the economy moves faster along the extraction path in the first

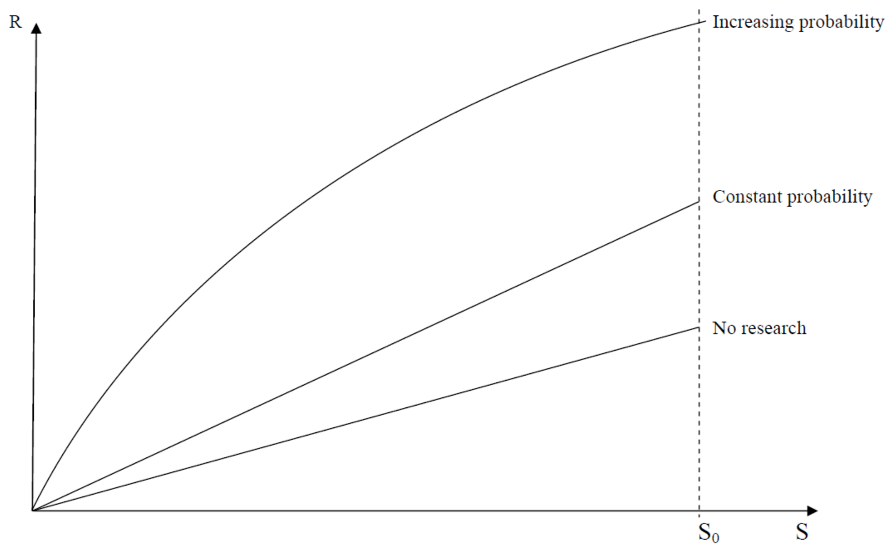

Figure 1: Planned near future extractions increase when there is backstop technology research.

results is that resource owners prefer to sell their resource earlier rather than later when they face the risk that their resource becomes worthless at some future point in time. The higher the probability that a backstop technology is developed, the steeper is the extraction path.

Third, suppose that the instantaneous probability that a backstop technology is developed starts at the same level as in the constant probability scenario and then continuously increases over time, $e^{-\rho(t)t}$ with $\rho'(t) > 0$. Then the slope of the extraction path is

$$\frac{dR}{dS} = \epsilon(\rho(t)t + \rho'(t) + i)$$

Near future extraction is larger and the extraction path is steeper than in the previous scenario.

case. This implies that at some point in time extraction has to be higher in the baseline case.

2.4 Expected Carbon Dioxide Emissions and the Cost of Global Warming

A positive research intensity, ρ, implies that the extraction path derived in section 3.1 may end at any moment in time causing the remaining resource to stay underground forever. So Figure 1 shows planned extraction paths.[5] Note that backstop technology research has two effects: it decreases the total sum of expected carbon dioxide emissions and it increase near future emissions of carbon dioxide. These two effects can best be seen by considering the following expression for expected carbon dioxide emissions:

Definition 2.2 *The expected sum of carbon dioxide emissions is*

$$Z(\rho) = \int_0^\infty e^{-\rho t} R(t;\rho) dt.$$

As time passes the probability that no backstop technology has been developed yet, $e^{-\rho t}$, decreases which implies that the probability that planned extraction will not be realized increases. This effect increases with ρ. However as ρ increases, $R(t;\rho)$ increases for small t. The first effect is a common argument in favor of alternative energy research and explains why it is seen as a potential solution to reduce the cost of global warming. The second effect makes alternative energy research less attractive.

Increasing near future carbon emissions causes more global warming in the near future. The time path of atmospheric carbon dioxide concentration affects the total cost of global warming for a number of reasons: First, the faster the increase in global average temperatures the more difficult - and hence more costly - it will be to adapt. Second, if catastrophic climate change is a concern, then delaying emissions may be beneficial because it allows to gather more information about the likelihood of catastrophic climate change (Weitzman, 2007). Third, incurring the cost of global warming later is likely to be preferable because standards of living are expected to be significantly higher in the distant future and the cost of global warming

[5] A planned extraction is induced by the time 0 extraction plans described by Proposition 1.

would be smaller fraction of income than it would it would be today.

Therefore it seems appropriate to apply a discount rate to the cost of global warming as the following definition does:

Definition 2.3 *The total cost of global warming is*

$$G(\rho, r) = \int_0^\infty e^{-rz} g(\rho, z) dz$$

where

$$g(\rho, z) = \tilde{g}\left(\int_0^z e^{-\rho t} R(t; \rho) dt\right)$$

and r *is a discount rate on the yearly cost of global warming,* $g(\rho, z)$*, and* $\tilde{g}$ *is a function relating the atmospheric stock of carbon dioxide at time* z *with monetary costs.*

The total cost of global warming minimizing research intensity ρ^* is a function of the discount rate r.[6] If the society cares much more about near future emissions than about distant future emission - for one or more of the three reasons outlined above - and sets a high r, then a low research intensity with its lower initial carbon dioxide emissions is preferable to a high one. On the other hand, if the society only cares about the total amount of emissions and not about how they are accumulated over time, r is low, then a high research intensity is preferable. This result is stated more formally in the following proposition:

Proposition 2.3 *Let* $\epsilon(\rho + i) < 1$ *and let* ρ^* *minimizes* $G(\rho, r)$*. Then* ρ^* *weakly decreases with* r*.*

Note that the assumption that $\epsilon(\rho + i) < 1$ is easily satisfied for all reasonable values of i, ρ and ϵ.[7] Before looking at the proof of Proposition 3, consider the following lemma:

[6] Note that ρ^* is optimal in the sense that it minimizes G. A society may not be interested in minimizing $G(\rho)$ but instead in minimizing $G(\rho) + X(\rho)$ where $X(\rho)$ is a cost of research function. This does however not change the spirit of the results in this section. In particular, even if research was free (X=0) it may be preferable for certain values of r to not engage in any research.

[7] Empirical estimates for ϵ are usually well below 1 and the interest rate i is usually assumed to be below 0.1. Even a very ambitious research project that would with 50%

Lemma 2.1 *Let $\epsilon(\rho+i) < 1$ and let $0 \leq \rho_1 < \rho_2 \leq 1$. Then $Z(\rho_1) > Z(\rho_2)$.*

Proof. First consider the problem under the assumption that the extraction cost are negligible. Then it follows from the shape of the extraction path previously derived that for a discrete time version of the problem the amount extracted at time t satisfies the following condition:

$$R_t - R_{t-1} = \epsilon(\rho + i)(S_t - S_{t-1}).$$

This implies that the closed from solution for the optimal extraction given initial stock S_0 is

$$R_t = (1 - \epsilon(\rho + i))^t \epsilon(\rho + i) S_0 \tag{2.9}$$

So the expected sum of carbon dioxide emissions is

$$Z(\rho) = \int_0^\infty e^{-\rho t}(1 - \epsilon(\rho + i))^t \epsilon(\rho + i) S_0 dt = \frac{-\epsilon(\rho + i)S_0}{-\rho + \ln[1 - \epsilon(\rho + i)]} \tag{2.10}$$

The above claim is true if $\frac{\partial Z}{\partial \rho} < 0$ which is satisfied if

$$-\ln[1 - \epsilon(\rho + i)] < i + \frac{\epsilon(\rho + i)}{1 - \epsilon(\rho + i)} \tag{2.11}$$

To see that equation (2.11) is satisfied note that $i \geq 0$ and that

$$-\ln[1 - a] < \frac{a}{1 - a}$$

for all a satisfying $0 < a < 1$.
Note that this argument can be generalized to positive extraction cost. With positive extraction cost the extraction path steepening effect of ρ is smaller than with zero extraction cost (see Equation 7), while the $e^{-\rho_j t}$ term in $Z(\rho_j)$ remains unchanged for each j, $j = 1, 2$. ■

Intuitively, the Lemma states that if minimizing total carbon dioxide emissions over time is a goal and it is of no concern how these emissions are

success find an alternative energy source within 15 years corresponds to a ρ that is smaller than 0.06.

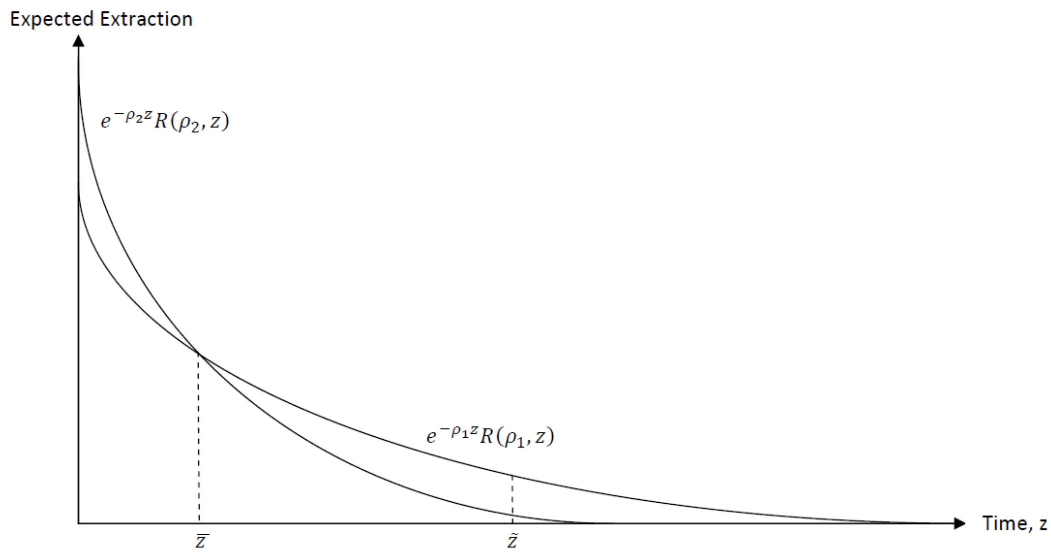

Figure 2: Intuition for the proof of Proposition 3

accumulated over time, then the highest research intensity feasible is the optimal choice.

Proof. [Sketch of the Proof of Proposition 3] Figure 2 shows the intuition for the proof for the special case that $\tilde{g}(x) = x$. The figure shows expected equilibrium extraction, $e^{\rho z}R(z;\rho)$, where z is the time index and ρ_1 and ρ_2 are research intensities which satisfy $\rho_1 < \rho_2$. The cost of global warming at time $\tilde{z}$, $g(\rho, \tilde{z})$, is represented by the area underneath the extraction curve and to the left of $\tilde{z}$. From Proposition 2 it follows that at $z = 0$

$$e^{\rho_1 z}R^*(z;\rho_1) > e^{\rho_2 z}R(z;\rho_2).$$

Consider the areas between the extraction curves to the right and left of $\bar{z}$. From the lemma it follows that the area to the left of $\bar{z}$ is smaller than to the right. This implies that there exists a $\tilde{z}$ such that for all $z > \tilde{z}$ it holds that $g(\rho_2, \tilde{z}) < g(\rho_1, \tilde{z})$. From here it follows that for $r = 0$

$$G(0, \rho_1) > G(0, \rho_2).$$

If r is small - if the society cares nearly equally about the near future and the discount future - then the eventually cost savings due to the lower total amount of emissions under research intensity ρ_2 will make ρ_2 the more attractive option. On the other hand, if r is large - the society cares much more about the near future than the discount future - then the initial cost savings under research intensity ρ_1 will make ρ_1 the more attractive option. ■

A corollary of Proposition 3 is that if a society cares sufficiently about the cost of global warming in the near future - so if r is large enough - then it is optimal to engage in no backstop technology research even if research is costless.

2.5 Policy and Extensions

2.5.1 Correcting the Extraction Path by Setting an Appropriate Tax Rate

This section considers the question whether there are any easy policy tools that can be used to correct the steepening of the extraction path under backstop technology research. It is well known that appropriate taxes can influence the extraction decisions of resource suppliers. This section outlines how an appropriately chosen value added tax can flatten the extraction path.

The government sets a value added tax rate $1 - \delta(t)$ that may change over time. Under assumptions 1,2, and 4 the optimization problem of the representative firm j is

$$\max_{\{R_j\}} \int_0^{\infty} \delta(t) P(R) R_j e^{-it-\rho t} dt \tag{2.12}$$

subject to

$$\dot{S}_j = -R_j$$

$$S_j(0) > 0$$

$$R_j, S_j \geq 0$$

and the Hamiltonian is

$$H = \delta(t) P(R) R_j - \lambda_j R_j$$

The solution has to satisfy three conditions:

$$\delta(t) \left[P(R) + P'(R) R_j \right] - \lambda_j = 0$$

$$\dot{\lambda}_j = (i + \rho) \lambda_j$$

$$\lim_{t \to \infty} e^{-it-\rho t} \lambda_j(t) S(t) = 0$$

The market outcome has to satisfy

$$\dot{P(R)} = (i + \rho - \hat{\delta})P(R)$$

where $\hat{\delta} = \frac{\dot{\delta}}{\delta}$. A positive $\hat{\delta}$ indicates a decreasing tax rate. Backstop technology research has no effect on the extraction path if $\rho = \hat{\delta}$. So to counteract the steepening of the extraction due to backstop technology research a *decreasing* tax rate on carbon based energy is required. This implies that within finite time subsidies for fossil fuel sales will have to be paid.

This result is in sharp contrast to the in the environmental economics literature frequently suggested *increasing* carbon tax rates.[8] From the supply side perspective, an increasing tax rate would actually cause a steeper extraction path and more near future greenhouse gas emissions. This illustrates the need for a more thorough look at the effects on energy markets when making environmental policy recommendations. Ultimately, the only way to mitigate the global warming problem is to find a way to induce the owners of fossil fuels to keep their fossil fuels underground. Any viable strategy to accomplish this has to consider both the supply of and demand for fossil fuels.

2.5.2 Carbon Capture Technology Research

Suppose that a decreasing tax rate on carbon based fuels is deemed undesirable. Then an alternative method to correct the extraction path is research towards developing an inexpensive carbon capture and storage technology (CCS).

A CCS technology removes planet-heating carbon dioxide from fossil fuel fired power plant chimneys and sequesters it safely beneath the ground. At present this technology is too costly to be commercially viable and there are some safety concerns (Rubin et al, 2007).

Potentially R&D in this area could lead to the development of a commercially viable CCS technology which could ultimately imply that fossil fuels may still an attractive energy source even after the development of a

[8] See for example Stern(2006), Nordhaus(1993) or Popp(2004).

backstop technology. Therefore CCS research decreases the probability that fossil fuels will become obsolete. As sections 2 and 3 of this chapter showed, it is ultimately the probability that fossil fuels become obsolete that leads to the increase in near future extractions. Thus, reducing this probability helps to reduce near future extractions.

2.5.3 Backstop Technology with a Per Unit Price b

So far the assumption was that the backstop technology once developed is available at zero cost. This simplification is convenient since it ensures that once the backstop technology is developed it instantaneously replaces fossil fuels as energy source. However, it is more realistic that the backstop technology will be associated with a positive per unit cost b. Then once the backstop technology is developed, either the per unit cost of extraction $c(S)$ is above b or it is below. If $c(S) > b$, then extraction of the resource will stop and only the backstop technology will be used. If $c(S) < b$, then the fossil fuel will be extracted and sold at price b until $c(S)$ reaches b.

The extraction path of the resource becomes less steep as the per unit price b of the backstop technology increases. To see this note that resource owners now have a smaller incentive to extract fast since they do no longer anticipate loosing all profit opportunity with the development of the backstop technology but only face a reduced profit opportunity.

Let $\Pi(S, b)$ be the value of a yearly annuity which has a present value equal to the profit that the resource owner can earn after the backstop technology has been developed. $\Pi(S, b)$ is weakly increasing in both S and b. The resource owner j maximizes the discounted sum of profits subject to some feasibility constraints:

$$\max_{\{R_j\}} \int_0^{\infty} [(P[R] - c[S])R_j + \rho\Pi(S, b)]e^{-it}e^{-\rho t}dt \tag{2.13}$$

subject to

$$\dot{S}_j = -R_j$$

$$S_j(0) > 0$$

$$R_j, S_j \geq 0.$$

The slope of the extraction path corresponding to the solution to the above problem is

$$\frac{dR}{dS} = \epsilon(i+\rho)\left[1 - \frac{c(S)}{P(R)}\frac{\epsilon n}{\epsilon n - 1}\right] - \frac{\epsilon n}{\epsilon n - 1}\frac{\rho\frac{\partial \Pi(S,b)}{\partial S}}{P(R)} \tag{2.14}$$

If b is large enough, the extraction path is less steep than under the zero cost backstop technology research. The size of this effect is determined by $\frac{\partial \Pi(S,b)}{\partial S}$, which is positive if b is large enough and zero otherwise. For very large b the extraction path described by equation (2.14) is very close to the extraction path in the absence of backstop technology research.

2.6 Numerical Example

The goal of this section is to illustrate the trade-off between higher near-future carbon emissions and the eventual development of a backstop technology predicted by the model outlined previously. The key question is whether the effect of backstop technology research on the extraction path is of an magnitude worthy of attention.

I match the extraction path of a baseline scenario - characterized by minimal research intensity and in which fossil fuel is not expected to become obsolete within this century - with an IEA projection on energy consumption growth (IEA, 2007) and time to depletion estimates (BP, 2007).[9] Then I consider the question how extraction would change if more backstop technology research was conducted.

For this I consider three different research agendas: First, a low research intensity with a 50 % probability that a backstop technology is developed within 75 years ($\rho = 0.00924$). Second, a medium or 50 years research intensity with $\rho = 0.01386$ which corresponds to a 50 % probability that a backstop technology is developed within 50 years. Third, a high research intensity with an expected time until the backstop technology research is successful of 25 years ($\rho = 0.02772$).

