The Political Economy of Market Mediated Incentives: The Case of Embodied Technologies

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*Different political parties place different values on the environment. In considering a two-party democratic system and capital-intensive technologies, we find that forward-looking governments incorporate the probability of losing power into their policy design. When the party in power values the environment, it levies an optimal dynamic tax that is larger than the Pigovian tax. We investigate the parameters that affect the magnitude of this gap, and assess the effect of the gap on social welfare and the adoption of clean technologies.*

*JEL code: L5, O2, O3, Q2, Q3*

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# I. Introduction

A large body of political science literature on Western democracies suggests that the diversity in values among political parties results in eventual changes of policy because, over time, parties transition to and from power, and different parties emphasize different values (Gunther & Diamond, 2003). Therefore, we ask how does the likelihood of regime change in future periods affect forward-looking politicians’ choice of policy instrument? We ask this question while focusing on policies that address externalities and lead to replacing polluting technologies with clean ones. In particular, in this paper, we develop a framework to determine the optimal tax set by a ruling party that recognizes the likelihood of losing power and investigate it under various political economy appeal criteria.

This paper aims to contribute to the extensive literature on the selection of environmental policies. The literature originated with the foundational work of Pigou (1932) and was later expanded by Baumol and Oates (1971), Weitzman (1974), Buchanan and Tullock (1975), Laffont and Tirole (1996a, 1996b), Holland (2012), and Tombe and Winter (2015), among many others. As the literature evolved, it incorporated considerations of political economic motives (e.g., Buchanan & Tullock, 1975; Hochman & Zilberman, 1978), uncertainty regarding economic outcomes (e.g., Weitzman, 1974), dynamics (e.g., Caparros, Just, & Zilberman, 2015), and the development of policy instruments (e.g., Laffont & Tirole, 1996a, 1996b). In much of the literature, the selected policies affected pollution by inducing the adoption of cleaner technologies.

While most of the literature on the selection of environmental policy tools takes a welfare economic perspective, we approach this question from a political economic vantage point. A large body of literature emphasizes the differences between politicians’ objectives and voters’ objectives, and investigates the implications for policy (e.g., Persson & Tabellini, 1999; Acemoglu & Robinson, 2001; Grossman & Helpman, 2001; Bohn, 2007; Rausser, Swinnen, & Zusman, 2011). In particular, the political economic literature recognizes that policy choices incorporate political considerations. One consideration we emphasize here is that politicians and the interest groups that support them recognize that power rotates among parties and, thus, challenges parties to enact policies that will not be overruled in the long run. The changes in the perspective on climate change and other policies between presidents Obama and Trump illustrates this point. Indeed, President Obama’s legacy on climate change is captured by his success in making climate change central to policy and getting many Americans to care about climate change despite the withering opposition from Congress. In doing so, the outgoing administration used the Antiquities Act of 1906 more times than any other administration in history, trying to solidify policy outcomes that will be difficult for the incoming Trump administration to reverse.

Several scholars have recognized politicians’ incentive to manipulate current policy and influence both elections and the policy choices of future governments (e.g., Persson & Svensson, 1989; Aghion & Bolton, 1990; Tabellini & Alesina, 1990; Persson & Tabellini, 2000; Azzimonti, 2011; Millner, 2013). In this paper, we incorporate this argument into our analysis of environmental policy design. We assume that some politicians place more weight on the environment than others, and that these politicians recognize the transition of power among ruling parties over time. Through this paper, we strive to understand the choice of financial incentives to address externality problems in a world where the ramifications of political transitions are understood.

For the sake of clarity and brevity, we use two simplifying assumptions. First, without much loss of generality, we develop a two-period model. Second, although the analysis only requires assuming irreversibility of investment (Arrow, 1968), we assume a putty–clay technology, where each firm employs its own fixed proportion technology that can be modified through investment. Assuming putty–clay technology enables us to arrive at simple expressions whose outcomes can be depicted in two-dimensional figures. Putty–clay technologies are a reasonable approximation of several capital-intensive industries (e.g., the electricity sector) and have been used in the past for analysis of environmental policies.[[4]](#footnote-4) While using the putty–clay specification, we assume that regulation may restrict the pollution per unit of output and prevent the use of some capital assets.[[5]](#footnote-5)

The analysis shows that given political uncertainty, when policy makers consider levying a tax, the party that places more weight on the environment sets an optimal tax that is larger than the Pigovian tax. We term the difference between the optimal tax and the dynamic Pigovian tax *the political uncertainty effect*. This difference increases when (i) the pollution decays slower over time, (ii) the weight placed on future outcomes increases, and (iii) the uncertainty regarding future elections increases. The economic ramifications of the political uncertainty effect increase as the demand becomes more elastic, with the tax incidence falling on the producers and more firms exiting the industry and becoming idle than otherwise would. The motivation for a higher tax than the Pigovian tax is then balanced with the politician’s desire to stay in power. Finally, we illustrate, numerically using data for the US electricity power sector, that when tax rates are low their increase results in more adoption of clean technologies, but this correlation is reversed when taxes are sufficiently large.

The paper proceeds as follows. The conceptual model is introduced in section II. Section III describes the two-period game. The analysis begins in section IV. In section V, we numerically investigate the equilibrium outcome and calculate the effect of policy on adoption using the case of the US electricity power sector. In section VI, we briefly discuss politicians’ policy choices from a behavioral political economic perspective. Concluding remarks are also offered.

# II. The Conceptual Model

Our model expands the short-term putty–clay model of Hochman and Zilberman (1978), by adding dynamic features and allowing the adoption of technology. For simplicity, we assume an industry that consists of many production units (e.g., firms, farms, machines), and that each production unit can produce 1 unit of output using a fixed proportion production function that uses a variable input and pollution. In the short run the technical coefficients of the production units are the outcome of past decisions. These coefficients vary among the units, and we assume their distribution function is well-behaved. The production units face constant input prices, where the variable input is measured in monetary terms that capture the costs per output unit (thus, the input price is normalized to 1). Formally, let denote the fixed input–output coefficient and the fixed pollution–output coefficient. A lower denotes a more cost-efficient firm, and a higher denotes the more pollution-intensive units. While the model can be made more complex by including other inputs, among other modifications, for brevity and simplicity this basic model suffices.[[6]](#footnote-6)

We assume a two-period model In each period, a firm remains active and produces one unit or becomes idle. Formally, assume firms maximize their profits, and define the current period *t* quasi-rents in the unregulated environment as:

|  |  |  |
| --- | --- | --- |
|  |  | (1), |

where denotes output price and subscript denotes period . We also assume forward-looking firms and competitive markets.