I assume that the number of firms is large and that they face an isoelastic demand function of the form

$$P = aR^m \tag{2.15}$$

where a is a measure for the market size and m is the elasticity of demand.[10]

For ease of programming, I formulate the empirical model as discrete time model with intervals that are one year long. Also, I normalize the size

[9] At current extraction rates, the world's known oil reserves are expected to be depleted within 40 years, natural gas reserves within about 70 years and coal reserves are expected to last about 150 years. However, the quantities consumed of each these three fossil fuels grow at very different rates which should eventually lead to gradual equalization of time to depletion rates: oil 0.7%, gas 2.5%, and coal 4.5% (2006 growth rates, BP 2007).

[10] This functional form is a common choice in the literature. See for example Chakravorty et al (1997) or Lin and Wagner (2007)

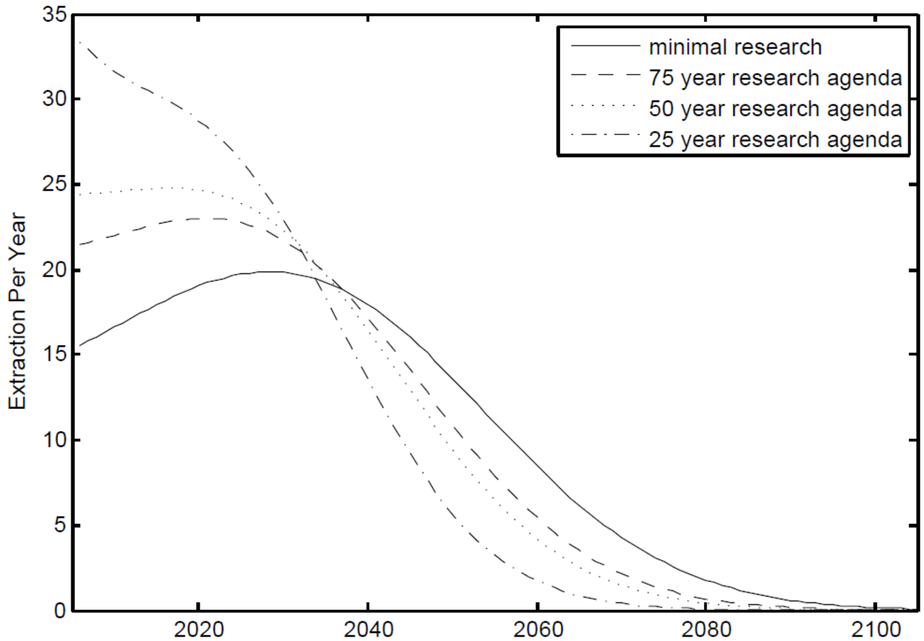

Figure 3: Extraction over time.

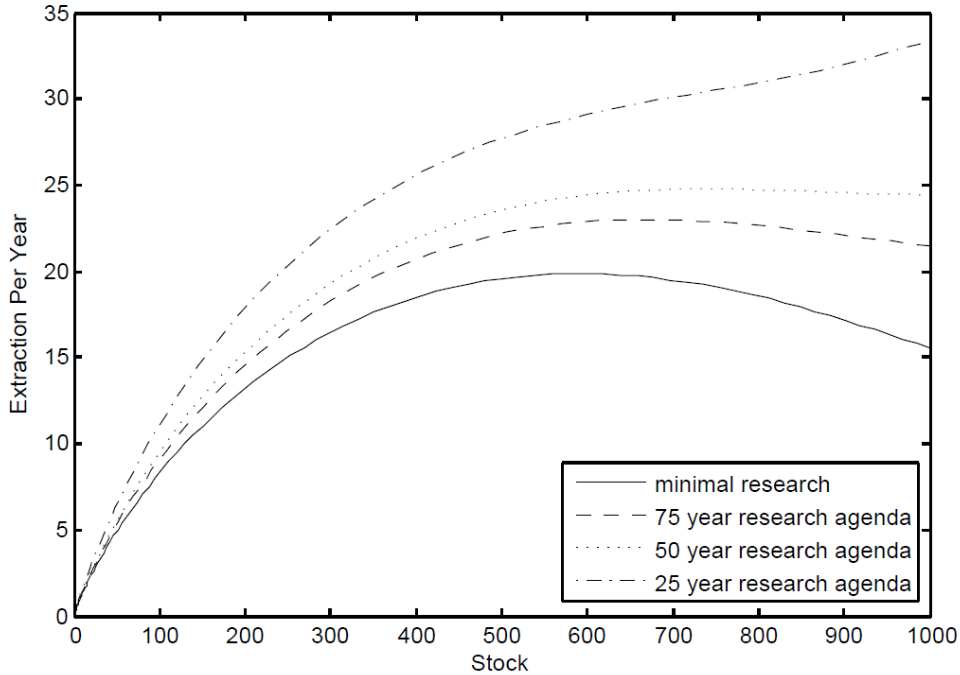

Figure 4: The extraction path.

of the stock of fossil fuels to 1000 and the initial per unit price under the minimal research agenda is normalized to 100. All other prices are to be interpreted relative to this initial price, amounts of the resource relative to the initial stock. The interest rate is set at 5% and is constant over time.

The demand elasticity is set at -0.4, based on estimations by Cooper (2003) who estimates price elasticities of demand for oil in 23 countries.[11] Further, I use cost of resource extraction estimates published in Chakravorty et al (1997), Chapman and Khanna (2006) and Harks (2007).[12]

To accommodate for the increase in fossil fuel consumption predicted

[11] Estimates of a similar magnitude can be found for example in Nordhaus (1979)

[12] The production cost of fossil fuels are typically between 15 and 40% of the market price. For some fossil fuels such as Gulf region crude oil, the production cost of one barrel of crude oil is only about 5$, less than 5% of the current spot price (Chapman and Khanna, 2006).

by the IEA, I introduce an exogenous demand shifter.[13] The IEA world energy consumption projections are available until 2030. The main scenario (Figures 3 to 6) assumes that fossil fuel consumption with present minimal backstop technology research ($\rho \approx 0$) grows until approximately 2035 and then eventually declines. There are three main reasons for an eventual decline of fossil fuel consumptions: First, the price of fossil fuel increases as it become more scarce. Second, energy efficiency is expected to increase. Third, world populations is expected to stop growing some time after 2040 (Population Division of the United Nations, 2006). The demand growth chosen for the main scenario is about 40 percent below the IEA estimate. A less conservative and closer to the IEA estimate is used in Figure 10. However, such a high demand growth over the next decades is only feasible with a production to reserve ratio well below the one currently observed. Therefore a more conservative estimate for demand growth seems preferable. In general, the magnitude of the effect of backstop technology research on the extraction path is larger if the demand growth is larger. Thus, the more conservative estimate for demand growth used here may understate the effect.

Figure 3 shows predicted fossil fuel extraction over time depending on choice of research agenda. With the minimal research agenda present time extraction is about 1.55% of the stock of the resource. This corresponds to a time to depletion of 67 years, which is close the estimate for the reserve to production ratio of natural gas and between the reserve to production ratio estimates for oil (38 years) and coal (135 years) (BP, 2007). The demand shifter is chosen so that fossil fuel consumption under the minimal research agenda grows by about 25% in the next 25 years.

According to Figure 3 initial extraction of the resource increases with research intensity. With the medium intensity (50 years) research agenda extraction increases about 60 % compared to the minimal research agenda.

[13] To match the IEA projection it is necessary to change the optimization problem in equation (**??**) to

$$\max_{\{R_j\}} \int_0^\infty (d(t)P[R] - c[S])R_j e^{-it-\rho t} dt$$

subject to $\dot{S}_j = -R_j$, $S_j(0) > 0$, $R_j, S_j \geq 0$ where $d(t)$ is a demand shifter that varies over time.

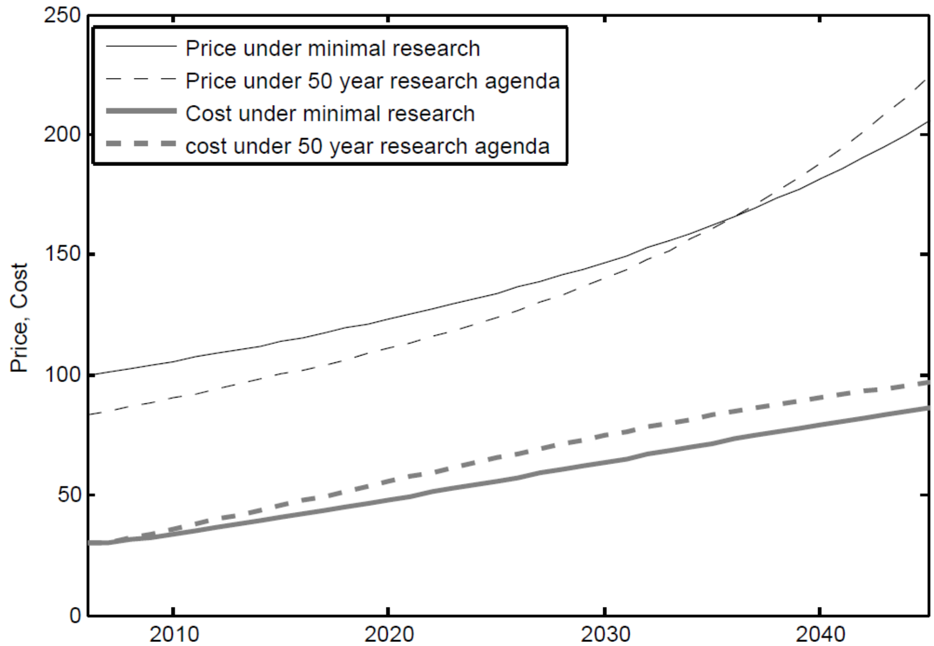

Figure 5: The price and cost paths.

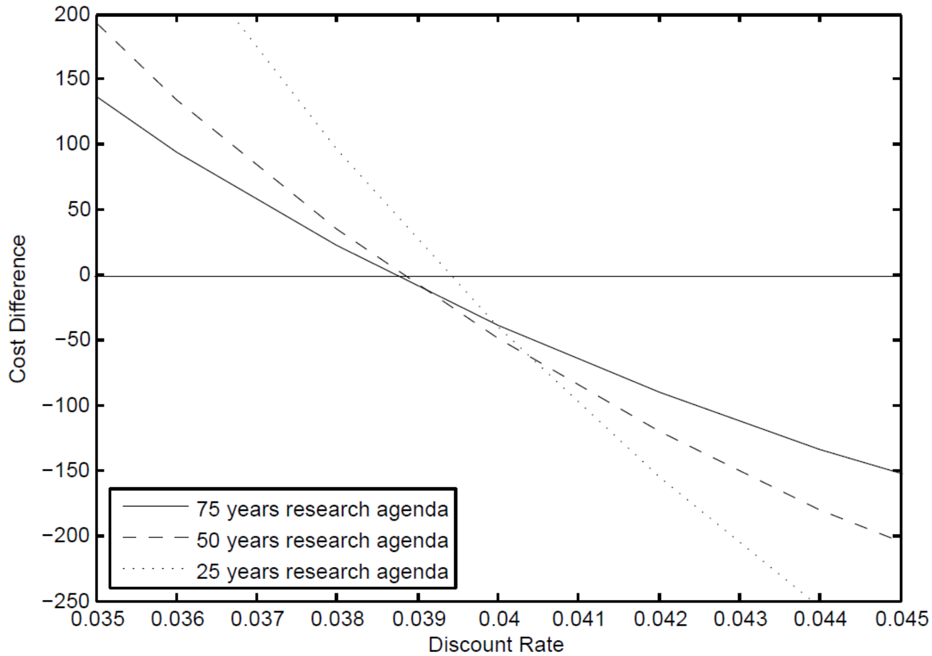

Figure 6: Cost of global warming with a linear cost function.

Figure 4 relates yearly extraction with the stock of the resource. The paths for the minimal, 75 years, and 50 years research agendas are initially upward sloping since the demand shifter leads to initially increasing extractions. Figure 5 shows the price and cost paths for minimal and medium research intensity. The cost paths of the medium research agenda is above the cost path of the minimal research agenda since costs increase with the amount of the resource extracted which is higher for medium research.

Figure 6 shows how for a linear cost of global warming function the total cost of global warming depend on the discount rate applied to global warming costs. The curves show the difference in cost between the minimal research agenda and the respective positive research agenda. A value below zero indicates that no research is less costly. At a discount rate of 4% no research is the least costly option.

Next, I consider some alternative parameter choices to see how sensitive

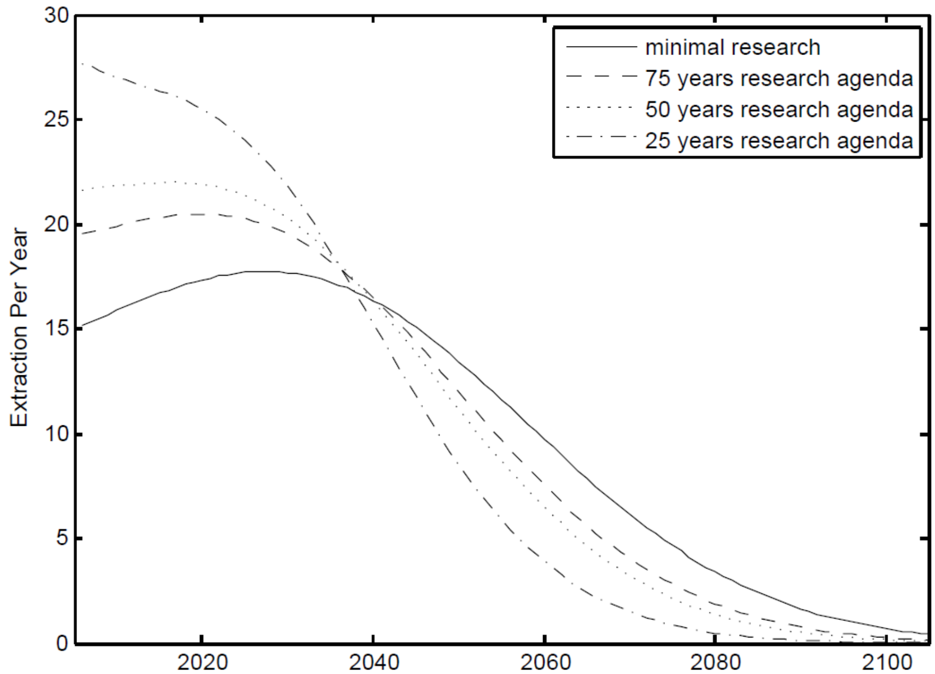

Figure 7: More elastic demand (m=-0.6).

the above results are. First, I consider the effect of a higher absolute elasticity of demand. Second, I study how the choice of the extraction cost function affects results. Third, I consider the sensitivity with regard to the interest rate. Figures 7 to 10 show equilibrium extraction for these alternative parameter values. While varying the above mentioned parameter choices, I use the same demand shifter as before. This allows to study the effect of changing one parameter. However, it should be noted that this demand shifter was initially chosen to ensure that the extraction path follows IEA predictions on consumption growth after the initial parameter choices had been made.

Assuming that the demand is significantly more elastic (m=-0.6, a 50% increase) leads to a smaller effect of backstop technology research on the extraction path (see Figures 7). However, the initial extraction level is still

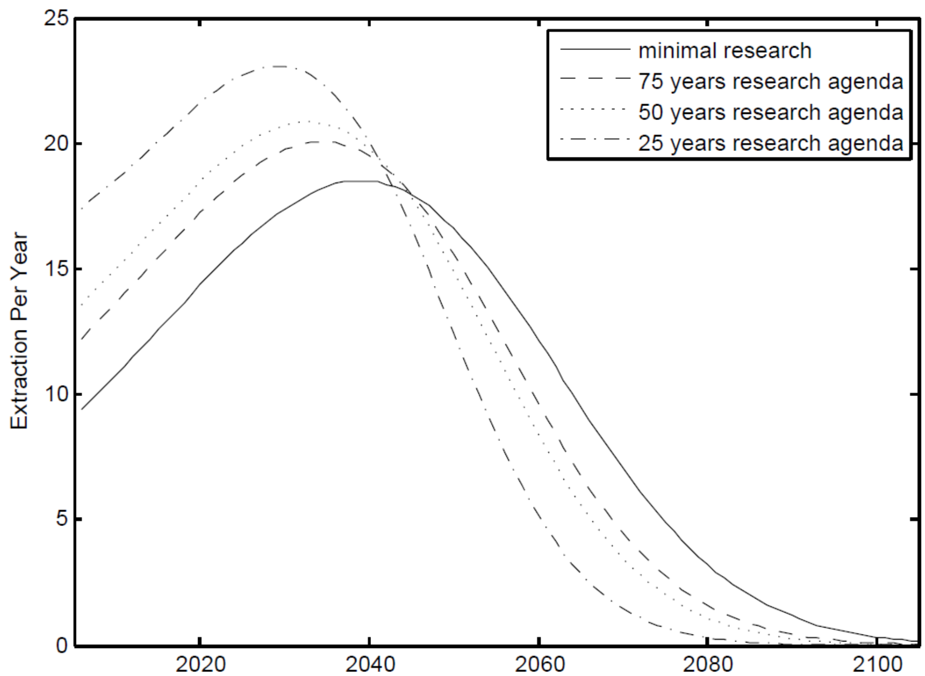

Figure 8: Initial extraction cost are 50% higher and increase 50% faster.