In the standard, putty–clay analysis, the firm chooses in the short run either to become idle and not produce or to remain active, earn non-negative quasi-rents, and produce at capacity. In the standard long term putty clay analysis the firm is choosing among many alternatives that are part of a neoclassical production function. However, our analysis expands the standard putty–clay model by considering the adoption of a distinct new technology – which introduces into the firm’s calculation a long-run irreversible decision. For example, the Block Island power company in Rhode Island[[7]](#footnote-7) decided to modify its operation by switching from relying on diesel to relying on of shore wind power. In making such decisions the firm is considering three alternatives:

1. Remain active and operate:
   1. Operate with the existing technology, i.e., the existing set of coefficients; or
   2. Adopt a new technology through investment, resulting in a different set of coefficients.
2. Become idle and stop operation.

This process yields technical coefficients that are continuously modified over time by the choice of technology, through adoption of distinct technologies rather than a subset of a continuous set of technologies as in Caparros et al. (2015). This approach allows us to apply the putty clay literature with the economics of adoption and to incorporate political uncertainty that impacts regulations. The assumption that many production units face these alternatives results in a different set of initial coefficients at each point in time. This modeling is consistent with the empirical literature that estimates the adoption of discrete technologies and evaluates technological change (Sunding & Zilberman, 2001).

A firm with the existing technology, i.e., with pollution intensity coefficient and cost intensity coefficient *,* may continue to operate or adopt a cleaner technology that requires investment per unit of output . If the firm makes an investment of *It* at period *t*, it reduces its pollution coefficient by a fraction of so that the pollution–output coefficient of the modified technology is . The new technology also increases the variable input cost by a fraction so that the production cost becomes

We assume learning-by-doing, which reduces the cost of utilizing the alternative technology (Arrow, 1962). Like others in the literature (Torani, Rausser, & Zilberman, 2016; Sagar & Van der Zwaan, 2006), we assume that the cost of alternative technology declines over time.[[8]](#footnote-8) Technically, we assume that adoption of the cleaner technology at the second period requires less upfront capital (i.e., , where , and adopting clean technology in the second period does not change the per-unit production costs (i.e., ). For simplicity, we also assume that .

To derive the aggregate supply of output, denoted by , we define an output capacity distribution function . The output capacity of firms located in the set for small and are simply . We assume that is a smooth function with compact support. This output capacity distribution function is used to define the aggregate output produced by firms located in region .

We now transition from the individual firm to the aggregate industry level (Johansen, 1972) and define the survival region. In the proposed framework, each firm is defined by its input–output and pollution–output coefficients. Then, the set of coefficients where firms’ profits are non-negative () is coined the *survival region*. Let denote the survival region in the space in period *t*, assuming no regulation (Figure 1). Then, assuming , can formally be defined as follows:

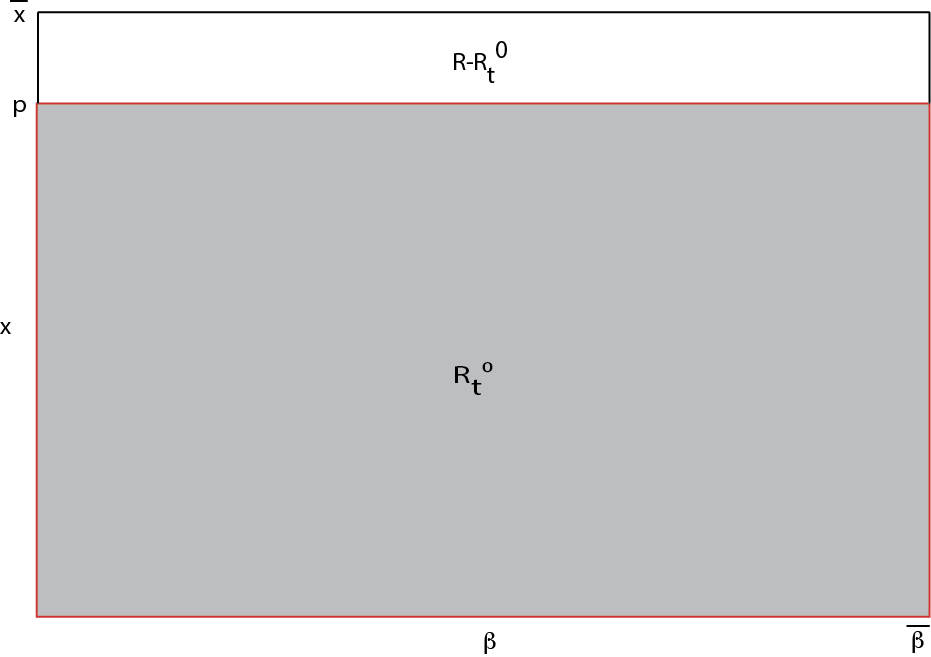


Figure 1. The survival region assuming no regulation.

The survival region is a function of prices, regulation, and technology. However, in the unregulated environment, the survival region is only affected by the output price. Once regulation is introduced, the survival region is also affected by the pollution policy and the alternative technology policy introduced. Under the unregulated environment, firms remain idle (Figure 1). In the unregulated environment, the industry generates aggregate output, aggregate pollution, and aggregate input, respectively, as follows:

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| --- | --- | --- |
|  |  | (2) |

Like the literature on stock pollution (Falk & Mendelsohn, 1993; Newell & Pizer, 2003), the industry generates a pollution flow, which in turn generates a pollution stock that decays over time. Climate change and greenhouse gas (GHG) accumulation are a stock pollution problem, where major GHGs include carbon dioxide, methane, nitrous oxide and fluorinated gases and have an average lifetime in the atmosphere that fluctuates between several weeks to thousands of years.[[9]](#footnote-9) Let denote the pollution stock in period , where the pollution flow in period is and where is the pollution-decay parameter. For simplicity, we normalize the initial pollution stock to 0; thus, . In addition, we assume that policy makers know the period t social cost of pollution, . The distinction between pollution flow and stock is important to our understanding of the parameters affecting the political uncertainty effect, and thus the gap between the optimal dynamic tax and the Pigovian tax, as shown below.