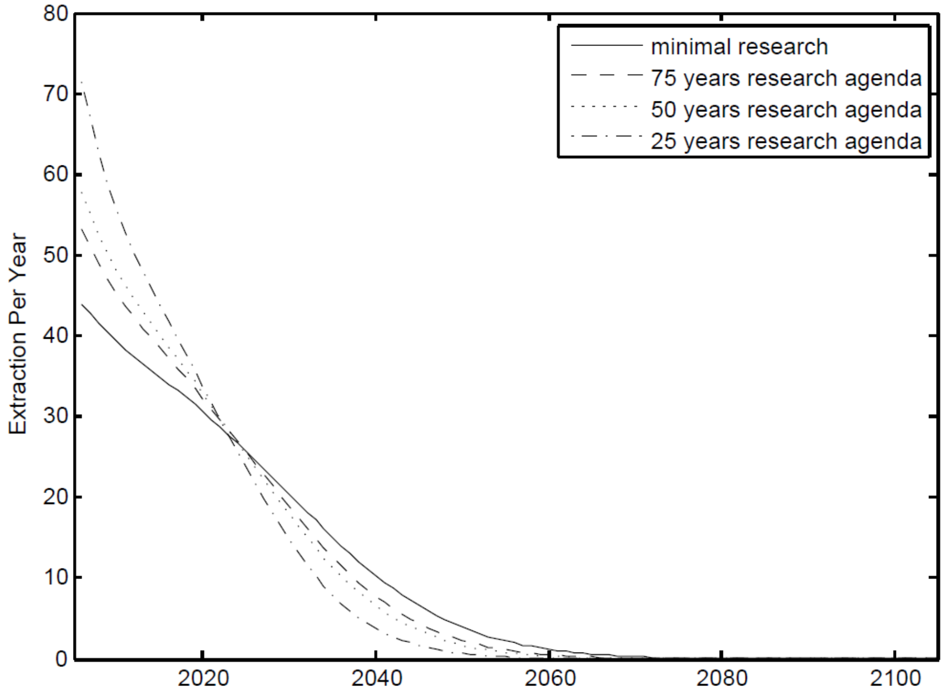

Figure 9: Interest rate is 7.5%.

about 45% higher under the medium research agenda than with minimal research.

Higher extraction cost also reduce the effect of backstop technology research intensity on resource depletion. Figure 8 shows a scenario in which costs start at 45% of the price of the resource under minimal research (a 50% increase) and increase 50% faster. With these higher costs the increase in initial extraction is 45 % between the minimal research and the medium research intensity scenarios.

Figure 9 illustrates the effect of a higher interest rate. A higher interest rate encourages faster depletion of the resource, while a lower interest rate encourages slower depletion. With a 50% increase in the interest rate as considered here, 99% of the stock is depleted more than 20 years earlier.

Finally, consider the sensitivity of the results with respect to the choice

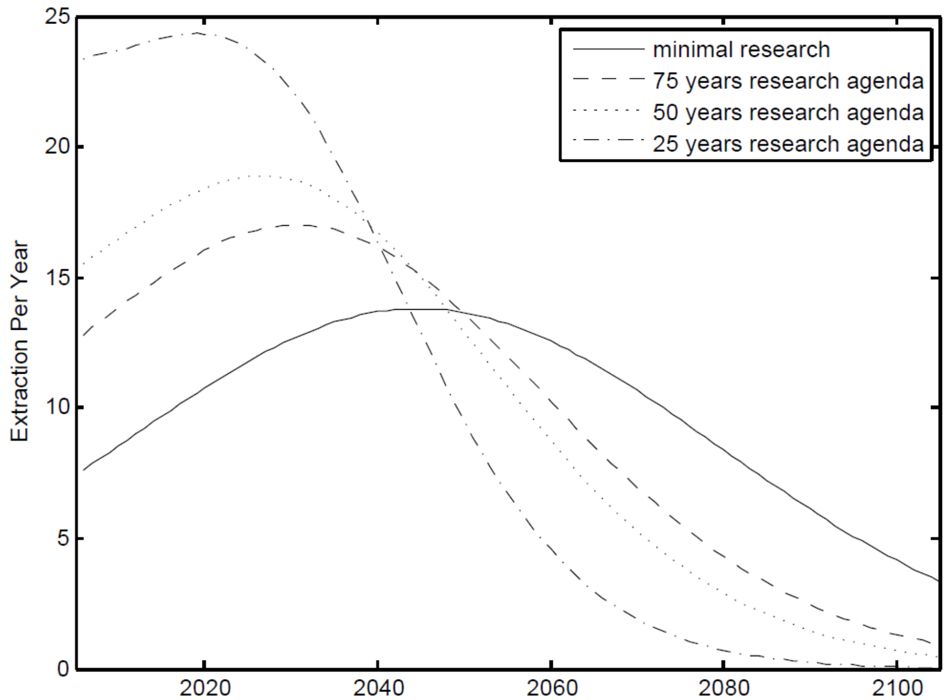

Figure 10: Energy demand growth until 2060.

of demand shifter, likely the parameter about which least information is available. Figure 10 shows extraction over time under the assumption that demand grows beyond 2030. The consumption of fossil fuels increases here until 2050 by 80% compared to the 2008 level, which corresponds to an average yearly growth rate of 1.4 %. Under this assumption the effect of backstop technology research is significantly larger than with the more conservative demand shifter previously considered.

Since backstop technology research does not just affect the extraction path of fossil fuels but also the price path, it affects the expenditures on energy. Table 1 shows energy cost savings of each research agenda relative to the cost of energy under minimal research under the assumption that the quantity of energy consumed is constant. Table 2 presents the same

Table 1: Energy cost savings if quantity does not change.

Energy cost savings		
	in 10 years	in 20 years
75 years research agenda	11.6%	9.4%
50 years research agenda	16.6%	13.2%
25 years research agenda	28.7%	22.2%

Table 2: Energy cost savings if quantity changes

Energy cost savings			
	in 10 years	in 20 years	in 50 years
75 years research agenda	-15.2%	-12.5%	-1.6%
50 years research agenda	-20.5%	-16.9%	-1.4%
25 years research agenda	-31.5%	-25.9%	1.5%

comparison under the assumption that quantity demand changes according to the long run elasticity used for the main variable case (0.4). The time frames considered are 10 and 20 years and 10, 20 and 50 years, respectively. If the amount of fossil fuels consumed remains unchanged, then going from a minimal research intensity to the 75 years research agenda results in energy cost savings of about 12% of energy cost expenditures under the minimal research intensity within 10 years. If the amount of energy consumed adjusts to the price change induced by the research agenda according to the long run elasticity, then the quantity increase more then makes up for the price decrease. This is reflected by the negative savings in Table 2. Energy expenditures increase for the first part of the time horizon considered and depending on the research agenda it take 45 to 60 years until the economy's total energy expenditures under the research agenda within that time frame are smaller than under minimal research. Tables 1 and 2 show two extreme scenarios: no quantity adjust to the price change and a very strong, instantaneous quantity adjustment. The actual savings should be expected between these two extremes.

To summarize, the numerical example suggests a significant effect of backstop technology research on the extraction of fossil fuels and hence global warming. The actual magnitude of the effect strongly depends on how much demand for fossil fuels will increase over the course of the 21st century. With growth of demand until the middle of the century or beyond, even a very small research intensity has a large effect on how atmospheric carbon dioxide is accumulated over time.

2.7 Conclusion

The problem of global warming is in essence the problem of transporting the stock of carbon currently underground into the atmosphere. Therefore this paper considered the question how backstop technology research affects global warming from a resource economics perspective.

The paper showed that backstop technology research encourages more near future fossil fuel extraction. Also, it showed that if a society sufficiently discounts the costs of global warming then even if research was costless it would still not be optimal to engage in it.

3 The Political Economy of Carbon Securities and Environmental Policy

3.1 Introduction

The design of policy is affected by lobbyists. A common feature is that there is a well-financed interest group on one side of the issue but not on the other. Carbon abatement policy is an example: While there are some environmental interest groups, there are better financed, more influential lobbies representing the interests of industries' that feel that they benefit from a low level of carbon abatement. However, the literature on the design of environmental policy tools rarely formally considers the impact of lobbies and the political economy dimension of the problem.

Most policy proposals to reduce greenhouse gas emissions extend over several decades. Frequently, the optimal policy suggested is characterized by a low initial carbon tax which then rises over time (see for example Nordhaus, 2007). The practical implementation of such a proposal is affected by a commitment problem: can a government today make a credible promise about the level of carbon taxes 20 years from now? This inherent uncertainty in the implementation is likely to discourage investment in carbon abatement technology.

The recent US climate bill, also referred to as Waxman-Markey bill, brings new attention to the question of how a carbon permit system should be designed and also illustrates the effect of lobbies on the application of policy. Markussen and Svendsen (2005) document how interest groups influenced the design of the EU greenhouse gas market.

This paper recognizes the role of lobbies in the design of environmental policy and suggests a carbon permit system designed to take advantage of the nature of the lobbying process. Under standard systems, there is one well organized lobby representing the interests of industries that heavily use carbon based energy sources. This lobby pushes for a high emission quota or correspondingly a low carbon tax. In most instances there is no well organized, financially powerful counterlobby in favor of low emissions. The main advantage of the policy instrument I propose is that it creates stakeholders with an interest in low carbon emissions. The active participation of this group in the policy-making process counterbalances the lobbying of the energy-consuming industry.

Specifically, suppose a total of n carbon securities is sold at time t=1. A carbon security gives the owner of the security the right to emit at time t=2 up to $\frac{1}{n}X$, where X is the society's total desired carbon emissions for period 2. The amount X is unknown to the potential buyer of the security at the time when she has to decide whether she wants to purchase a security or not. At the beginning of period 2, the political process determines the society's total desired industrial carbon emissions, X. When choosing X the political process takes into account the voters' preferences and any contributions from lobbies representing either the interests of the energy-consuming industry or the owners of carbon securities.[14] While both traditional permits and these carbon securities establish property rights, there are some important differences. Traditional permits give the owner the right to emit a fixed amount of carbon which is set prior to the sale of the permit. Carbon securities entitle the owner to a fixed proportion of total emissions, which have not yet been set at the time when the securities are sold. The order of selling permits and determining the emission quota is different between carbon securities and traditional permits. Additionally, the government can at any time print additional permits after the initial sale, while it cannot print additional securities until the current securities have matured. Alternatively, it is possible to think of a carbon security as a bond that pays a coupon in the form of a carbon allowance of $\frac{1}{n}X$.

The paper considers a two-period model of an economy using carbon securities. The key results of the two-period model extend in a straight forward manner to a multi-period framework in which a security is valid until period T and gives the owner the right to emit a fixed proportion of total desired emissions each period between 2 and T.[15] Therefore the paper

[14] The term 'energy-consuming industry' is used to refer to all industries which would be subject to a carbon tax or a carbon permit system. For example, the Waxman-Markey proposal applies to about 85% of firms.

[15] A related yet significantly different policy tool are long term permits as proposed by

focusses on the more tractable two-period model.

The paper adds a political economy perspective to the literature on environmental policy instrument design. As in Grossman and Helpman (1994), the government's decision making is not only influenced by social welfare considerations but also by lobbies who make campaign contributions if they feel that attempting to influence the carbon price is in their best interest. For example, under a carbon tax system the energy-consuming industry has an incentive to lobby for a low tax rate. Under a carbon securities system, the lobby of the energy-consuming industry is in favor of a large emission total, X, while the owners of the securities have an incentive to organize and lobby in favor of an emission quantity that maximizes the value of the securities.

The games considered are common agency games with one agent, the government, and depending on the choice of the policy instrument, one or two principals, the active lobbies. Two policy instruments are considered: a standard carbon tax, in the following referred to as *tax game*, and the carbon securities introduced above, referred to as *carbon securities game*.[16] One lobby represents the interests of firms which consume significant amounts of carbon based energy sources (oil, coal, natural gas etc.). If the profits of these firms depend on the carbon price, their lobby has an incentive to take part in the political process. The other lobby represents the interests of the owners of carbon securities. This lobby is either active or inactive depending on the choice of the policy instrument. Under a traditional tax system the lobby of the owners of carbon securities is inactive. With a system based on carbon securities this lobby is active since the return on investment on these securities depends on the government's choice of a carbon price.

I show that carbon securities have a number of advantages over existing systems. First, the lobbying process leads to a carbon price level that is

McKibbin and Wilcoxen (2002). However, their long-term permit entitles the owner to emit a specified amount of carbon every year for the life of the permit. To the best of my knowledge no permit system with long term permits with ex ante uncertain yearly emission allowance has been suggested.

[16] In the framework considered demand is deterministic within a period and therefore a carbon tax is equivalent to a traditional cap and trade system.

closer to the social optimum than with a traditional tax or permit system. This is a direct consequence of the presence of stakeholders with an interest in low carbon emissions. Second, climate and political uncertainty have a smaller effect on the expected variance in the carbon price. While there is ex ante uncertainty about the amount of carbon emissions allowed per security, the variance of the carbon price is smaller. Third, there is higher investment in energy saving technology under the system I propose. Carbon securities provide stronger incentives to develop and adopt abatement technology since they encourage both a higher carbon price and a more stable carbon price. Fourth, a system based on carbon securities also has implications for commitment to environmental policy. In contrast to most of the literature which takes commitment as exogenous (either by assuming ex ante commitment to a certain policy level or as ex post optimal, time-consistent policy reaction), the introduction of carbon securities alters the policy environment so that the government can, in effect, credibly commit to long term policies even when the government can only commit to property rights but not to tax rates or policy levels.

The most widely used model to study the competitive process among special interest groups is a common agency game (Bernheim and Whinston, 1986). This framework has been adapted to study a wide variety of issues, including trade policy (Grossman and Helpman, 1994), commodity taxation (Dixit, 1996) and labor market policies (Rama and Tabellini, 1998). Aidt (1998) applies the framework to environmental policy to study how a tax scheme intended to combat an externality affects individual sectors. Similar to Le Breton and Zaporozhets (2007) and Le Breton and Salanie (2003), I extend the common agency framework to include political and climate uncertainty. The Grossman-Helpman model is supported by a number of empirical studies (see for example Goldberg and Maggi, 1999; Gawande and Bandyopadhyay, 2000). Since this type of model describes the political economy of trade remarkably well, the hope is that it is also suitable to describe the underlying dynamics of environmental policy.

The paper also contributes to the literature on environmental policy instruments (see for example Baumol and Oates, 1988; Stavins, 2004; Metcalf,

2009) but takes a new approach to policy instrument design by explicitly taking political economy consideration into account.

The following section describes the model. Sections 3 and 4 study the equilibrium under a traditional tax system and a system with carbon securities, respectively. Section 5 considers the welfare benefits of switching from a carbon tax or permit system to carbon securities. Section 6 concludes.

3.2 The Model and Discussion

The first part of the section describes the model, the second part discusses the underlying assumptions of the model.

3.2.1 The Model

Both the tax game and the carbon securities game consist of two periods. In the first period, the government announces the policy instrument of its choice: either a carbon tax or carbon securities. If carbon securities are the chosen policy instrument, the government holds an auction to sell the securities. There are m energy-consuming firms. Each firm i chooses its level of investment in abatement technology I_i. The energy-consuming industry and the owners of carbon securities each organize themselves as a lobby. It is assumed that the owners of carbon securities are not members of the energy-consuming industry.[17] In the second period, information about the policy maker and the expected cost structure of global warming is revealed. The lobby or lobbies then offer their contribution schedule(s) which are conditional on the carbon price selected. The government chooses the level of the carbon price that maximizes its welfare. Then the owners of carbon securities sell the carbon allowance, $\frac{1}{n}X$, they received per security to firms required to hold a carbon allowances equal to their carbon emission in period 2. The following describes the stages of the game in more detail starting with the last stage.

Consider period 2 of the carbon securities game. Let demand for energy, D, be deterministic, then setting an emission level X and setting a carbon price are equivalent. For each level of aggregate investment in energy-saving technology, X determines the carbon price via

$$D(p, I) = X \tag{3.1}$$

where D is a decreasing function of both the carbon price p and aggregate investment in energy saving technology I. Alternatively, in the tax game

[17] The second part of this section considers this and most other assumptions in detail.

the government sets the price of carbon p directly. For ease of comparison between the tax game and the carbon securities game and also to stay within the established convention of the literature based on Grossman and Helpman's (1994) 'Protection for Sale', the government's choice variable is the carbon price in both games.

Social welfare depends on the amount of carbon emissions. On the one hand, high emissions lead to more global warming and hence higher global warming related costs G_W. These cost are a decreasing function of p, $\partial G_W/\partial p < 0$, and also a decreasing function of I, $\partial G_W/\partial I < 0$.

On the other hand, a high carbon price has adverse effects on social welfare since it has negative effects on the energy-consuming industry and leads to higher consumer prices. Social welfare is here to be thought of as discounted GDP. This consumption cost, G_C, increases with p, $\partial G_C/\partial p > 0$, but decreases with I, $\partial G_C/\partial I < 0$. The social cost of the carbon price is defined as

$$G(p, I) = G_W(p, I) + G_C(p, I) \tag{3.2}$$

$G(\cdot)$ is the difference between the expected cost of global warming which decrease with emissions, X, and the benefits of a low energy price. Figure 1 shows G, G_W and G_C. The functions G_W, G_C and G satisfy the following assumptions:

Assumption 3.1 *The cost function G has the following characteristics:*

(a) For a given investment level I, the cost function G has a unique minimizer, referred to as p^*:

$$\frac{\partial G_W}{\partial p \partial p} + \frac{\partial G_C}{\partial p \partial p} > 0$$

(b) The minimizer of G, p^*, increases with aggregate investment:

$$\frac{\partial p^*}{\partial I} > 0$$

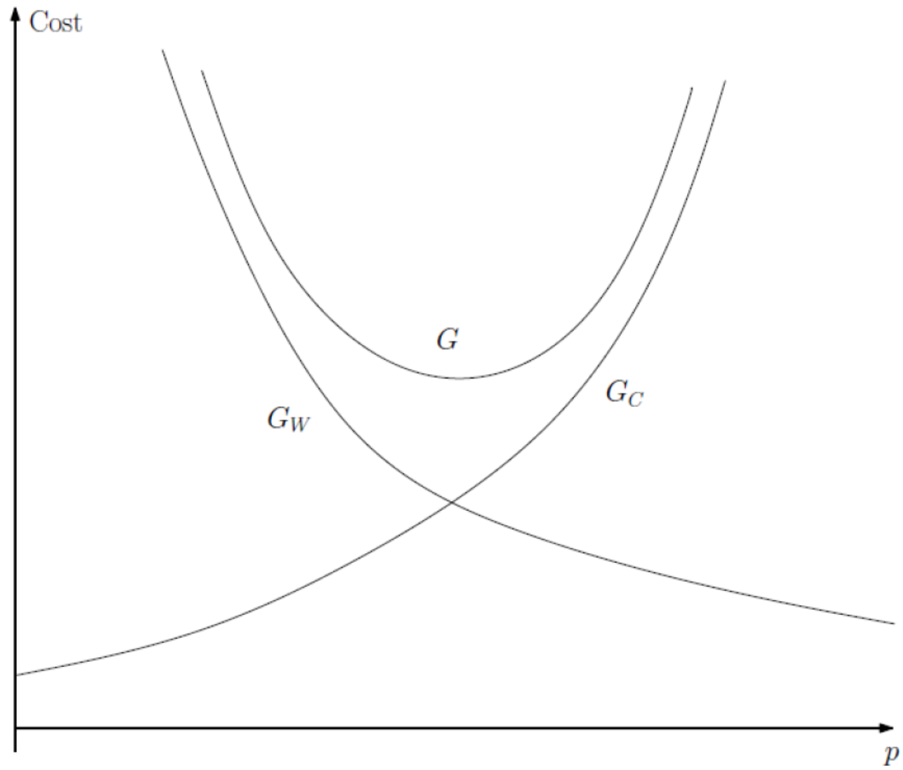

Figure 11: The cost of the carbon price function.

(c) *If a tighter climate goal is preferred, deviations from the optimal level, p^* are worse. So, for all $p < p^*$ the derivative of G becomes steeper as p^* increases.*

The government maximizes the weighted sum of campaign contributions and voters' welfare. W_G denotes the welfare of the government:

$$\max_p W_G(p, \theta, I) = C_B(p, \theta, I) + C_E(p, \theta, I) - \theta G(p, I) \tag{3.3}$$

C_B and C_E are the campaign contributions of the carbon securities holders and the energy-consuming industry, respectively. The variable, θ, can be understood as the government's preference variable. In the Grossman Helpman model it is interpreted as the weight of voter welfare relative to campaign contributions. A politician with a high value of θ values the interests of the electorate more highly than a politician with a low value of θ. In the terminology of Le Breton and Zaporozhets (2007), a politician with a low θ is a bad or corrupt politician since he is more willing to depart from social welfare when deciding upon which price to set. In this paper, θ is interpreted as climate or political uncertainty. So in period 1, when the investment decision is made, θ is unknown. At the beginning of the second period, θ is realized. Section 3.2 elaborates on how θ can be used to describe climate and political uncertainty.

Next, consider the lobbying stage of the game.

Assumption 3.2 *The energy consuming industry and its lobby satisfy the following assumptions:*

(a) The firms of the energy consuming industry are able to organize themselves into a lobby group in order to influence the political process.

(b) The lobby of the energy-consuming industry does not face any borrowing constraints when they make campaign contributions.

The gross of contributions welfare of the energy-consuming industry is

$$W_E = \sum_{i=1}^{m} \pi_i(I_i; p) - I = \Pi(p) - I \tag{3.4}$$

where p is the carbon price (input price), π_i is the profit of firm i and Π is the total profit of the industry. The lobby of the industry chooses the contribution C_E to maximize net of contributions industry welfare:

$$\max_{C_E} \Pi(p) - I - C_E(p) \tag{3.5}$$

The gross of contributions welfare of the owners of carbon securities is the value of the securities in the second period minus the amount they had to pay to purchase the securities in the first period:

$$W_B(p, I) = -p\frac{\partial \Pi}{\partial p} - \xi n$$

where ξ is the price that the government sold an security for and n is the total number of securities. The sale of the carbon securities takes the form an auction. So ξ is the equilibrium price at the securities auction.[18] The revenue of the owners of the securities, $-p\frac{\partial \Pi}{\partial p} = -p\Pi'(p)$, is the product of the carbon price and the emission quota. A carbon security holder prefers a carbon price that maximizes $-p\Pi'(p)$.

As for the lobby of the energy-consuming industry, it is assumed that there are no borrowing constraints. So contributions can be as large as gross of contribution welfare of the lobbying group.[19]

Assumption 3.3 *The owners of the carbon securities satisfy the following assumptions:*

(a) The owners of carbon securities are able to organize themselves into a lobby group in order to influence the political process.

(b) The lobby of the owners of carbon securities does not face any borrowing constraints when they make campaign contributions.

Finally, consider the investment stage.

Assumption 3.4 *The individual firms and the industry satisfy the following assumptions:*

[18] This carbon securities auction is not explicitely modelled here. Conducting an auction has the advantage for the government that it maximizes its revenue. However, all results of the paper also follow thorough if the carbon securities would be sold at a fixed price (which could be zero).

[19] While the model does not explicitely address the question what effect campaign contribution limits have, this question is implicitely addressed by the weight of social welfare, θ. For example, if there are very tight caps on campaign contributions, this is equivalent to politicians having a very high θ. The equilibrium carbon price in either case is close to the social welfare maximizing carbon price.

(a) *Each firm i believes itself too small to have any meaningful impact on the carbon price p or the aggregate investment level I.*

(b) *No industry-wide coordination is possible on investment.*

(c) *The profit function of the energy consuming industry satisfies (in the relevant range) for all p that $\Pi'(p) < -p\Pi''(p)$ where $-\Pi'(p)$ is the industry demand for coupons.*

(d) *All firms in the industry are monopolistically competitive.*

In period 1, each firm individually chooses an investment level I_i which determines its demand for energy in the following period. For given p, I and θ an individual firm's profit is

$$w_i(I_i; p, I, \theta) = \pi(I_i; p) - I_i - \frac{1}{m} C_E(p, \theta, I) \tag{3.6}$$

where $\pi(I_i, p)$ is the profit of firm i, C_E is the contribution made by the energy consuming industry, I_i is investment in energy-saving technology. Aggregate investment is $I = \sum_{i=1}^{m} I_i$. The carbon price p is an input price. Thus, $\frac{\partial \pi}{\partial p} < 0$. An individual firm's demand for energy is $-\frac{\partial \pi}{\partial p} = -\pi'$.

If a firm invests, it requires less energy for its production. So for any p,

$$\frac{\partial(-\pi')}{\partial I} < 0.$$

In other words, for a given carbon price, a firm's demand for energy decreases with the investment level.

3.2.2 Discussion of the Model

An important question is who would buy the carbon securities when the government auctions them in the first period. The effectiveness of carbon securities as a policy tool depends on the allocation of the carbon securities in the second period. There is an incentive to form a lobby in favor of maximizing the value of the securities unless the carbon securities are all held by carbon using firms *and* each firm's proportion of carbon securities is the same as the firm's share of future carbon emissions. The benefits of carbon securities are larger if a high fraction of the securities is held for investment purposes (resale) and not for a firm's own carbon consumption. This paper focuses on the benchmark case in which all securities are held by outsiders to the carbon-using industries since there are several strong arguments why it is unlikely that a large fraction of the securities is bought by carbon using firms in the first period.

Carbon securities are financial assets with a highly uncertain future value. The future value of carbon securities is affected by climate uncertainty, political uncertainty and uncertainty about the demand for fossil fuels.[20] It seems therefore plausible to anticipate that a large share of securities is bought by investment banks and other entities specialized on investment in assets with uncertain returns. Carbon using firms choosing not to buy carbon securities in period 1 but carbon allowances in period 2 is equivalent to firms buying an input for production instead of producing it themselves. Firms frequently choose not to internalize parts of the production process.[21]

A look at the market for forward SO_2 allowances supports this argument. Each year the Environmental Protection Agency (EPA) auctions seven year forward SO_2 allowances, each of which gives the owner the right to emit one ton of SO_2 seven years after the auction takes place. One might expect that these forward allowances are bought by powerplants that anticipate that they will require SO_2 allowances seven years from now. However, this is typically not the case. The majority of bidders in forward SO_2 allowances auctions are not entities that purchase SO_2 allowances for their own consumption. For example, at the 2009 Acid Rain Allowance Auction the three largest bidders were JP Morgan, Barclays Bank and Morgan Stanley. Less than 1% of the allowances were bought by entities that are not investment banks. Forward SO_2 allowances are financial assets characterized by significant uncertainty with respect to their future value. Therefore, entities like

[20] This last source of uncertainty is not explicitly modelled here but could be added to the model without affecting the main conclusions of the paper.

[21] An alternative way of saying this is to note that firms do not purchase all inputs with long term contracts. Eventually, it seems likely that options markets for carbon coupons would developed to hedge the risk of unexpected coupon price fluctuations.

investment banks that are specialized on pricing risky assets are at a natural advantage. Also, acquiring information about the SO_2 market and hiring experts to make forecasts of SO_2 prices is costly. Therefore, there are likely significant economies of scale which favor investment banks.[22] [23]

A notable difference between SO_2 forward allowances and carbon securities is that only for the later there is an incentive to buy them to prevent the formation of a counterlobby.[24] If the lobby of the carbon using firms coordinates and buys all securities it can prevent the formation of a lobby of carbon securities holders. As outlined above there are strong reasons why an average carbon using firm is unlikely to be interested in purchasing carbon securities. So any plan involving a purchase of all carbon securities by the carbon using firms has to overcome a significant free-rider problem. A firm in the carbon using industries prefers that other firms in the industry purchase all securities but would rather not purchase any securities itself. It seems very unlikely that the lobby of carbon using firms would be able to monitor if their members choose to purchase an appropriate amount of carbon securities. This is much more difficult to monitor than if firms pay their lobby contributions.

In addition, both cornering a security market and colluding are illegal in most countries. Politicians have a strong incentive to enforce these laws since they benefits from the presence of an additional interest group. With an addition interest group representing people who bought carbon securities for investment purposes, politicians receive higher campaign contributions and the equilibrium policy level is closer to the social optimum and should

[22] It is important to keep in mind that the group of carbon using firms consists of many more firms than just large multi-national energy firms (which might have sufficient economies of scale to hire experts). A carbon system typically affects a very large number of firms - 85% of firm in the case of the Waxman-Markey proposal. Thus, a large number of firm affected by the abatement policy are small and medium size firms.

[23] There is a difference between carbon securities and forward allowances in another respect. Forward SO_2 allowances constitute a very small share of the overall amount of SO_2 allowances. Carbon securities would cover the entire market for carbon emission allowances. However, the argument here addresses the nature of the asset, which is quite similar.

[24] The owner of a forward SO_2 allowance has been promised exactly 1 ton of SO_2 emissions, so there is scope for negotiations and hence no need for lobby formation.

hence appeal more to the electorate. Finally, note that in any situation in which there are two or more lobbies there may in principle be advantages for the lobbies if they get together and form one super-lobby since it allows them to capture all surplus from the political relationship with the government. In practice, there is little evidence that lobbies or industries take over competing lobbies or industries to then jointly maximize their lobbying and extract surplus from the government.

Next, consider assumptions about the firm: Assumption 3.2(a) states that firms are able to coordinate their efforts on lobbying for a favorable carbon price but according to part 3.4(b) cannot or choose not to coordinate their investment decisions. There are two main reasons why this is a plausible assumption: First, competition laws in most countries limit opportunities for industry wide coordination when it comes to investment projects. Second, the free-riding problem is harder to overcome when investments are large relative to revenue as is the case when it comes to investment. Also, while it is fairly easy for the other firms to observe if a firms contributes to the lobby, it is much harder to observe how much a firm invests in abatement technology. So free-riding is a more pressing concern when it comes to investment than for lobby contributions. This is a very similar argument as the argument above why firms do not coordinate to purchase carbon securities. Assumption 3.4(a) is realistic if a large number of firms are subject to the requirement to purchase carbon allowances. This is true for most carbon tax or cap and trade systems.[25] Assumptions 3.2(b) and 3.3(b) state that each lobby is sufficiently funded to make optimal campaign contributions. Essentially, this says that the lobby members are able to overcome the free-rider problem when it comes to organizing their lobby. Assumption 3.4(c) is satisfied in the range of p in which the industry's expenditures on energy increase with the permit price. The condition can also be interpreted as a condition about the curvature of the profit function. At all p, the Arrow Pratt measure, $\frac{-\Pi''(p)}{\Pi'(p)}$, has to be larger than $\frac{1}{p}$. Since empirical observations strongly suggest that at current fossil fuel prices an increase in the

[25]In particular, this must hold for any plan similar to the recent Waxman-Markey proposal which covers 85% of carbon emissions.

price leads to higher expenditures on fossil fuels, this assumption is realistic for virtually every climate policy goal currently under serious consideration.

In the model demand for energy each period is deterministic: there is no uncertainty in the demand for carbon. In other words, this assumption states that the periods for which carbon securities pay carbon allowances are sufficiently short. Including uncertainty would not affect the fundamental results - in particular with respect to the comparison between the traditional permit or tax system and a system with carbon securities.

In principle, environmental policy is also influenced by environmental interest groups like Greenpeace, the Sierra Club, Earthwatch and others. In practice, the influence of these groups on policy setting is likely to be small compared to industry lobbies. A main reason for this is limited funding. In the case that environmental interest groups have the ability to influence policy, it seems likely that their attention would shift from global warming to other environmental issues once a system with carbon securities led to a carbon close to the social optimum. Therefore environmental interest groups are not explicitly considered in the model.

3.3 The Tax Game

This section considers the tax game. Recall that the key difference between the tax game and the carbon securities game is that in the former one of the two lobbies has no incentive to be active.

3.3.1 The Equilibrium

The two period game considered here can be solved by backward induction. First, the menu auction stage in which p is determined has to be considered. In a second step, the individual firm's investment decision can be analyzed. The investment decision depends on the expected carbon price and potentially on the variance of the carbon price.

Definition 3.1 *An equilibrium of the lobbying stage of the tax game is a contribution function $C_E(p, \theta, I)$ and a carbon price p such that*

a. *the contribution function maximizes the joint welfare of the lobby's members given the carbon price p*

b. *carbon price p maximizes the government's objective taking the contribution function as given*

The lobby offers a contribution function, which specifies a financial contribution depending on the government's choice of the carbon price. Thus, the game is a menu auction (Bernheim and Whinston, 1986).

Definition 3.2 *An equilibrium of the tax game is a contribution function $C_E(p, \theta, I)$, a set of individual firm investment levels $(I_1, ...I_m)$ and a carbon price p such that*

a. *for each firm i, $I_i \in \Im$ maximizes the expected net of contributions welfare of the firm given the expected equilibrium contribution schedules and carbon price*

b. *$C_E(p, \theta, I)$ and p are an equilibrium of the menu auction stage of the carbon securities game*

The following proposition states the necessary and sufficient conditions for an equilibrium of the menu auction stage of the tax game.

Proposition 3.1 *[Lobbying Stage Equilibrium with Tax] Given the aggregate investment level I, (C_E^0, p_T) is an equilibrium of the lobbying stage if and only if*

a. C_E^0 *is feasible*

b. p_T *maximizes* $C_E(p;\theta, I) - \theta G(p; I)$

c. p_T *maximizes* $W_E(p;\theta, I) - \theta G(p; I)$

d. there exists a p^E *that maximizes* $W_G(p;\theta, I)$ *such that* $C_E^0(p^E) = 0$

Proof. The proposition follows immediately from Lemma 2 of Bernheim and Whinston (1986). The first condition is a standard feasibility condition. The second condition requires that the carbon price is optimal for the government since $C_E(p;\theta, I) - aG(p; I)$ is the government revenue after contributions have been received. The third and fourth conditions together state that the lobby's contribution schedule has be optimal. ■

In general, there are a large number of equilibria in menu auctions. However, only equilibria supported by so-called truthful contribution schedules are stable to non-binding communication among players. Also, the best response set to any strategy played by an opponent includes a truthful strategy (Bernheim and Whinston, 1986). Therefore, I focus in the following on equilibria supported by truthful contribution schedules.

Definition 3.3 *A truthful contribution schedule takes the form* $C_i(p;\theta, I, B_i) = \max[0, W_i - B_i]$ *where* B_i *is a constant.*

Corollary 3.1 *Suppose the contribution schedule is truthful. There is a unique equilibrium. The equilibrium carbon price* p_T *satisfies* $\theta G'(p) = \Pi'(p)$.