***Lemma 1.*** *(1) The survival region is weakly increasing in the producer price, such that .*

*(2) Aggregate output, aggregate pollution, and aggregate input are weakly increasing in the producer price. That is, .*

Assuming a downward-sloping demand function , the equilibrium price is determined by . At this equilibrium price (i.e., ), the marginal firm earns zero quasi-rents (i.e., ). Assuming pollution does not affect benefits from the goods consumed, consumer surplus (CS) and producer surplus (PS) are, respectively:

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| --- | --- | --- |
|  |  | (3), |

where denotes economic surplus abstracting from the environment. When a party does not account for the damage economic activity inflicts on the envrionment, it will set policy to maximize over time.

Finally, like Parry, Williams, and Goulder (1999), we define social welfare assuming separability between economic activities and environmental amenities, and define the social welfare of period *t* when Party *j* is in power:

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

# III. The Two-Party Two-Period Game

We want to assess the implications of uncertainty with respect to the political survival of the incumbent government and to better understand its strategic incentives to manipulate policy and tie the hands of future governments. Politicians value staying in power, but they also recognize that this is not certain. In section VI, we will discuss politicians’ choice of policy instrument from a behavioral political–economic perspective, assuming that elections are affected by politicians’ policy choices. However, for now, we assume that elections are random and examine the regulatory outcome, since this simplifying assumption does not qualitatively change the main result of the paper yet it enables a more succinct presentation than otherwise.

Thus, we assume a two-party system (i.e., Party A and Party B) and a two-period game. Furthermore, although in the first period Party A is in power, we denote the probability that the incumbent will stay in power as We assume that the pollution tax choice will not affect the survival of the government. Specifically, Party A is in power in the second period with probability , and Party B is in power in the second period with probability . We also assume that Party A strives to maximize social welfare over the two periods, which has both market surplus (i.e., ) and environmental costs of pollution (i.e., ), but Party B places no weight on the environment. Although we could assume Party B’s preferences are different than Party A’s (Jack, Kousky, & Sims, 2008; List & Sturm, 2006), we choose a stronger assumption. This stronger assumption, through the separability between economic and environmental benefits (i.e., Eq. (4)), emphasizes the effect of political uncertainty regarding future outcomes on the policy design.

Formally, let denote Party A’s objective function and denote Party B’s objective function. Also, let denote the discount factor. The first period starts with Party A in power. Given a policy instrument (i.e., tax), Party A chooses the value of that maximizes (where denotes social welfare, i.e., Eq. (4), of period *t* when Party *j* is in power):

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| --- | --- | --- |
|  |  | (5) |

We use a two-period framework to illustrate the effect of uncertainty regarding future political outcomes on policy design. A similar approach, for example, was employed by van der Ploeg (2013) when illustrating the Green Paradox.

Let denote the policy that maximizes Eq. (5). Given policy , units decide whether to remain active and whether to adopt the clean technology. The outcomes of these decisions define the first-period survival region, based on the recognition that policy may change the next period. Then, current-period profits and welfare materialize. At the beginning of the second period, a random draw transitions the political system to the second period. If this results in Party A staying in power (i.e., Party A is reelected), then the second-period policy maximizes :

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

Let denote the policy that maximizes Eq. (6). However, if the random draw results in Party B being in power, then policy is set to maximize the sum of consumer and producer surplus, . Once the ruling government sets the policy, the previously active units decide whether to remain active, and active units that have not yet adopted the clean technology decide whether to adopt it. Then, the second-period profits and welfare materialize.

# IV. Party A’s Optimal Dynamic Tax

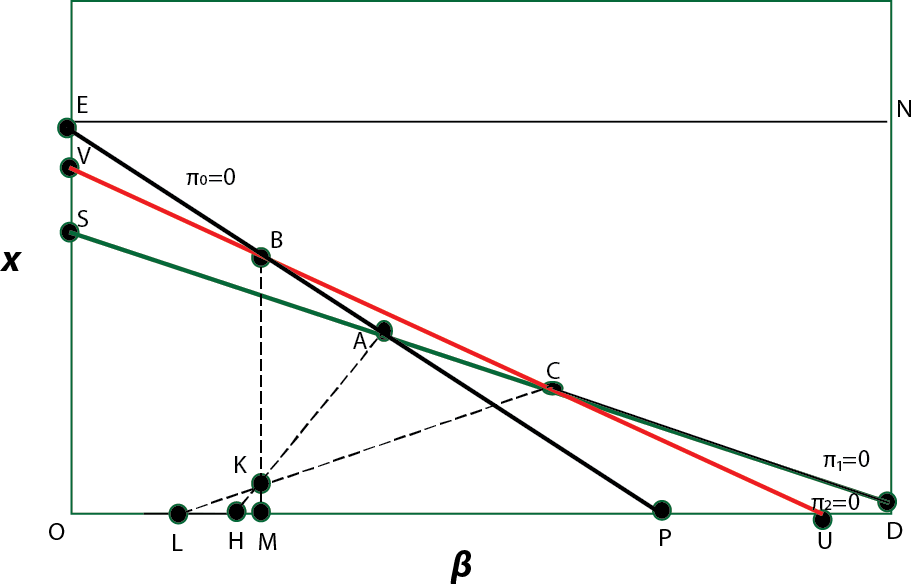
Assume Party A is the political party that holds power in the government in the first period, and recall that Party A sets policy that aim to maximize social welfare over time. In the first period, this government will usher in a pollution tax that maximizes Eq. (5) – a maximization problem that accounts for the uncertainty regarding future events (through the probability that the incumbent will stay in power as ), and assuming a political environment that lacks mechanisms that support policy commitments over time. Below, we characterize this optimal dynamic pollution tax.

When denoting the instantaneous profit of period *t*, , let subscript denote the party in power, and subscript *m* denote firms that adopted the technology in period *m* where subscript *m=0* denotes firms that never adopted the technology. Let denote firms’ discounted stream of profits viewed from the first period perspective. Because firms are forward-looking, in the first period they maximize the following expected stream of profits:

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

Appendix C analyzes the firm’s decision when facing a tax at period 1 and suggests that the firms faces three options. It also identifies three regions in the space – corresponding to the decision rules of the production units. The units are assigned to two groups-

1. *Firms that remains active and operate:*
   1. *Firms located in region EBCKHO of Fig. 2 operate using the existing technologies.*
   2. *Firms located in region DCKH of Fig. 2 adopt the new technology via investment.*
2. *Firms that become idle and stop operation are located in region EBCDN of Fig.2.*



***Figure 2.*** *The first period survival region*

Policy resulted in inefficient and dirty firms exiting the industry (i.e., firms located in region EBCDN of Fig. 2). It also resulted in efficient yet dirty firms remaining active and staying operational while adopting the new technology through irreversible investment (i.e., firms located in region DCKH of Fig. 2). This suggests that if the US EPA’s 2015[[10]](#footnote-10) proposal to regulate power plants is enacted and results in a pollution tax on coal plants, it will lead to inefficient coal plants shutting down and the relatively efficient plants shifting to more environmentally benign technologies.

Next, we move from the micro to the macro and define the survival regions. We use Eq. (7) to define the first-period survival region (i.e., – region DCBEO in Fig. 2):

Let denote the first-period modification region whereby firms located in region earn the highest quasi-rents when adopting the pollution abatement technology in the first period (i.e., firms that are the dirtier yet more efficient). These firms locate in region DCKH of Fig. 2. The units that become idle and stop operating locate in region (i.e., region EBCDN of Fig. 2); that is, policy resulted in inefficient and dirty units exiting the industry. In section V, we exploit the simplicity borne from our assumption of putty–clay technologies and depict the numerical outcomes.

We define the *Pigovian tax* as the tax that internalizes the negative externality caused by market activities, assuming no strategic behavior. It is the tax derived under the assumption of competition without taking into account political uncertainty. We, then, further expand the definition of the Pigovian tax and assume that pollution is a stock variable. This will result in a *dynamic Pigovian tax* that accounts for both current as well as future pollution damages (e.g., Xepapadeas, 1992). When we do not take strategic behavior into consideration, the dynamic Pigovian tax equals the expected discount marginal damage over time. Finally, we define the optimal dynamic tax as the dynamic Pigovian tax while accounting for the strategic behavior; that is, while accounting for the political uncertainty.

Next, we introduce the government and investigate the effect of policy on the survival and modification of regions and thus aggregate pollution. In the first period, Party A sets the optimal dynamic tax that maximizes Eq. (5); the derivation is presented in Appendix A where it is shown that the pollution and output is declining, and the number of units that adopt the technology increase.

Let denote the reduction in flow of pollution in the first period. Party A’s policy lowered pollution in the first period (i.e., ); it reduced the number of active units and induced some active units to modify their technology and adopt cleaner technologies. However, the policy enacted in the first period also affected the second period’s pollution stock; not only reduced the first-period pollution stock, yielding a decline of in the second-period pollution stock, but the first-period policy also permanently changed the technology employed by the industry.

At the beginning of the second period, a random draw transitions the political system to the second period. If it results in reelecting Party A, then the second-period optimal tax maximizes Eq. (6). However, if Party B is elected, then, for simplicity, we assume that the tax is set to 0 (recall that Party B does not place any weight on damage to the environment). Thus, we propose the following:

***Lemma 2.*** *Given the aforementioned assumptions, the dynamic Pigovian tax at period 1 is:*

*Period 2’s Pigovian tax, on the other hand, is just the static Pigovian tax; that is:*

*=*

**Proof:** The proof is in Appendix A.

The first period dynamic Pigovian tax, , can be decomposed into two elements: (i) the current period marginal social cost of pollution – that is, the marginal damage of the current-period pollution (i.e., *the static Pigovian tax effect*: ); and (ii) the future marginal cost of pollution – that is, pollution is a stock and thus affects the next period (i.e., *the pollution stock effect*: ). Put differently, the Pigovian tax denoted equals the difference between the marginal private cost and the social cost calculated at the optimal solution while accounting for dynamics.

Building on Lemma 2, we can also characterize the optimal dynamic tax – that is, the tax that maximizes Party A’s objective function (Eq. (5)):

***Proposition 1.*** *Given the aforementioned assumptions, Party A’s optimal dynamic tax in period 1 is:*

*At the beginning of the second period, a random draw transitions the political system to the second period. If this results in Party A being reelected, then the second-period optimal tax equals the static Pigovian tax:*

*=*

*Otherwise, when Party B is in power in period 2, the tax is set to 0; that is:*

**Proof:** The proof is in Appendix A.

The optimal dynamic tax can be decomposed to three elements: two associated with the Pigovian tax, and the third separates from the Pigovian tax. That is, the first two elements define the Pigovian tax (the static Pigovian tax effect, i.e., ), and the pollution stock effect (i.e., ). The third element is borne from the uncertainty regarding future elections, namely, *the political uncertainty effect,* i.e., ).

Proposition 1 leads to the following:

* 1. Proposition 1 suggests that the dynamic Pigovian tax may not be the optimal tax from a political economic perspective, even when the number of producers and consumers is large.[[11]](#footnote-11) Given political uncertainty (i.e., ) that the future is important (i.e., ) and that pollution is a stock (i.e., ), in equilibrium, Party A sets a higher pollution tax than the dynamic Pigovian tax; that is, .
  2. However, assuming no political uncertainty and that Party A is in power in both periods (i.e., ):
     1. The first-period tax equals the dynamic Pigovian tax and the political uncertainty effect equals zero; that is,.
     2. In addition, if the future carries no weight (i.e., ) and/or pollution is only a flow (i.e., ), then government policy only affects the current period and the first-period optimal tax is the static Pigovian tax; that is, .

When no uncertainty exists regarding future governments (i.e., ) and pollution is a flow, , Party A has no incentive to diverge from the static Pigovian tax (bullet point (b. ii)). However, when and (i.e., no political uncertainty), the optimal policy that maximizes social welfare is the dynamic Pigovian tax (bullet point (b. i)); that is, . On the other hand, if political uncertainty exists (i.e., then Party A’s optimal policy diverges from the dynamic Pigovian tax and, because the investment is irreversible, Party A uses the current policy to tie the hands of future governments and force larger changes in the current period than are suggested by the Pigovian tax (bullet point (a)). Proposition 1 also suggests the following:

***Corollary 1.*** *The optimal tax of Party A gets larger with the greater the weight placed on the future (δ), the slower pollution decays (Ψ), the less likely it is that Party A gets reelected (α), and/or the aggregate predetermined pollution target is smaller .*

Corollary 1 suggests that as Ψ and α decline, and/or δ and increase, the optimal dynamic tax is larger (Proposition 1) and the supply curve locates further down and to the right (Lemma 1). It points out the trade-off between economic development and the environment and that the political uncertainty effect inflates the cost borne by this trade-off, leading Party A to levy a higher tax in the first period than otherwise.