Proof. First, consider uniqueness. When the contribution schedule is truthful, condition (b) of Proposition 3.1 simplifies to

$$C_E(p) - \theta G(p) = W_E(p) - B_E - \theta G(p)$$

where B_E is a constant. Therefore, conditions (b) and (c) of Proposition 3.1 lead to the same first order condition. Second, to see that the equilibrium carbon price p_T satisfies $\theta G'(p) = \Pi'(p)$ start with either condition (b) and (c) of Proposition 3.1 and replace W_E with the expression in Equation 3.4:

$$W_E(p) - B_E - \theta G(p) = \Pi(p) - I - \theta G(p)$$

Note that while I depends on p since the individual firm's investment decision, I_i, in the investment stage in period 1 depends on p, once the lobbying stage is reached I has been determined and the government's choice of p does not affect I. Therefore, the FOC characterizing the equilibrium of the tax game is $\theta G'(p) = \Pi'(p)$. ■

Proposition 3.2 *[Equilibrium Price Comparison] The carbon price under a tax system is lower than the socially optimal price: $p_T < p^*$.*

Proof. Since p is an input price Π is a decreasing function of p:

$$\Pi' < 0$$

This implies that the tax game equilibrium price, p_T, has to be in the range of p in which it holds that $\theta G'(p) < 0$. Figure 12 shows Π', $\theta G'$, and the social welfare maximizing carbon price p^*. From Assumption 3.1 it follows that $\theta G'(p) < 0$ for all $p < p^*$ Therefore, $p_T < p^*$: The price under the tax system has to be below the price which maximizes social welfare. ■

Figure 12 illustrates this proposition. The equilibrium price is below the socially optimal price due to the lobbying of the energy-consuming industry.

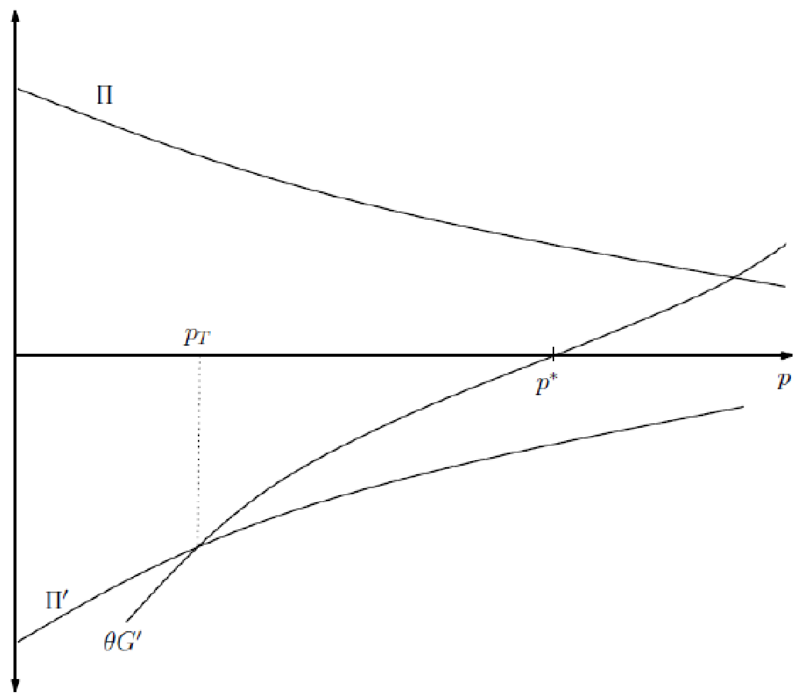

Figure 12: The tax game equilibrium

3.3.2 Effect of Uncertainty

In period 1, there may be significant uncertainty about the state of the world in period 2. This can take the form of either climate uncertainty (how costly global warming is) or political uncertainty (what party will be in charge). This section shows how both types of uncertainty can be considered within the framework of the model. The goal is to study uncertainty while keeping the model as simple as possible. The following shows that the variance of θ can be interpreted as either political uncertainty or climate uncertainty.

First consider political uncertainty: a situation in which in period 1 it is unknown which party will be in charge of choosing the carbon price once time 2 is reached. Suppose there are at least two parties and these parties differ in how important it is for them that the carbon price is close to p^*. In other words, they have different θ's. The ex ante (period 1) variance of period 2's carbon price depends on the distribution of θ. One explanation for differences in θ is that the political parties can differ with respect to how corrupt their politician are. In other words, they may place different weight on campaign contributions relative to voter welfare.

Next, assume that there is no political uncertainty (all politicians have an θ equal to θ_H) but there is considerable uncertainty about the climate. The social cost of carbon function can either be G or F and this uncertainty is not resolved until period 2 is reached. The state of the world characterized by social cost of carbon function G can be thought of as a state with high climate sensitivity and global warming imposing significant cost to society. The state of the world characterized by social cost of carbon function F can be interpreted as a state with either low climate sensitivity, efficient geoengineering options or low cost of global warming. If the social cost of carbon function is G then the socially optimal carbon price is p_G^* and any downward deviations are expensive. Hence G' is steep (see Figure 13). If the social cost of carbon function is F then the socially optimal carbon price is p_F^* and any downward deviations are less expensive than under G.

As Figure 13 shows, the same equilibrium as under F can be found by using G and choosing the appropriate θ - here θ_L. Therefore, to keep things

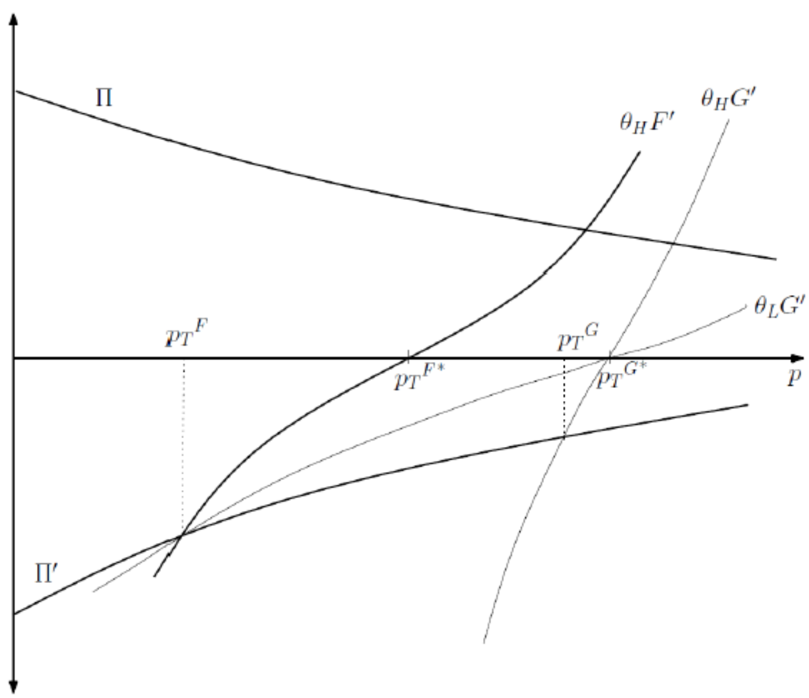

Figure 13: Uncertainty in θ can be interpreted as uncertainty in G.

as simple as possible both climate uncertainty and political uncertainty is in the following studied by varying θ.

3.3.3 A Comparison to a Traditional Permit System

Most of the literature considers carbon tax systems and cap and trade systems as policy instruments with significant differences and correspondingly different advantages and disadvantages. Within the model considered here both instruments have more similarities than differences. Hence it is useful to consider them together. The two policy instruments are essentially equivalent here since (i) there is no demand uncertainty within a period, (ii) both under the tax and the cap and trade system, the policy is set at the beginning of period 2 and (iii) there is no banking of permits since there is only one period. So it does not make a difference whether the carbon price is chosen by the government or whether an emission quantity is chosen. Both lead to the same equilibrium.

The assumption that there is no demand uncertainty within a period, is more realistic for short periods than for long periods. The model could be extended to the case of demand uncertainty. However, demand uncertainty affects both a traditional cap and trade system and the here proposed system equally, so for the purpose of comparing an existing mechanism to a new mechanism, very little is gained by including demand uncertainty.

3.4 The Carbon Securities Game

The previous section illustrated the effect of the presence of a lobby representing the interests of energy-consuming industry on the equilibrium carbon price, the variance of the carbon price and equilibrium investment in alternative energy. It showed that the equilibrium carbon price under a traditional tax or permit system is below the social optimum. This section proposes an alternative to a traditional tax or permit system which is superior with respect to the level of the carbon price and has interesting properties with respect to climate and political uncertainty.

Compared to other carbon abatement policy instruments, the key feature of system with carbon securities is that the amount of carbon emissions allowed per security is determined after the security has been sold. Each of the n carbon securities gives its owner the right to emit up to $\frac{1}{n}$ of the society's total desired carbon emissions for year 2, X. This amount X is unknown to potential buyers at time 1 when they have to decide whether they want to purchase a security or not. Once all securities have been sold, firms choose their level of investment in energy-saving technology technology. In period 2 the political process determines X, taking into account the voters' preferences, the aggregate investment level and any contributions from lobbies representing either the interests of the energy-consuming industry or the the owners of carbon securities.

The securities game is a common agency game with two principals, the lobbies of the energy-consuming industry and the holders of carbon securities, and one agent, the government, who has the discretionary power of selecting the carbon price (Bernheim and Whinston, 1986). Lobbyists compete by simultaneously offering contribution schedules conditional on the policy ultimately selected. The government chooses the carbon price which maximizes its welfare, which depends on the weighted sum of campaign contributions and social welfare.

As in the previous section on the tax game, there are essentially two periods. In the first period the following actions and events take place: The government sells n securities. The owners of the securities form a lobby and the energy-consuming industry forms a lobby. Each firm in the energy-consuming industry chooses its investment level. In the second period, the lobbies find out how much the government is influenced by campaign contributions. The lobbies then offer their contribution schedules. The government chooses an amount of desired maximum carbon emissions X and thereby determines the price of carbon p. Each security owner sells $\frac{X}{n}$ carbon allowances to firms in the energy-consuming industry at a price of p per unit of carbon.

The government has similar preferences as in the previous section. The only addition is that the government now receives campaign contributions not just from the lobby of the energy-consuming industry but from the lobby representing the interests of the permit holders.

3.4.1 The Equilibrium of the Carbon Securities Game

The fundamental difference between the carbon securities game and the tax game is that in the former there is political competition while in the later there is not. In the carbon securities game there are two active lobbies, while in the tax game only the lobby of the energy consuming industry is active. Political competition has a strong effect on the equilibrium carbon price and campaign contributions.

Definition 3.4 *An equilibrium of the menu auction stage of the carbon securities game is a set of contribution functions* $\{C_E(p, \theta, I), C_B(p, \theta, I)\}$ *and a carbon price* p *such that*

- *a. each contribution function maximizes the joint welfare of the group's members given the carbon price and the other groups contribution function*
- *b. carbon price* p *maximizes the government's objective taking the contribution function as given*

Definition 3.5 *An equilibrium of the carbon securities game is a set of contribution functions* $\{C_E(p, \theta, I), C_B(p, \theta, I)\}$*, an investment level* I *and a carbon price* p *such that*

a. *I maximizes the expected net of contributions welfare of the energy consuming industry given the expected equilibrium contribution schedules and carbon price*

b. $\{C_E(p,\theta,I), C_B(p,\theta,I)\}$ *and* p *are an equilibrium of the menu auction stage of the carbon securities game*

Proposition 3.3 *[Menu Auction Equilibrium with Securities] Given the investment level* I*,* (C_B^*, C_E^*, p_S) *is an equilibrium if and only if*

a. C_E^**,* C_B^* *are feasible*

b. p_S *maximizes* $C_B(p,\theta,I) + C_E(p,\theta,I) - \theta G(p,I)$

c. p_S *maximizes* $W_B(p,\theta,I) - \theta G(p,I) + C_E(p,\theta,I)$

d. *there exists a* p^B *that maximizes* $W_G(p,\theta,I)$ *such that* $C_B^*(p^B) = 0$

e. p_S *maximizes* $W_E(p,\theta,I) - \theta G(p,I) + C_B(p,\theta,I)$

f. *there exists a* p^E *that maximizes* $W_G(p,\theta,I)$ *such that* $C_E^*(p^E) = 0$

Proof. Similarly to Proposition 1, the result follows from Lemma 2 of Bernheim and Whinston (1986). The first condition states that the contribution has to be nonnegative and must not be greater than the aggregate income of lobby's members. Condition (b) states that the government chooses a carbon price to maximize its own welfare. Conditions (c) and (d) ((e) and (f)) ensure that the contribution schedule of the lobby of the banks (the lobby of the energy intensive industry) is optimal. ■

Corollary 3.2 *Suppose contribution schedules are truthful. There is a unique equilibrium. The equilibrium carbon price* p_S *satisfies* $\theta G'(p,I) = -p\Pi''(p,I)$.

Proof. Uniqueness under truthful strategies follows directly from Propositions 6 and the definition of truthful strategy:

$$C_B(p,\theta,I) = W_B(p) - B_B$$

and

$$C_E(p,\theta,I) = W_E(p) - B_E$$

Therefore, conditions (b), (c) and (e) lead to the same first order condition when strategies are truthful. To derive this FOC, take for instance condition (c):

$$W_B(p,\theta,I) - \theta G(p) + C_E(p,\theta,I) = -p\Pi'(p) - \xi n - \theta G(p) + W_E(p) - B_E =$$

$$= -p\Pi'(p) - \xi n - \theta G(p) + \Pi(p) - I - B_E$$

where I, B_E, ξ and n do not depend (in this stage) on the choice of p. Therefore, the first order condition that characterizes the equilibrium of the carbon securities is $\theta G'(p,I) = -p\Pi''(p,I)$. ■

3.4.2 Comparison with a traditional tax or permit system

This section addresses the question how the carbon securities system I propose compares to systems currently in use or proposed in the literature. First, I consider the question how the equilibrium carbon prices compare to each other. Second, I look at implications of climate or political uncertainty on the variance of the carbon price. Third, the effect on investment in energy-saving technology is analyzed. Fourth, advantages and disadvantages of either system for the government are considered.

With a traditional permit system or a carbon tax, only the energy consuming industry has a strong financial incentive to lobby for a carbon price in its favor. Introducing property rights for emissions creates a counterbalancing force: now there is a group that has a strong financial interest in lobbying for a high carbon price. Hence, the equilibrium carbon price is higher. However, under both system the carbon price below the social optimum. The following proposition states this.

Proposition 3.4 *While the carbon price under either system is below the social optimum, $p_T < p^*(I^{Tax})$ and $p_S \leq p^*(I^{Permit})$, in the carbon securities game the carbon price is higher than in the tax game: $p_T < p_S$.*

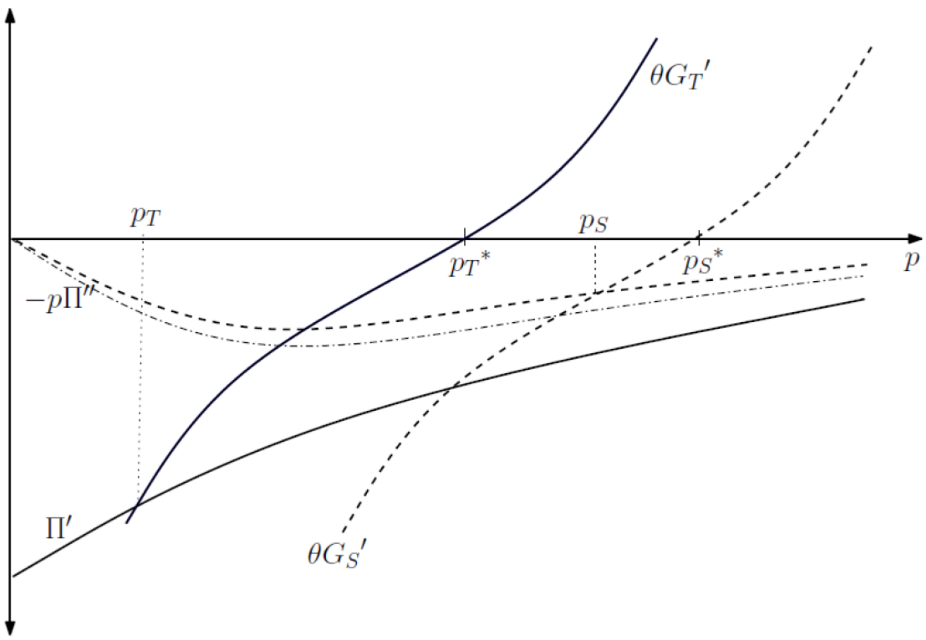

Figure 14: The equilibrium of the carbon securities game.

Proof. First, consider the tax game. The tax equilibrium price, p_T is below the socially optimal carbon price, $p^*(I^{Tax})$. This follows directly from the FOCs of the tax game. Since $\Pi'(p) < 0 \; \forall \; p$, p_T has to be in the range where $G(I^{Tax})$ is downward sloping. Hence $p_T < p^*(I^{Tax})$. Similarly, as $-p\Pi''(p) < 0 \; \forall \; p > 0$, p_S is in the range where $G(I^{Permit})$ is downward sloping. Second, Assumption 7(c) states that

$$\Pi'(p) < -p\Pi''.$$

Assumption 3.4(c) together with G being convex and investment increasing with the equilibrium carbon price implies that $p_T < p_S$. Note that if the profit function of the industry is linear in p (in other words if it is not possible to substitute away from fossil fuels), p_S is equal to $p^*(I^{Permit})$. Example 1 illustrates the relationship between the equilibrium price in the tax game and in the carbon securities game. ■

Consider Figure 14. Under a tax system, the equilibrium carbon price is p_T. Now suppose that the government switches to the carbon securities system. If firms' investment in the first period is unaffected by this switch of policy instruments, then the new equilibrium with carbon securities is at the intersection of the dash dotted line and the $\theta G'_T$ line. So there is an increase of the equilibrium carbon price as a result of lobbying by the carbon security holders. As forward looking actors, firms anticipate in period 1 that there switch from a carbon tax to carbon securities implies that carbon emissions in the second period will be more expensive. Therefore, they will invest more in carbon abatement technology in the first period. This increase in first period investment affects both the $\theta G'$ line and the $-p\Pi''$ line. The $\theta G'$ shifts to the right and the $-p\Pi''$ line shifts upwards in response to an increase in aggregate investment I. So the equilibrium carbon price with carbon securities is p_S.