Given the definition of the survival region, we can also show the following:

***Proposition 2.*** *The greater the weight placed on the future (δ), the slower the pollution decays (Ψ), the less likely that Party A gets reelected (α) , and/or the aggregate predetermined pollution target is smaller .:*

1. *The smaller the number of active firms in equilibrium; and*
2. *The higher the equilibrium price and thus the smaller the economic surplus defined as the sum of consumer and producer surplus, i.e., .*

*Furthermore, the number of active firms decreases with the current and next period investment levels, as does the consumer surplus (). The change in producer surplus (), on the other hand, is determined by the demand elasticity.*

Next, we investigate the sensitivity of the equilibrium outcome to the demand parameters and thus the demand elasticity. Technically, we assume a linear demand function, i.e., where , and total differentiate the equilibrium condition of supply equals demand. In what follows, let denote the elasticity of demand, and the elasticity of supply.

***Proposition 3.*** *Under the following conditions, demand elasticity increases:*

1. *and , ceteris paribus; or*
2. *and is small enough such that , where measures the relative change in the equilibrium price when moving from b to (b+) where , ceteris paribus.*

*That is, for a sufficiently small supply elasticity, an increase in the intercept or slope of the demand curve results in a larger demand elasticity, i.e., increases.*

*The increase in the intercept, i.e., a, results in larger consumer and producer surpluses, i.e., both CS and PS increase. It also results in more active firms in equilibrium. On the other hand, the increase in the slope of the demand curve results in less firms in equilibrium, and in less consumer and producer surpluses, i.e., both CS and PS decrease.*

*Finally, assume an increase of both the slope and the intercept of the demand curve such that the elasticity of demand increases yet the equilibrium outcome is unchanged, then the consumer surplus increases while the producer surplus is unchanged.*

Next, we investigate the effect of a pollution tax on adoption rates of clean technologies in the US electricity power sector, while focusing on employment, output, and adoption. We elected not to calculate social welfare since we did not want to make explicit assumptions on consumers’ preferences and thus their demand for electricity.

## **V. Regulating Coal: The Case of Pareto Distribution**

Coal is the largest source of energy feedstock used for the generation of electricity worldwide. However, it is also one of the largest worldwide anthropogenic sources of carbon dioxide releases. As a valuable nonrenewable resource, the production, consumption, and trades related to coal have generated enormous economic profits. On the other hand, the combustion of coal produces severe emissions of pollutants that exacerbate the GHG effect and air pollution. In the following section, we assume that the government designed the optimal dynamic tax policy to combat pollution and alleviate the negative ramifications associated with electricity power generation, given the political uncertainty it faces regarding the outcome of future elections.

To further understand the effect of policy instruments on the adoption of cleaner technologies in the electricity sector, we introduce a specific distribution function and calculate the optimal outcome. We assume that the output–capacity distribution function follows a generalized Pareto distribution. This distribution function has been used extensively in the trade literature (Helpman, Melitz, & Rubinstein, 2008; Melitz & Ottaviano, 2008; Chaney, 2008), and its aggregation across firms yields a Cobb-Douglas production function (Houthakker, 1955). The Cobb-Douglas framework has been used extensively in the context of pollution since the work of Baumol and Oates (1971).

Technically, we assume firms are distributed according to the following generalized Pareto distribution function:[[12]](#footnote-12)

.

We limit the numeric simulation to shape parameters and , thus assuming the output capacity distribution function places more weight on the high-polluting and inefficient units. This is consistent with Shapiro and Walker (2015).

## V.1 Calibrating the model for the numerical example

The data used to calibrate the numerical model are based on the electricity sector in the US and supplemented with the literature when needed (Table 1). The US Energy Information Administration (EIA) (2013) included data on 6,668 plants that generated a total of about 4 billion megawatts in 2015.[[13]](#footnote-13) In the analysis that follows, we assume that the variable input is labor. Then, given total employment in the electricity sector of 193,144,[[14]](#footnote-14) we calibrate the productivity parameter (i.e., ) using Eq. (2). We also use power plant information to derive estimates of price and investment (i.e., upfront costs). For simplicity and brevity, we assume the US electricity sector is a competitive sector. We also assume a 50% decline in upfront costs in the second period[[15]](#footnote-15) and that the probability that Party A is reelected is 55%. We assumed a linear demand for electricity and calibrated the demand using existing data.

We present the various calculations in Appendix B, where we use the generalized Pareto distribution function to derive the survival regions and calculate output. Our assumptions suggest that one unit of output is equivalent to 70,750 megawatts. Assuming the electricity sector is producing 30% of annual GHGs produced in the US, and given that the US generated about 6,500 million tons of CO2 in 2012,[[16]](#footnote-16) the yield is 0.05 million tons of CO2 per pollution unit.

## V.2 The tax regime

In what follows, assume a counterfactual scenario of an optimal (dynamic) tax of and per pollution unit. Because we consider political uncertainty and a stock pollution, the dynamic Pigovian tax of the first period is smaller than the optimal dynamic tax; that is, the dynamic Pigovian tax is .

Table 1.The baseline parameters.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | Value | Parameter | Value | Parameter | Value |
|  | 2115.3 |  | 2.00 |  | 2.00 |
|  | 10.34 |  | -0.82\* |  | 0.50 |
|  | 1.60 |  | 0.80 |  |  |
|  | 0.95 |  | 0.55 |  | 0. 5 |
|  | 0.05 |  |  |  | 1 |

\* Numerous studies attempted to estimate electricity demand in the US using various statistical methods. While focusing on residential electricity demand, Silk and Joutz (1997) arrived at an own-price elasticity of -0.62%. Dergiades and Tsoulfidis (2008), on the other hand, estimate the short- and long-run price elasticities of demand at -0.39% and -1.07%, respectively. Yet Paul, Myers, and Palmer (2009) estimate the US short-run price elasticities of demand and show that, depending on the region and the end-consumers, the elasticity falls somewhere between -0.04 and -0.32, while the long-run price elasticities of demand range between -0.02 and -1.15.

However, the question of how adoption rates in the electricity sector vary across regimes remains. We address this question next by deriving the output, input, and adoption rates. The survival and adoption regions in the - plane are derived in Appendix B.1, where key outcomes are presented in Table 2. The tax policy results in firms facing the following choices:

1. *Remains active and operate, and either*
   1. *operate using the existing technologies or*
   2. *adopt the new technology through irreversible investment.*
2. *Become idle and stop operation.*

Similar to the predictions derived above in the analytical analysis, the tax policy results in inefficient and dirty units exiting the industry – inefficient polluting coal plants exit the industry while the more efficient ones remain active and adopt cleaner technologies (e.g., Carbon Capture and Storage technologies). The tax regime yielded a reduction of 1,137 terawatts in electricity generated, and resulted in an adoption rate of 54% among the units that remain operational. The policy also resulted in the input used in the power sector declining by almost 40%.

Using the calibrated demand and Eq. (3), we calculated the change in the consumer and producer surplus because of regulation. These calculations suggest that the introduction of a pollution tax resulted in the consumer surplus declining by 29%, whereas producer surplus declined by 15%.

Table 2. The effect of the first period policy instruments.

|  |  |  |
| --- | --- | --- |
|  | No Regulation | Tax Regime |
| Output (terawatt hours / year) | 4,000 | 2,863 |
| input (#) | 193,144 | 118,766 |
| Pollution (million tons of CO2) | 1,885 | 1,602 |
| Adoption (terawatt hours) |  | 1,558 |
| % Change in consumer surplus |  | -29% |
| % Change in producer surplus |  | -15% |

*V.3 The demand elasticity*

The tax incidence and its impact on stakeholders varies as the demand elasticity changes. If the demand is perfectly inelastic, there is no impact on the firms and the amount produced does not change. The tax burden falls solely on consumers and there are no environmental benefits from regulation. However, as the demand becomes more and more elastic, the tax burden shifts to firms and the effect of regulation is more substantial. Regulation leads to larger declines in output and thus aggregate pollution. With perfect elastic demand, the tax burden falls solely on firms.

As the elasticity changes, the tax burden on the various groups of firms (adopters, non-adopters) also varies. To quantify these effects, we introduced assorted elasticities while holding aggregate pollution at the baseline level and recalibrating the marginal damage and, thus, the optimal tax in equilibrium (Fig. 3). The numerical calculations show that the lower the elasticity of demand in absolute value and the lower the taxes, the smaller the reduction in the electricity generated and the reduction of inputs used in the power sector compared to the unregulated scenario.

Graph D(P) for various P

Graph S(P) for various P

Show intersection

Different elasticity – graph results, graph for adoption, exit, quantities, tax

Political Uncertainty – graph for adoption, exit, quantities, tax

When the demand is relatively inelastic, the tax burden falls on consumers and firms’ incentives to remain active and adopt the cleaner technology are larger than those when demand is relatively elastic. Thus, taxes are lower The framework suggests that less elastic demand curves result in a smaller tax burden on the firms yields higher prices and quantities and less incentives to exit but more to adopt. Firms consider two things:

1. The loss of revenues because of producer price changes.
2. The lower the elasticity of demand the lower the tax that will result in firms adopting the new technology

Of note is that when taxes become large enough (marginal damage is sufficiently large), higher taxes do not result in more adoption, but they do result in more electricity generating units exiting the industry and becoming idle. Thus, if we further increase the second-period tax from 3 per kWh to 3.5 per kWh, then the amount of electricity generated using clean technologies declines to 2,127 terawatts (compared to 2,135 terawatts when second-period is 3 per kWh). The analysis suggests that beyond a threshold the increase in taxes does not result in more adoption of clean technologies, but rather in more firms exiting the industry and thus lower output. The implications of this counter-factual analysis are that larger marginal damages lead to substantially larger declines in inputs use, that is the decline in input use significantly increase beyond a given threshold.



*Figure 3a. Output, adoption and the firms exiting the industry*



*Figure 3b. The second period damage from pollution*

*Figure 3. Demand elasticity and the industry's response to pollution regulation*



*V.4 Robustness of the results*

A broad set of parameters was used to evaluate the sensitivity of the results to our assumptions. We began by revising the shape parameters of the Pareto distribution. While building on Shapiro and Walker (2015), who estimated the shape parameters of the Pareto distribution for several US industries, we used their average across all industries of 5.71. We also simulated a scenario that builds on Rubin et al. (2004), who estimated the learning curve of flue gas desulfurization systems for US coal power plants, resulting in a progress ratio of 89%, which corresponds to a learning rate of 11%.[[17]](#footnote-17) We also recalculated employment and adoption for various political uncertainty parameters, i.e., , and first-period investment levels, i.e., . Other scenarios simulated to understand the robustness of our results included varying the value of between 0.15 and 0.85 and calibrating the model to a different set of decay parameters, one at a time. All parameters qualitatively confirmed the results discussed above, albeit the magnitude of the effects fluctuated.

**VI. Elections Are Not Random – only words**

Throughout the last half century, several theories have been advanced to explain governments’ policy choices. Such theories usually take into account the influence of various groups of agents within the economy, such as consumers and producers, on decision makers (Becker, 1988; Grossman & Helpman, 2001; Peltzman, 1976; Posner, 1974; Zusman, 1976). Recently, political scientists developed the selectorate theory (de Mesquita, Smith, Siverson, & Morrow, 2005). The essence of this theory is that leaders need to hold office to reach their objectives. The theory assumes that leaders, who are in positions of authority, will want to keep their positions and that politicians’ policy decisions are compatible with their desire to stay in office and retain their power (Downs, 1957). Non-random election is motivated by the real world, where elections are not random but rather the outcome of actions taken by the incumbent government.

The analysis, so far, assumes that elections are exogenous to policy decisions. Given an industry embodied with capital-intensive technologies, the analysis shows that the optimal dynamic tax is set higher than the Pigovian tax. However, how does the analysis change when elections are influenced by policy decisions? How, for example, do the ruling party’s policy decisions change when loss in market surplus (consumer plus producer surpluses) due to carbon tax reduces the likelihood of the ruling party being reelected? In these scenarios, the likelihood of being elected, i.e., α, is not exogenous but endogenous to the policy decision. Technically, we expand Party A’s objective function (Eq. (5)) and assume that the likelihood of Party A remaining in power in the second period is not exogenous, but is a function of the first period economic surplus and pollution ; that is, let denote the likelihood of Party A remaining in power in the second period, where . Thus, the optimal dynamic tax solves the following:

|  |  |  |
| --- | --- | --- |
|  |  | (5’) |

# Assume that is concave, i.e., , and define elasticity . Then, the effect of policy on the likelihood of Party A staying in power in the second period is decomposed into two effects: first, the negative effect of policy on economic surplus (i.e., ), and second, the positive effect of policy on the pollution stock (i.e., ).