If there is no effect on investment, the carbon price increases to 'p_S under constant investment.' However, since there is now a higher equilibrium carbon price and investment is more attractive under a higher carbon price, there is higher equilibrium investment. Under Assumption 3.4, an increase of the investment level, leads to an increase of the socially optimal carbon price. The new socially optimal carbon price is ${p_S}^*$. The equilibrium carbon price under the increased investment level is p_S.

Thus, the carbon price is higher in the carbon securities game for two reasons. First, there is the *lobbying effect*. Having political competition over the carbon price mitigates the effect of the lobby of the energy-consuming industry. Second, there is an *investment effect*. A change in the equilibrium price affects investment in energy saving technology. This change in the investment level has an effect on the socially optimal carbon price and therefore also on the equilibrium carbon price. The size of the effect depends on how sensitive investment is to carbon price changes, how much the socially optimal carbon price depends on investment and on the industry profit function (how easy it is to substitute away from energy sources that require permits).

Next, consider the effect of the choice of the policy instrument on the

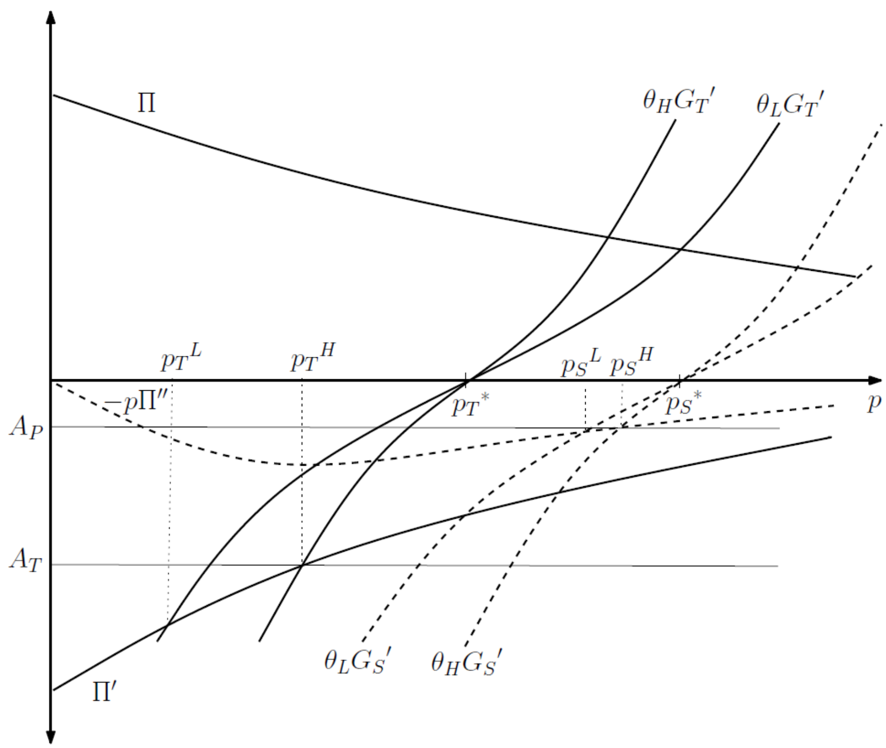

Figure 15: The effect of a change in θ.

variance of the equilibrium carbon price when there is either climate or political uncertainty. As outline in Section 3.3.2 uncertainty is modeled as change in the parameter θ. Figure 15 illustrates the effect of changing θ from θ_H to θ_L for both the carbon securities and tax game equilibrium.

The change in the tax equilibrium price, $\triangle p_T = p_T^H - p_T^L$, is larger than the change in the carbon security price, $\triangle p_S = p_S^H - p_S^L$ if either one of the following conditions is satisfied (a) Π' is sufficiently smaller than $-p\Pi''$, (b) $2\Pi'' + p\Pi''' > 0$ and (c) Π is close to linear.

Proposition 3.5 *Suppose one or more of the three conditions above is satisfied. Then the variance of the price of carbon is smaller under carbon securities than under a carbon tax or traditional permit system.*

Proof. Consider Figure 15 and note that by Assumption 3.1 G'_P is at least as steep as G'_T. The figure includes two horizontal lines, A_P and A_T, for illustration. The horizontal distance between $\theta_H G'_T$ and $\theta_L G'_T$ and between $\theta_H G'_P$ and $\theta_L G_P$ increases as A decreases. The condition (a) states that essentially states that the distance between A_P and A_T has to be sufficiently large. Clearly when that is the case, $\triangle p_T$ is larger than $\triangle p_S$. Condition (b) is a statement about the slope of $-p\Pi''$and Π'. It states that if $-p\Pi''$ is flatter than Π' then since by Assumption 3.4(c) $\Pi' < -p\Pi''$ it has to be true that $\triangle p_T$ is larger than $\triangle p_S$. This condition does not have to be true for all values of p but only for those in the range of p_S and p_T. The effect of a close to linear Π, condition (c), is illustrated in Example 1. ■

Example 3.1 *Consider the case of a linear profit function. This is the situation in which investment is essentially equivalent to gaining access to a specific blueprint for production technology and this technology requires a constant amount of carbon based energy per unit of output. If* Π *is linear then* Π'' *and* Π''' *are equal to zero. Therefore,* $p_S = p^*$ *and* $\frac{dp_S}{d\theta} = 0$*. However,*

$$\frac{dp_T}{d\theta} > 0$$

So as expected, the tax equilibrium price increases with θ*: With a high* θ*, the government puts more weight on social welfare and the tax equilibrium price is higher.*

Thus, with a linear profit function variance in θ translates into price uncertainty in the tax game but not in the carbon securities game.

The equilibrium carbon price is a function of θ under either system. However, the carbon price under a tax system is more responsive to changes in θ than with carbon securities.

Suppose θ is large, then both with carbon securities and a traditional scheme, the carbon price is close to p^*, the socially optimal price. However, if θ is small then $p_T \ll p^*$, while p_S is relatively close to p for all θ.

In general, how close p_S is to p^* depends on the curvature of the profit function. For an almost linear profit function, p_S is very close to p^*. The more convex the profit function the larger the distance between p_S and p^*. The profit function is very convex if it is very easy to substitute away from fossil fuels. As long as Assumption 3.4(c) holds, the profit function can only have a small amount of curvature. If it had more curvature, then substituting away from fossil fuels would be very easy and the response to an increase in the price of fossils would be a decrease in the total expenditures on fossil fuels.

Next, consider investment in energy-saving technology. So far the model only explicitly considered an investment option in period 1 but of course there also exist opportunities to invest in energy-saving technology at later points in time. Later investment has the advantage that by then some of the uncertainty present in the first period has been resolved. It is important to note that any such investment is not likely to be perfectly recoverable in case it turns out to be an unprofitable investment. The reason is that if investment in energy-saving technology turn out to be unprofitable for one firm this is most likely due to the carbon price being very low. In other words, the investment considered is investment that can only be used for reducing energy consumption, not for other purposes. However, with the carbon price being very low the resale value of energy-saving equipment or machinery is very low. Therefore investment is (mostly) irreversible. The question how early (period 1) investment in energy-saving technology is affected by the choice of the policy instrument is consequently best approached from the perspective of the investment under uncertainty literature (Dixit and Pindyck, 1994).

Assumption 3.5 *Suppose that θ represents climate uncertainty and that θ follows a random walk (or a Brownian motion if the problem is considered in continuous time).*

Think of θ as a signal that arrives at the beginning of each period and provides information about the expected cost of global warming. Then it is reasonable to assume that the best estimator of θ_{t+1} is θ_t. A random walk is a good characterization for such a process.

Proposition 3.6 *Assume Assumption 5 holds. Then there is more investment in carbon abatement technology in a system based on carbon securities than under a carbon tax or traditional permit system.*

Proof. There are two forces that encourage early investment under a system based on carbon securities. First, the expected carbon price is higher. The expected return from investment in energy-saving technology increases with the carbon price. Hence, an increase in the expected carbon price increases period 1 investment. Second, since θ follows a random walk, increasing uncertainty delays firm level investment and leads to lower levels of investment. This follows directly from work by Pindyck (1988), Hassett and Metcalf (1994) and others. ■

Switching from a traditional tax system to carbon securities affects both the level of the carbon price and the variance of the carbon price. The increase in the expected carbon price makes investment in alternative energy more attractive. The reduction in the variance of the carbon price also encourages investment if the nature of the uncertainty is a random walk and the investment is (partially) irreversible. Intuitively, investment in abatement technology is attractive if the carbon price is high but not if it is low. By waiting until uncertainty is resolved a firm avoids making the costly mistake of having invested but the state of the world turning out to be a low socially optimal carbon price (global warming not a serious problem). A decrease of the uncertainty over the future returns from investment, reduces the value of waiting and therefore makes investment in period 1 more attractive.[26][27]

Also, in the carbon securities game the expected level of global warming is lower than in the tax game due to two effects: First, the carbon price

[26] If uncertainty is better characterized as a mean stationary jump process than as a random walk, Hassett and Metcalf (1994) show that aggregate investment can under some conditions be enhanced by increasing uncertainty. However, in their model profitability of investment is determined by the state of world when the investment is undertaken. Here profitability of investment depends on the entire sequence of states of the world beginning at the moment that the investment is undertaken.

[27] In this paper differs from Acemoglu et al (2009 in so far as that here the trigger for technological change is a change in the policy tool (or institutional setup).

in the carbon securities game is higher because it is closer to the socially optimal carbon price. Second, the socially optimal carbon price in the carbon securities game is higher because there is more investment in energy saving technology. Both effects leads to less global warming in the case of the securities game.

Next, consider government revenue under both the system with permits as bonds with uncertain coupons and under a traditional tax or permit system. Both a traditional permit system and the carbon securities system can be designed so that there is government revenue from selling or auctioning permits. If permits are auctioned off, the revenue is equal in size to that of a tax that generates the same amount of emissions. Assumption 4(c) and Proposition 4 imply that government revenue is larger under the here proposed policy instrument than under traditional alternatives.

Finally, consider the effect of the policy instrument choice on total campaign contributions. Grossman and Helpman (1994) show that if a lobby faces no opposition from competing interests it is able to extract all surplus from its political relationship with the government. This implies that contributions of the energy-consuming industry in the tax game are equal to the difference of the social cost of carbon function under the tax game equilibrium price and the social cost of carbon function under the socially optimal price. If there are two active lobbies as in the carbon securities game, the government captures all of the surplus from the political relationships.

3.5 Welfare Benefits of Switching from a Carbon Tax to Carbon Securities

The above analysis raises the question what the size of the welfare benefit of switching from a carbon tax or permit system to a system with carbon securities is. Since carbon securities have not been implemented anywhere yet, there is no policy experiment available to learn from. There are several factors that make estimating the size of the welfare benefits a challenge. First, the benefits of any carbon abatement policy are subject to considerable uncertainty due to limited knowledge about the climate system and the cost of climate change. Second, to estimate the welfare effect of a switch from a carbon tax to carbon securities, estimates of the demand *function* for carbon-based energy and the government's weight on social welfare relative to campaign contributions would be helpful. These estimates are not available. Third, the model here assumes a one country world. In reality, some countries may attempt to free ride on other countries' abatement efforts and this may have a not negligible effect on the equilibrium. Fourth, while a higher carbon price and less uncertainty in the carbon price should facilitate investment in carbon abatement technology, the magnitude of this effect is unclear. The same holds for potential positive externalities of this increase in the investment level.

However, it is possible to calculate a first rough estimate of the welfare benefits. The following estimates of abatement policy benefits taken from Nordhaus (2008) are to be understood as estimates that may be subject to significant modeling, behavioral and measurement errors. The present value gain of conducting optimal abatement policy (a carbon price equal to p^* according to the terminology used here) is 3.37 trillions of 2005 U.S. \$ compared to business as usual (no controls). The present value gain of a policy like the Kyoto Protocol is 0.15 trillions of 2005 U.S. \$ compared to the same baseline.[28] If the Kyoto Protocol is a reasonable first approximation of the outcome of environmental policy with carbon taxes or permits as policy instruments, then .0.15 trillions can be interpreted as the welfare gain under a tax or traditional permit system (compared to no abatement). This assumes that the main cause of the below optimal abatement levels we observe is interest group influence and not a free rider problem. If the free rider problem was the main reason for the low abatement efforts we observe, then large polluters should be more willing to abate while smaller countries should be less willing to abate. This is however not the pattern we observe.

If demand for energy is very inelastic, then a system based on carbon securities should get quite close to the optimal abatement policy.[29] Hence,

[28] This refers to the original Kyoto Protocol in which the United States did not participate.

[29] Cooper (2003) provides price elasticities for crude oil for 23 countries and shows that

a first estimate of the welfare gain with carbon securities is 3.37 trillions (compared to no abatement policy). So switching from a system based on carbon taxes or permits to a system based on carbon securities leads to a welfare gain equal of roughly 3.22 trillions of 2005 U.S. $. This estimate does not yet include potential benefits from positive externalities resulting from increased investment in carbon abatement technology or from the decrease of the variance of the carbon price.

Since the United States currently consider passing a climate bill, an interesting question is what the gain would be from switching from a scenario in which the United States does Waxman-Markey and the rest of the world does Kyoto to worldwide carbon securities. Nordhaus (2008) does not provide welfare estimates for this scenario However, the emission targets under Waxman-Markey are slightly less strict than the emission targets would be if the United States were to follow the Kyoto Protocol, a scenario for which Nordhaus (2008) provides estimates. Therefore, the welfare gain from switching from the a scenario in which the United States does Waxman-Markey and the rest of the world does Kyoto to worldwide carbon securities, is between 2.44 trillions and 3.37 trillions and likely the actual number is closer to 2.44 trillions than to 3.37 trillions. As before, this estimate does not yet include potential benefits from positive externalities resulting from increased investment in carbon abatement technology or from the decrease of the variance of the carbon price.

demand is mostly very inelastic.

3.6 Conclusion and Further Research

From a political economy perspective, there are important differences between carbon securities and carbon taxes and cap and trade systems. Previous models comparing these policy instruments ignore this political economy dimension.

The paper showed that carbon securities have significant advantages over existing systems. First, the creation of stakeholders with an interest in a high carbon price counterbalances the efforts of the lobby of the energy-consuming industry. This leads to a carbon price level that is closer to the social optimum than with a traditional tax or permit system. Second, climate uncertainty and political uncertainty have a smaller effect on the expected variance of the carbon price which leads to more predictability for the market participants. Third, there is higher investment in abatement technology with carbon securities. Fourth, commitment to environmental policy is endogenous under the proposed system since it makes commitment to abatement policy the government's optimal choice.

The current model considers two periods. A first period in which securities are sold and investment takes place and a second period in which lobbying takes place. An important extension is the n period model. In this multi-period model each security pays $n-1$ allowances - one allowance in each but the first period. The multi-period model will address the question how the choice of the policy tool affects how investment expenditures are distributed over the n periods. My conjecture is that carbon securities encourage investment in early periods compared to traditional policy tools.

Another area for future research is the application of the mechanism proposed in this paper to other problems which involve a public good, for example public provision of TV broadcast stations.

4 The Performance of Carbon Securities When Some Carbon-Using Firms Purchase Carbon Securities

4.1 Introduction

In any environmental policy system based on carbon securities an important consideration is who will purchase the carbon securities. As outlined in Chapter 3 there are several reasons why it is likely that a large number of carbon emitters will not purchase carbon securities in period one but instead purchase carbon allowances in the second period from the entities that hold carbon securities.[30]

This benchmark case in which all securities are held by outsiders to the carbon-using industries is supported by the following arguments: Since carbon securities are financial assets with highly uncertain future value it seems plausible to anticipate that a large share of securities is bought by investment banks and other entities specialized on investment in assets with uncertain returns. Carbon abatement legislation in most countries affects a large number of small and medium sized firms which are likely be at a significant disadvantage compared to investment banks when it comes to investing in risky assets. The market for forward SO_2 allowances supports this argument. The majority of bidders in forward SO_2 allowances auctions are not entities that purchase SO_2 allowances for their own consumption but instead investment banks.[31]

This chapter addresses the question what happens if some of the carbon emitters purchased carbon securities in the first period for their own consumption. For example, it might be attractive for very large carbon using firms to purchase some carbon securities. A large enough firm may

[30] Recall that carbon securities are sold in period one. The owner of a carbon security receives a carbon allowance in period which she can either sell or use for her own carbon using production activity. The size of the carbon allowance is a fixed share of the total carbon emissions desireed by the government for the second period.

[31] For example, at the 2009 Acid Rain Allowance Auction the three largest bidders were JP Morgan, Barclays Bank and Morgan Stanley. Less than 1% of the allowances were bought by entities that are not investment banks.

have sufficient economies of scale to make it attractive to employ a number of specialists for investment in risking assets and in particular the pricing of carbon securities. I find that the equilibrium price if some securities are held by insiders is between the carbon securities equilibrium price with 100% outsider ownership and the tax equilibrium price.

4.2 If Carbon-Using Firm Purchase Carbon Securities

The setup in this section is very similar to the model outlined in Chapter 3. The only difference is that now the carbon securities are in part held by carbon-using firms to satisfy their own consumption of carbon allowances.

If an outsider to the carbon using industry owns a carbon security, this investor prefers a carbon price that maximizes the value of the carbon securities, $-p\Pi'(p)$. This changes if a carbon security is held by an insider to the carbon-using industry. An insider owns carbon securities for his own consumption of carbon allowances and possibly in addition to that in order to sell any left over carbon allowances to other firms. The insider prefers an emission quota high enough so that her own carbon emissions are covered by her carbon allowances. However, there is hardly any profit realized from selling any left over allowances if the price is very low. Hence, a carbon price of zero is not profit maximizing for a carbon using firm that owns carbon allowances.[32]

Suppose that of the m identical firms in the industry a fraction α holds the n permits. The remaining firms have to purchase emissions coupons after the menu auction stage from these αm firms. Further, assume that the assumption below holds:

Assumption 4.1 *Each of the αm firms holds the same share of the carbon securities.*

The firms belonging to the fraction α are both users of coupons and sellers. As they require coupons themselves, they benefit from a low carbon price, however, since they sell their leftover coupons, a high carbon price can be of advantage to them.

As in Chapter 3, consider a common agency game. The two groups of firms have different interest, therefore it makes more sense for them to form separate lobbies. Each lobby attempts to affect the carbon price in their favor. Their gross of contributions payoff of the $(1-\alpha)m$ firms that did not purchase any carbon securities is

[32] Carbon-using firms that do not purchase carbon securities prefer a carbon price equal to zero.

$$W_{E(1-\alpha)}(p, I_\alpha, I_{1-\alpha}) = (1-\alpha)\Pi(p, I_\alpha, I_{1-\alpha}) - I_{1-\alpha}$$

and the gross of contributions payoff of the αm firms that did purchase carbon securities is

$$W_{E\alpha}(p, I_\alpha, I_{1-\alpha}) = \alpha\Pi(p, I_\alpha, I_{1-\alpha}) - I_\alpha - (1-\alpha)p\Pi'(p, I_\alpha, I_{1-\alpha}) - \xi n$$

where I_α and $I_{1-\alpha}$ are the respective aggregate investment levels.

The government maximizes the weighted sum of campaign contributions and voters' welfare. W_G denotes the welfare of the government:

$$W_G(p, a, I_\alpha, I_{1-\alpha}) = C_{E(1-\alpha)}(p, I_\alpha, I_{1-\alpha}) + C_{E\alpha}(p, I_\alpha, I_{1-\alpha}) - aG(p, I_\alpha, I_{1-\alpha})$$

The timing of actions and events is the same as in the previous section. Note that α equal to 1 represents the case in which all securities are owned by carbon consuming firms. A value of α equal to 0 represents the benchmark case discussed in Chapter 3 in which carbon security ownership is entirely in the hands of outsiders.

Refer to the equilibrium price of the permit game as $p_{\alpha Securities}$. Proposition 4.1 states how the equilibrium price with some insider ownership compares to the equilibrium price with only outsider ownership and the carbon tax equilibrium price.

Proposition 4.1 *Depending on α, the equilibrium price with some securities held by insiders is between the carbon securities equilibrium price with outsider ownership and the tax equilibrium price: $p^{Tax} < p^{\alpha Securities} < p^{Securities}$.*

Proof. The first order condition describing the equilibrium if a fraction α

of the firms in the industry holds the n permits is

$$\alpha\Pi'(p) - (1-\alpha)p\Pi''(p) - aG'(p) = 0.$$

Recall from Chapter 3 that the equilibrium condition characterizing the first order condition of the tax game (equivalent to $\alpha = 1$) is

$$\Pi'(p) - aG'(p) = 0$$

and the first order condition of the carbon securities game is

$$-p\Pi''(p) - aG'(p) = 0.$$

Therefore the equilibrium price in the case considered here, $p_{\alpha Permit}$, satisfies $p_{Tax} < p_{\alpha Securities} < p_{Securities}$. Figure 16 illustrates the equilibrium. ■

Consider Figure 16. This figure illustrates the equilibrium if some of the carbon securities are held by carbon-using firms. In this case the equilibrium price lies between the equilibrium price with a carbon tax and the equilibrium price with carbon securities with 100% outsider ownership. The line $\alpha\Pi'(p) - (1-\alpha)p\Pi''(p)$ is the new left-hand side of the FOC that describes the equilibrium. This line describes the marginal campaign contributions as a function of the carbon price. Weighted social welfare, the upward sloping θG line, shifts to the right since the equilibrium carbon price is now higher, which increases investment in abatement technology, and hence the social welfare maximizing carbon price is higher.

Corollary 4.1 *A system based on carbon securities performs better with respect to equilibrium carbon price, variance of the carbon price and investment level than a system based on either a carbon tax or traditional carbon permits if at least one of the carbon using firm does not purchases a share of carbon securities that is equal to its share of carbon emission. A carbon securities system performs as well as a tax or traditional permit system if every carbon using firm purchases a share of carbon securities that is equal*

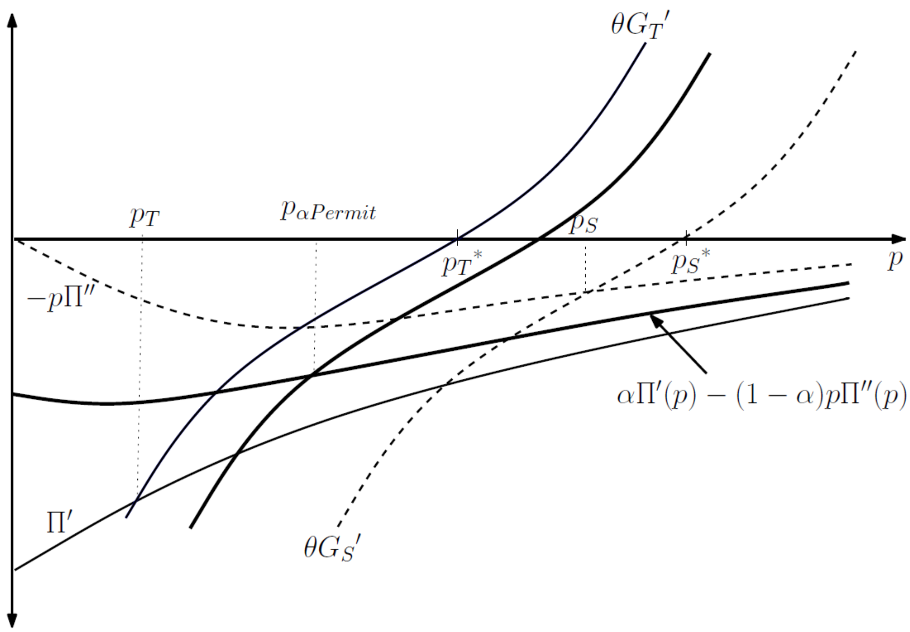

Figure 16: The equilibrium price for α where $0 < \alpha < 1$ is between the equilibrium price with a carbon tax and the equilibrium price with carbon securities.

to its share of future carbon emission.

So far this chapter only considered the case that all securities are held by carbon-using firms and the fraction α specified how many of the firms own securities and how many do not. It is of course also conceivable that some securities are held by carbon using firms and some securities are held by outsiders to the carbon-using industry. However, this case is analytically equivalent to the case discussed above. It makes no difference if a carbon using firm purchases a security for investment purposes or if an outside investor purchases the carbon security for investment purposes. All that matters is what fraction of securities is held for investment purposes or in other words held with the intend to sell allowances.

Finally, consider Assumption 4.1 once more. Only if Assumption 4.1 holds and $\alpha = 1$, carbon securities perform as poorly as a carbon tax. If Assumption 4.1 does not hold and $\alpha = 1$, carbon securities perform better than a carbon tax. The more unequal the ownership distribution among the carbon using firms, the better a carbon securities system performs.

In practice this means that unless the unlikely event that all securities are bought by carbon-using firms and each firm purchases a fraction of carbon securities that exactly equals its share of future total emissions, carbon securities perform better - both with respect to the level of the equilibrium price and with respect to the variance of the equilibrium price - than a carbon tax system or a traditional carbon permit system.

This *superperfect distribution* in which all securities are bought by carbon-using firms and each firm purchases a fraction of carbon securities that exactly equals its share of future total emissions is not just highly unlikely to occur in practice but is also undesirable from the perspective of a politician. The reason is that campaign contributions are lower for securitiy distributions close to the superperfect distribution.

4.3 Conclusion

This chapter addressed the question how a system based on carbon securities performs if some of the carbon-using firms purchase carbon securities. A carbon securities system leads to an equilibrium price closer to the social optimum, a smaller variance of the price and higher investment than a system based on either a carbon tax or traditional carbon permits if at least one of the carbon using firm does not purchases a share of carbon securities that is equal to its share of carbon emission. A carbon securities system performs as well as a tax or traditional permit system if every carbon using firm purchases a share of carbon securities that is equal to its share of carbon emission. So there is essentially no risk from introducing a carbon securities system but with a high probably there is a gain.

5 Carbon Securities and the Choice of the Lobbying Model

5.1 Introduction

In the previous chapter the political process is modelled as a common agency game in which each lobby offers a contribution schedule to the government and the government maximizes a weighted sum of contributions and welfare. The equilibrium under a carbon securities system is essentially a compromise between the interest of the lobby representing the carbon-using industries and the interest of the lobby of the carbon securities holders and social welfare considerations. This *compromise equilibrium* maximizes the welfare of the government.

While the common agency approach to modelling how special interests shape policy is probably the most widely used approach, there are some alternative approaches. This chapter considers how the results of Chapter 3 depend on how special interest groups shape policy and what happens if the assumption that the lobbying game is described by a common agency game is dropped. One potential alternative way to model the interaction between lobbies and a government is a Tullock game.This chapter first briefly describes the Tullock game and then considers the performance of carbon securities if the lobbying model used is a Tullock game (Tullock, 1980).

The second half of the chapter sketches a model that describes a situation in which lobbies do not just attempt to influence politicians via campaign contributions but in addition attempt to influence the position of the median voter via advertising. Such as model has to my knowledge not yet been developed, however, it seems that this is exactly what happens in many areas of policy. Lobbies and interest groups do not just influence politicians but also influence the public opinion. To influence the public opinions, lobbies use for example advertising campaigns. A prominent example are the API advertising campaigns (see Figure 17).

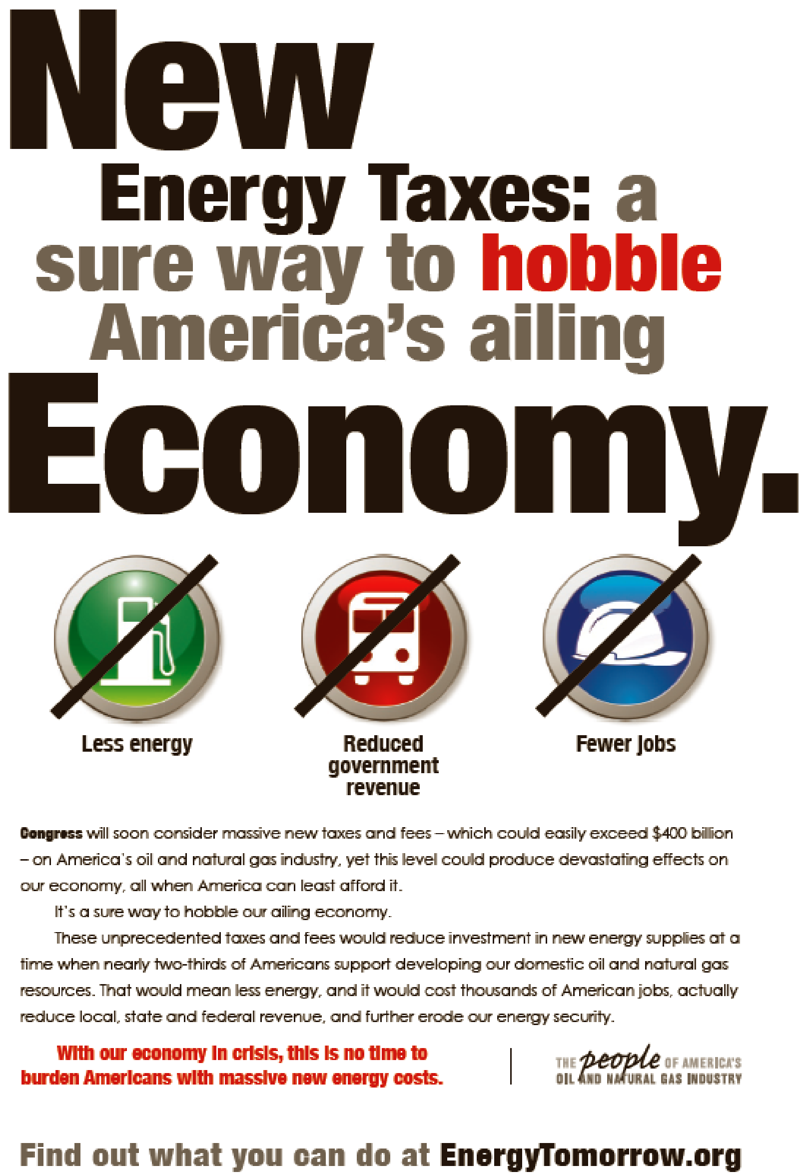

Figure 17: From a recent API advertising campaign. Retrieved from www.api.com on January 10, 2010.

5.2 Tullock Game

5.2.1 Description of the Tullock Game

A Tulluck game (Tullock, 1980) is one way to model a rent seeking contest. In the original form of the game, there are two players who compete for a monopoly rent. The probability that a player wins the rent is given by the ratio of the expenditures of the player himself and the total expenditures of both players. Let the amount that the lobby of the carbon-using industry spends on lobbying be x_E and the amount that the lobby of the carbon security holders spends is x_B. As in Chapter 3 assume that the carbon security holders are not members of the carbon using industry.

Let p_E be the carbon price preferred by the carbon using industry. In the absence of subsidies, $p_E = 0$. Let p_B be the carbon price that maximizes the payoff of the holders of carbon securities.

If the lobby of the carbon-using industry wins the Tullock contest, the carbon price chosen by the government is p_E. On the other hand if lobby of the holders of the carbon securities wins the Tullock contest, the carbon price chosen by the government is p_B. So unlike in a common agency framework where the outcome can be interpreted as a compromise between competing interests, in a Tullock game the outcome will either favor one side or the other.

5.2.2 The Performance of Carbon Securities in a Tullock Game

Let the probability of winning the contest be

$$\psi_i = \frac{x_i}{x_i + x_j}$$

where $i = E, B$ and j always denotes the other lobby.First, consider the equilibrium with a carbon tax, which is equivalent to the equilibrium under a traditional carbon permit system.

Proposition 5.1 *The tax equilibrium price is equal to the price preferred by the carbon using industry:* $p_{Tax} = p_E$.

Proof. This result follows immediately from the nature of the Tullock game. There is only one lobby present, this lobby will always win the contest and the policy implemented will be the policy preferred by the lobby. ■

Next, consider the equilibrium with carbon securities.

Proposition 5.2 *The carbon securities equilibrium price is either the price preferred by the carbon using industry or the price preferred by the holders of carbon securities. The expected carbon securities equilibrium price is closer to the social optimum than the equilibrium price under a carbon tax or permit system.*

Proof. The first part of the statement follows from the nature of the Tullock game. For the second part of the statement note that both lobbies make positive contribution payments in equilibrium. So the expected carbon securities equilibrium price is

$$E(p_S) = \psi_E p_E + \psi_B p_B$$

and lies between p_E and p_B. ■

Finally, consider, the variance of the carbon price.

Proposition 5.3 *The variance of the carbon price under a system based on carbon securities is larger than under system with a carbon tax or traditional carbon permits.*

Proof. If the lobbying game is modelled as Tullock game, with a carbon tax the equilibrium price is always p_E. Hence, the variance of p_{Tax} is zero. With carbon securities, the equilibrium price is either p_E or p_B and the variance is positive. ■

So if the lobbying game takes the form of a Tullock game, switching from a carbon tax to carbon securities moves the expected carbon price closer to the social optimum but also increases the variance of the carbon price. The following section provides some arguments why a common agency game may be the more realistic way to model environmental policy.

5.3 Is Environmental Policy Better Described by a Common Agency or a Tullock Game?

While a Tullock game is a good model of, for example, public procurement, the common agency framework is in many respects more suitable to describe the interaction between a government and lobbies that shapes environmental policy. There are three main reasons for this.

First, the equilibrium of the common agency game characterizes well how most bills are the outcome of negotiations and compromises, as opposed to one clear winner and one loser. Although a bill is voted on and either passed or not - and this may seem like a binary decision - the usual process is that a bill is negotiated and amendments are added *until* there is a majority for the bill. Hence the political process resembles more a choice out of a continuum of alternatives then a binary choice.

Second, an issue like environmental policy is of concern to voters. Therefore, politicians who want to be reelected are unlikely to ignor social welfare as they do in the Tullock game. Social welfare matters in the common agency framework but not in the Tullock game.

Third, we typically don't observe policy switching with a high frequency from one extreme to another as we would expect if the policy process was best described by a Tullock game.

So the common agency framework has three significant advantages over the Tullock game for an application like environmental policy. However, this is not to say that the common agency framework is flawless. A valid criticism of the common agency framework is that both sides pay after the decision has been made. This contradicts the observation that payments are typically made before the decision is made. However, the repeated interaction between policy makers and interest groups may explain why making payments after the decision has been made is not unreasonable. After one decision is always before another decision.