# The probability of getting re-elected is not exogenous to the chosen policy. In addition, because Party B does not account for the environment when designing policy, . The proposition follows as:

***Proposition 3.*** *The effect of first-period policy on the probability that Party A will get reelected in the second period impacts Party A’s first-period policy decisions. Specifically:*

*More specifically, if:*

1. *and : Voters respond to the levying of a tax through less support to Party A, resulting in a lower optimal tax in equilibirum than otherwise; that is, .*
2. *and : Environmentally aware voters respond to the levying of a tax through more support to Party A, resulting in a higher tax in equilibirum than otherwise; that is, .*

# Proof. The proof was deferred to the Appendix E.

Because Party A cares about the environment, setting a higher policy in the current period leads to wider diffusion of the clean technology; it solidifies the transition toward clean technologies. The motivation for a higher tax than the Pigovian tax is then balanced with the politician’s desire to stay in power. Thus, while environmentally aware constituencies lead to higher taxes, ceteris paribus, i.e., concern for the response of constituencies that emphasize employment, output, and prices, leads to lower taxes.

The first order condition of Eq. (5’) is depicted in Fig. 2, where three alternative scenarios are presented. In the first, the curve depicting the first order condition intersects the x-axis at point A. This scenario denotes our baseline analysis whereby the elections outcome is exogenous to the policy choice. However, assuming the probability of being reelected increases with economic surplus, politicians’ desire to stay in power will lead them to choose a smaller optimal dynamic tax in equilibrium than otherwise. Under this alternative scenario, the first order condition shifts down and to the left and the equilibrium outcome is depicted through point B in Fig. 2. Finally, the third scenario depicts an outcome where the electorate values the environment and favors politicians that minimize the damage economic activity inflicts on the environment, leading to a larger optimal dynamic tax than the baseline analysis suggests. Under this alternative scenario, the first order condition shifts up and to the right, and the equilibrium outcome is depicted through point C in Fig. 2. Party A balances the incentive to levy an optimal dynamic tax that is larger than the Pigovian tax with the party’s desire to remain in power.

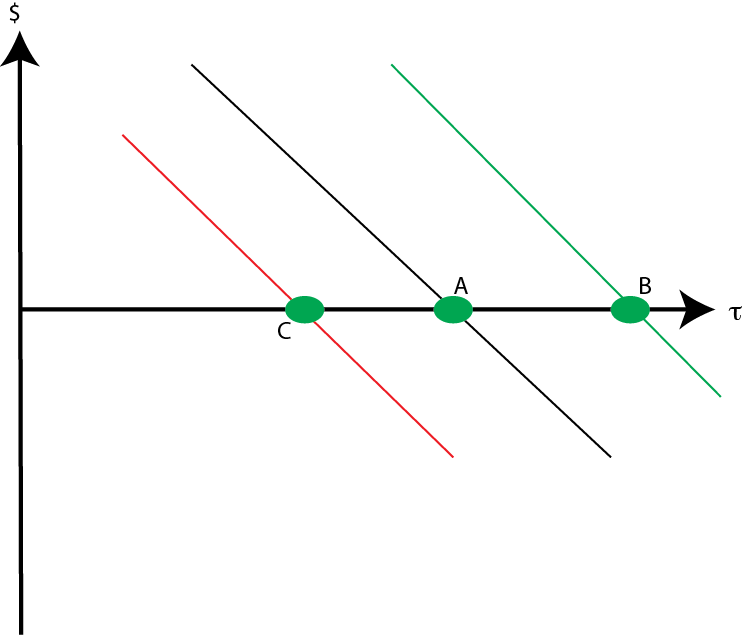


Figure 2. The political economy of elections and the optimal tax.

**VII. Discussion and Concluding Remarks – climate change?? QJE FISHER & ARROW. TECHNICAL UNCERTAINTY YOU WAIT, POLITICAL UNCERTAINTY YOU GO FASTER**

This paper shows that in a world with uncertainty regarding future governments, establishing a pollution tax in industries relying on capital-intensive technologies may result in the optimal dynamic tax being larger than the Pigovian tax. The analysis is a partial-equilibrium one. General equilibrium effects are important for understanding the welfare consequences of first- versus second-best policies (e.g., Goulder, Parry, Williams III, & Burtraw, 1999; Bento, Goulder, Jacobsen, & Haefen, 2009; Lapan & Moschini, 2012; Fowlie, Greenstone, & Wolfram, 2015; Soubeyran, Tidball, Tomini, & Erdlenbruch, 2015). Second-best policies might affect the rate of innovation in the long run and/or encourage massive changes in concentration within industries (Ryan, 2012). In this paper, however, we aim to understand the importance of political uncertainty, and partial equilibrium analysis allows us to focus on its first-order welfare effects. The focus on the putty–clay framework and solving for the partial equilibrium is for brevity and simplicity and is without loss of generality. Thus, many of the results hold if, for example, the framework employed in Arrow (1968) is used.

Although it is outside the scope of this work, one implication of the analysis is that for highly inelastic demand scenarios, the industry may not object to a tax and, under plausible political scenarios, the industry may even join environmentalists in promoting a tax. Under this scenario, consumers will likely object to the policy. On the other hand, if the demand is very elastic, consumers may join the environmentalists, but the policy will be opposed by the industry. In future work, we plan to investigate this tension and better understand the formation of winning coalitions, meaning coalitions whose lobbying activity yields policy outcomes that favor the winning coalition’s preferences. We also plan to statistically test the hypotheses presented in this paper and to explore empirically the dynamics of a capital-intensive industry (i.e., the power sector) and how it responds to regulation.