The following section extends the common agency model by allowing lobbies to both directly influence policy and indirectly influence policy by shaping public opinion. Such a model could offer further insights and seems like a more realistic description of how lobbies influence the political process.

5.4 A Median Voter Lobbying Model

Lobby groups do not just influence politicians directly via campaign contributions. They also influence public opinion and thereby indirectly the decision of the politician. If a lobby group is able to influence public opinion or in the other words the position of the median voter in its favor, the lobby group can increase the probability that the politician will choose a policy that is in its favor. After all, most politicians tend to choose policies preferred by a majority of voters either because they are concerned about the perceived social welfare effects of their policy or because they care about being reelected.

This section briefly sketches a model in which lobbies do not just attempt to influence politicians via campaign contributions but in addition attempt to influence the position of the median voter via advertising. The model is overall quite similar to the model outlined in Chapter 3 Section 2.1 and retains many features of a standard common agency lobbying model. The major difference is that each lobby chooses both a contribution schedule and an advertising expenditure instead of just a contribution schedule. The solution of the model is left for future research.

As in Chapter 3, the tax game and the carbon securities game consist of two periods. In the first period the following events take place: The government announces if the policy instrument is a carbon tax or carbon securities. If carbon securities are the chosen policy instrument, the government holds an auction to sell the securities. There are m energy-consuming firms. Each firm i chooses its level of investment in abatement technology I_i. The energy-consuming industry and the owners of carbon securities each organize themselves as a lobby. It is assumed that the owners of carbon securities are not members of the energy-consuming industry. Each lobby chooses a level of advertising A intended to influence the public opinion about the optimal carbon price level.

In the second period the following events take place: Information about the policy maker and the perceived cost structure of global warming is revealed. This perceived cost structure is influenced by advertising expenditures of the lobbies and possibly by new information that becomes available. The lobby or lobbies then offer their contribution schedule(s) which are conditional on the carbon price chosen. The government chooses the level of the carbon price that maximizes its welfare. Then the owners of carbon securities sell the carbon allowance, $\frac{1}{n}X$, they received per security to firms required to hold a carbon allowances equal to their carbon emission in period 2.

Consider the stages of the game in more detail starting with the last stage. As before, let demand for energy, D, be deterministic, so that setting an emission level X and setting a carbon price are equivalent. For each level of aggregate investment in energy-saving technology, X determines the carbon price via

$$D(p, I) = X \tag{5.1}$$

where D is a decreasing function of both the carbon price p and aggregate investment in energy saving technology I. In the tax game the government sets the price of carbon p directly. As before, for ease of comparison between the tax game and the carbon securities game and also to stay within the established convention of the literature based on Grossman and Helpman's (1994) 'Protection for Sale', the government's choice variable is the carbon price in both games.

Perceived social welfare depends on the amount of carbon emissions and on advertising levels. So while social welfare in Chapter 3 was taken to be discounted GDP and therefore an objective quantity, here politicians are interested in perceived social welfare. Perceived social welfare is subjective in the sense that it can be influenced by advertising. On the one hand, high emissions lead to more global warming and hence higher global warming related costs G_W. These cost are a decreasing function of p, $\partial G_W/\partial p < 0$, and also a decreasing function of I, $\partial G_W/\partial I < 0$. On the other hand, a high carbon price has adverse effects on social welfare since it has negative effects on the energy-consuming industry and leads to higher consumer prices. This consumption cost, G_C, increases with p, $\partial G_C/\partial p > 0$, but decreases with I, $\partial G_C/\partial I < 0$. In the presence of advertising in favor of a low (high) carbon price, perceived social welfare with a low (high) carbon price will be higher than if there had been advertising in favor of a high (low) carbon price. The social cost of the carbon price is defined as

$$G(p, I, A_E, A_B) = G_W(p, I, A_E, A_B) + G_C(p, I, A_E, A_B) \tag{5.2}$$

$G(\cdot)$ is the difference between the expected perceived cost of global warming which decrease with emissions, X, and the perceived benefits of a low energy price. The functions G_W, G_C and G satisfy the following assumptions:

Assumption 5.1 *The cost function G has the following characteristics:*

(a) For a given investment level I, the cost function G has a unique minimizer, referred to as p^*:

$$\frac{\partial G_W}{\partial p \partial p} + \frac{\partial G_C}{\partial p \partial p} > 0$$

(b) The minimizer of G, p^*, increases with aggregate investment:

$$\frac{\partial p^*}{\partial I} > 0$$

(c) If a tighter climate goal is preferred, deviations from the optimal level, p^* are worse. So, for all $p < p^*$ the derivative of G becomes steeper as p^* increases.

(d) Advertising levels are nonnegative. An increase in advertising by the carbon using industry (advertising in favor of a low carbon price), decreases the perceived optimal carbon price

$$\frac{\partial p^*}{\partial A_E} < 0$$

and an increase in advertising by the carbon security holders (advertising in favor of a low carbon price), increases the perceived optimal *carbon price*

$$\frac{\partial p^*}{\partial A_B} > 0$$

The government maximizes the weighted sum of campaign contributions and voters' perceived welfare. W_G denotes the welfare of the government:

$$\max_p W_G(p, \theta, I, A_E, A_B) = \tag{5.3}$$

$$= C_B(p, \theta, I, A_E, A_B) + C_E(p, \theta, I, A_E, A_B) - \theta G(p, I, A_E, A_B)$$

As before, C_B and C_E are the campaign contributions of the carbon securities holders and the energy-consuming industry, respectively. The variable, θ, is the government's preference variable and is interpreted as the weight of voters' perceived welfare relative to campaign contributions. A politician with a high value of θ values the interests of the electorate more highly than a politician with a low value of θ. As before, in period 1, when the investment decision is made, θ is unknown. At the beginning of the second period, θ is realized.

Next, consider the lobbying stage of the game.

Assumption 5.2 *The energy consuming industry and its lobby satisfy the following assumptions:*

(a) The firms of the energy consuming industry are able to organize themselves into a lobby group in order to influence the political process.

(b) The lobby of the energy-consuming industry does not face any borrowing constraints when they make campaign contributions.

The gross of contributions and welfare of the energy-consuming industry is

$$W_E = \sum_{i=1}^{m} \pi_i(I_i; p) - I = \Pi(p) - I - A_E \tag{5.4}$$

where p is the carbon price (input price), π_i is the profit of firm i and Π is the total profit of the industry. In the second period, the lobby of the industry chooses the contribution C_E to maximize net of contributions industry welfare:

$$\max_{C_E} \Pi(p) - I - A_E - C_E(p) \tag{5.5}$$

In the first period, the lobby chooses A_E to maximize the expression in (5.5) while anticipating C_E and p. The gross of contributions welfare of the owners of carbon securities is the value of the securities in the second period minus the amount they had to pay to purchase the securities in the first period:

$$W_B(p, I) = -p\frac{\partial \Pi}{\partial p} - \xi n - A_B$$

where ξ is the price that the government sold an security for and n is the total number of securities. The sale of the carbon securities takes the form an auction. So ξ is the equilibrium price at the securities auction. The revenue of the owners of the securities, $-p\frac{\partial \Pi}{\partial p} = -p\Pi'(p)$, is the product of the carbon price and the emission quota. A carbon security holder prefers a carbon price that maximizes $-p\Pi'(p)$.

As for the lobby of the energy-consuming industry, it is assumed that there are no borrowing constraints. So contributions can be as large as gross of contribution welfare of the lobbying group.

Assumption 5.3 *The owners of the carbon securities satisfy the following assumptions:*

(a) The owners of carbon securities are able to organize themselves into a lobby group in order to influence the political process.

(b) The lobby of the owners of carbon securities does not face any borrowing constraints when they make campaign contributions.

Next consider the advertising stage. Each lobby chooses an advertising level to maximize its welfare anticipating the outcome of the second stage lobbying game. Finally, consider the investment stage.

Assumption 5.4 *The individual firms and the industry satisfy the following assumptions:*

(a) Each firm i believes itself too small to have any meaningful impact on the carbon price p or the aggregate investment level I.

(b) No industry-wide coordination is possible on investment.

(c) The profit function of the energy consuming industry satisfies (in the relevant range) for all p that $\Pi'(p) < -p\Pi''(p)$ where $-\Pi'(p)$ is the industry demand for coupons.

(d) All firms in the industry are monopolistically competitive.

In period 1, each firm individually chooses an investment level I_i which determines its demand for energy in the following period. For given p, I, A_E, A_B and θ an individual firm's profit is

$$w_i(I_i; p, I, \theta) = \pi(I_i; p) - I_i - \frac{1}{m}[C_E(p, \theta, I, A_E, A_B) - A_E] \tag{5.6}$$

where $\pi(I_i, p)$ is the profit of firm i, C_E is the contribution made by the energy consuming industry, A_E and A_B are the advertising level, I_i is investment in energy-saving technology. Aggregate investment is $I = \sum_{i=1}^{m} I_i$. The carbon price p is an input price. Thus, $\frac{\partial \pi}{\partial p} < 0$. As in chapter 3, $-\frac{\partial \pi}{\partial p} = -\pi'$ is an individual firm's demand for energy.

As in Chapter 3, if a firm invests, it requires less energy for its production. So for any p,

$$\frac{\partial(-\pi')}{\partial I} < 0.$$

In other words, for a given carbon price, a firm's demand for energy decreases with the investment level.

The median voter lobbying model briefly outlined above for the case of carbon abatement policy has potentially many applications in various areas of policy analysis. For example, the behavior of lobbies involved in health care policy is probably better described by the model above than by a model in which lobbies only attempt to influence politicians directly via campaign contributions. Further research in this area could provide interesting insights. It seems reasonable to assume that the relative cost of bribing politicians and influencing G - in other words the parameter θ - will determine relation of advertising expenditures and campaign contributions in equilibrium. Further, carbon securities are likely to perform better than either a carbon tax or carbon permits in this type of model with respect to the level of the equilibrium carbon price, variance and investment. An interesting question is under what conditions there might be advertising wars in the carbon securities equilibrium.

5.5 Conclusion

There are a number of reasons why a Tullock game does not seem to be the appropriate way to model the interaction between politicians and lobbies in the area of environmental policy. The common agency game seems the more appropriate model. An interesting extension of the common agency model could be a median voter model as outlined in the second half of this chapter. While such a model is analytically significantly more complex, it may provide very interesting new insights by allowing lobbies to influence politicians both directly and indirectly.

There are some other ways to model the competition between lobbies. For instance, lobbies could provide the decision maker with information about the state of the world (like the cost associated with different policy options). In this case the lobbying process could be described as a signalling game (Potters and van Winden, 1992). In principle, two lobbies should provide the policy maker with more information than just one lobby. Therefore the decision made by the government is likely to have a higher expected social welfare level associated with it if carbon securities are the policy instrument than with a carbon tax or carbon permits.

6 An Application: SO_2 Securities

6.1 Introduction

Acid rain is a broad term referring to both wet and dry deposition from the atmosphere containing higher than normal amounts of nitric and sulfuric acids, which are particularly damaging to lakes, streams, and forests and the plants and animals that live in these ecosystems. The objective of the EPA's Acid Rain Program is to limit the amount of NO_x and SO_2 emitted into the atmosphere since these two chemicals are the main contributors to acid deposition (EPA, 2007).[33]

Title IV of the Clean Air Act set a goal of reducing annual SO_2 emissions by 10 million tons below 1980 levels. To achieve these reductions, the law required a two-phase tightening of the restrictions placed on power plants fired by fossil fuels. Phase I began in 1995 and affected 445 units at mostly coal-burning electric utility plants. Emissions data show that 1995 sulfur emissions at these units were reduced by almost 40 percent below their required level. Phase II began in the year 2000. It tightened the annual emissions limits for the units covered under Phase 1 and also set restrictions on smaller, cleaner plants fired by coal, oil, and gas. The total of units covered increased to over 2,000 units.

Under the SO_2 allowance system, one SO_2 allowance is required for each ton of SO_2 a coal-fired power plant emits during a year. The SO_2 allowances have been allocated for free to the power plants through 2037 based on their operations in the baseline years of 1985-1987. Additional SO_2 allowances can be bought to meet emissions requirements. To create a marketplace in addition to private trades between affected units, the EPA holds an annual auction for 125,000 spot and 125,000 7-year forward allowances.

For each ton of SO_2 emitted in a given year, one allowance is retired, that is, it can no longer be used. Allowances may be bought, sold, or

[33] When sulfur dioxide and nitrogen oxides are released from power plants and other sources, prevailing winds blow these compounds across state and national borders, sometimes over hundreds of miles. Thus, a local solution to this externality problem is not feasible.

banked. Anyone may acquire allowances and participate in the trading system. Sources are required to hold a quantity of allowances equal or greater than the amount of SO_2 emitted during that year. Any excess allowances can be banked for use in future years. If emissions exceed allowances, units have to pay a penalty and have to surrender allowances for the following year to the EPA to offset their excess emissions.

6.2 An evaluation of the SO_2 Allowance System

The current system promotes cost-effectiveness by permitting allowance holders to transfer their permits among one another. The intention is that those who can reduce their sulfur emissions at the lowest cost have an incentive to do so and sell their leftover allowances to those for whom it would be more costly to cut emissions.

The system currently is best characterized as a traditional permit system with predominately free allocation of permits and banking of permits. According to the model developed in the previous sections, the emission target of the program, 10 million tons of SO_2 below 1980 level, corresponds to the Tax Game equilibrium of Chapter 3 Section 3. This would imply that the amount of SO_2 to be emitted under the Acid Rain Program is above the social optimum. The reason is that there is a strong lobby representing the interests of the power generating industry but no counterbalancing, financially strong lobby representing agents with an interested in a high allowance price.

The hypothesis that the current cap of sulfur emissions is higher than the optimal emission level is supported in the recent literature on the SO_2 Allowance System. Israel (2007) provides evidence for SO_2 emissions being above social welfare maximizing levels by studying the behavior of environmental interest groups. Smith and Yates (2003) provide a theoretical foundation for this result.

6.3 A System with SO_2 Securities

The current SO_2 allowance system uses a combination of annual allocation and annual allowance auction. With a system based on carbon securities there would be one initial auction of securities and then each year each of the securities pays an allowance which is equal to some ex ante unknown amount of tons of SO_2. Units can purchase the amount of allowances they require at a coupon market place run by the EPA. The allowance that each security pays is determined each year by the EPA or the government.

As under the current system, monitoring can be conducted under the Continuous Emission Monitoring Rule and the Allowance Management System (AMS) can be used to keep track of securities and allowances.

Similar to the current system, units must purchase a quantity of allowances equal to their emissions on the coupon market place. Allowances are only valid for one year and if they are not used during that year they loose their value. Units have to pay a penalty if their emissions in any one year are higher than their total of allowances for that year.

Both the current system and carbon securities encourage cost-effectiveness. In a system based on carbon securities, all SO_2 emitters are required to purchase an amount of allowances equal to their sulfur emissions at the end of each year. Each source has an incentive to reduce emissions up to the point where reducing emissions by one more ton is more costly than the (expected) price of one allowance on the allowance marketplace.

The main advantage of introducing a system based on carbon securities is that it facilitates the setting of an SO_2 price closer to the social optimum than can be expected under the current system as I've shown in Proposition 4. This would mitigate the inefficient level of sulfur emissions found by Israel (2007). As I showed in Proposition 5, another significant advantage of carbon securities is that there is less uncertainty about the future price of allowances. This encourages early investment in technology that allows reductions in SO_2 emissions.

6.4 Conclusion and Further Research

This chapter showed that switching the current SO_2 allowance system to an SO_2 securities system would be quite straightforward and should not be more costly to monitor. Overall, there are many similarities in the practical implementation of permit or cap and trade systems and a system based on emission securities.

7 Conclusion

Chapters 3 to 6 of this dissertation show that there are important differences between carbon securities and carbon taxes and cap and trade systems if the effects of lobbies on the political process are considered. This is in contrast to previous models which ignored this political economy dimension when comparing these carbon abatement policy instruments.

Carbon securities have four significant advantages over existing systems. First, the creation of stakeholders with an interest in a high carbon price counterbalances the efforts of the lobby of the energy-consuming industry. The resulting equilibrium carbon price is closer to the social optimum than with either a traditional tax or permit system. Second, climate uncertainty and political uncertainty have a smaller effect on the expected variance of the carbon price. This leads to more predictability for the market participants. Third, there is higher investment in abatement technology with carbon securities. Fourth, commitment to environmental policy is endogenous under the proposed system since it makes commitment to abatement policy the government's optimal choice.

The fourth chapter addresses the question how a system based on carbon securities performs if some of the carbon-using firms purchase carbon securities. The above four advantages all still exist if at least one of the carbon using firms does not purchases a share of carbon securities that is equal to its share of carbon emissions. A carbon securities system performs as well as a tax or traditional permit system if every carbon using firm purchases a share of carbon securities that is equal to its share of carbon emission. So there is essentially no risk from introducing a carbon securities system but with a high probably there is a gain.

The fifth chapter provides some arguments why the common agency game is the most appropriate model currently available to model the political process when it comes to climate policy. The sixth chapter showed that switching the current SO_2 allowance system to an SO_2 securities system would be quite straightforward and should not be more costly to monitor.

Overall, there are many similarities in the practical implementation of permit or cap and trade systems and a system based on emission securities.

An area for future research is the application of the mechanism proposed in this paper to other problems which involve a public good. An interesting extension of the common agency model could be a median voter model as outlined in the second half of this chapter. While such a model is analytically significantly more complex, it may provide very interesting new insights by allowing lobbies to influence politicians both directly and indirectly.

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