# References

1. Acemoglu, D., & Robinson, J. A. (2001). Inefficient redistribution. *American Political Science Review*, *95*(3), 649–661.
2. Aghion, P., & Bolton, P. (1990). Government domestic debt and the risk of default: A political-economic model of the strategic role of debt. In R. Dornbusch & M. Draghi. (Eds.), *Public debt management: Theory and history* (pp. 315-349). Cambridge University Press.
3. Arrow, K. J. (1962). The economic implications of learning by doing. *Review of Economic Studies*, *29*(3), 155-173.
4. Arrow, K. J. (1968). Optimal capital policy with irreversible investment. *Value, Capital and Growth*, 1-20.
5. Azzimonti, M. (2011). Barriers to investment in polarized societies. *American Economic Review,* *101*(5), 2182–2204.
6. Babcock, B. A., Lakshminarayan, P.G., Wu, J. J., & Zilberman, D. (1997). Targeting tools for the purchase of environmental amenities. *Land Economics*, *73*(3), 325–339.
7. Baumol, W. J., & Oates, W. E. (1971). The use of standards and prices for protection of the environment. *Swedish Journal of Economics*, *73*, 42–54.
8. Baumol, W. J., & Oates, W. E. (1988). *The theory of environmental policy*. Cambridge, MA: Cambridge University Press.
9. Becker, G. S., (1998). A theory of competition among pressure groups for political influence. *Quarterly Journal of Economics*, *98*(3), 371–400.
10. Bento, A. M., Goulder, L. H., Jacobsen, R., & Haefen, v. R. H. (2009). Distributional and efficiency impacts of increased US gasoline taxes. *American Economic Review*, 99, 667–699.
11. Berck, P., & Helfand, G. (1990). Reconciling the von Liebig and differentiable crop production functions. *American Journal of Agricultural Economics*, *72*(4*)*, 985–996.
12. Bohn, F. (2007). Polarisation, uncertainty and public investment failure. *European Journal of Political Economy, 23*(4),1077–1087*.*
13. Buchanan, J. M., & Tullock, G. (1975). Polluters’ profits and political response: Direct controls versus taxes. *American Economic Review*, *65*(1), 139–147.
14. Caparros, A., Just, R., & Zilberman, D. (2015). Dynamic relative standards versus emission taxes in a putty-clay model. *Journal of the Association of Environmental and Resource Economists, 2*(2), 277–308.
15. Chaney, T. (2008). Distorted gravity: The intensive and extensive margins of international trade. *American Economic Review*, *98*(4), 1707–1721.
16. Chen, X., & Khanna, M. (2012). Explaining the reductions in US corn ethanol processing costs: Testing competing hypotheses. *Energy Policy, 44*, 153–159.
17. Cooper, R. W., & Haltiwanger, J. C. (2006). On the nature of capital adjustment costs. *Review of Economic Studies, 73*(3), 611–633.
18. Dasgupta, A. K. (1970). Some problems of estimating the long-run marginal costs of electricity: A vintage capital approach. *Economics of Planning*, *10*(3), 193–220.
19. Davis, S. J., & Haltiwanger, J. (1991). *Gross job creation, gross job destruction and employment reallocation* (No. w3728). National Bureau of Economic Research.
20. Dergiades, T., & Tsoulfidis, L. (2008). Estimating residential demand for electricity in the United States, 1965–2006. Energy Economics 30 (5), 2722–2730.
21. Downs, A. (1957). An economic theory of political action in a democracy. Journal of Political Economy, 65(2), 135-150.
22. Falk, I., & Mendelsohn, R. (1993). The economics of controlling stock pollutants: an efficient strategy for greenhouse gases. *Journal of Environmental Economics and Management, 25*(1), 76–88.
23. Fowlie, M., Greenstone, M., & Wolfram, C. (2015). *Do energy efficiency investments deliver? Evidence from the Weatherization Assistance Program*. [Working paper].
24. Fuss, M. (1978). Factor substitution in electricity generation: A test of the putty clay hypothesis. In M. Fuss & D. McFadden (Eds.), *Production economics: A dual approach to theory and applications, Vol. 2 of History of Economic Thought Chapters* (pp. 187–214). Amsterdam and Holland: North-Holland Publishing Co.
25. Goulder, L., Parry, I. W. H., Williams III, R. C., & Burtraw, D. (1999). The cost effectiveness of alternative instruments for environmental protection in a second-best setting. *Journal of Public Economics*, *72*, 329–360.
26. Grossman, G., &. Helpman, E. (2001). *Special interest politics*. Cambridge, MA: MIT Press.
27. Grubler, A., Nakicenovic, N., & Victor, D. G. (1999). Dynamics of energy technologies and global change. *Energy Policy*, *27*(5), 247–80.
28. Gunther, H., & Diamond, L. (2003). Species of political parties: A new typology. *Party Politics*, *9*(2), 167–199.
29. Helpman, E., Melitz, M., & Rubinstein, Y. (2008). Estimating trade flows: Trading partners and trading volumes. *Quarterly Journal of Economics*, *123*(2), 441–487.
30. Hochman, E., & Zilberman, D. (1978). Examination of environmental policies using production and pollution microparameter distributions. *Econometrica*, *46*(4), 739–760.
31. Houthakker, H. S. (1955). The Pareto distribution and the Cobb-Douglas production function in activity analysis. *Review of Economic Studies*, *23*, 27–31.
32. Holland, S. P. (2012). Emissions taxes versus intensity standards: Second-best environmental policies with incomplete regulation. *Journal of Environmental Economics and Management*, *63*, 375–387.
33. Jack, B. K., Kousky, C., & Sims, K. R. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences, 105*(28), 9465–9470.
34. Johansen, L. (1972). An integration of micro and macro, short run and long run aspects. In *Contribution to Economic Analysis* 75, Amsterdam and Holland: North-Holland Publishing Co.
35. Khanna, M., & Rao, N. D. (2009). Supply and demand of electricity in the developing world. In G. Rausser, K. Smith, & D. Zilberman, (Eds.), *Annual review of resource economics*, Vol. 1. Annual Reviews: Palo Alto, California.
36. Laffont, J. J., & Tirole, J. (1996a). Pollution permits and compliance strategies. *Journal of Public Economics*, *62*(1–2), 85–125.
37. Laffont, J. J., & Tirole, J. (1996b). Pollution permits and environmental innovation. *Journal of Public Economics*, *62*(1–2), 127–140.
38. Lapan, H., & Moschini, G. (2012). Second-best biofuel policies and the welfare effects of quantity mandates and subsidies. *Journal of Environmental Economics and Management*, 63, 224–241.
39. List, J. A., & Sturm, D. M. (2006). How elections matter: Theory and evidence from environmental policy. *The Quarterly Journal of Economics, 121*(4), 1249–1281.
40. McDonald, A., & Schrattenholzer, L. (2002). Learning curves and technology assessment. *International Journal of Technology Management*. *23*(7/8), 718–45.
41. Melitz, M. J., & Ottaviano, G. I. P. (2008). Market size, trade, and productivity. *Review of Economic Studies*, *75*(1), 295–316.
42. de Mesquita, B. B., Smith, A., Siverson, R. M., & Morrow, J. D. (2005). *The logic of political survival*. MIT Press: Boston, MA.
43. Millner, A. (2013). Policy distortions due to heterogeneous beliefs: Some speculative consequences for environmental policy. In A. Kollmann, J. Reichl, & F. Schneider (Eds.), *Political economy and instruments of environmental politics*. CESifo seminar series.
44. Moffitt, L. J., Zilberman, D., & Just, R. E. (1978). A ‘putty clay’ approach to aggregation of production / pollution possibilities: An application in dairy waste control. *American Journal of Agricultural Economics*, *60*(3), 452–459.
45. Newell, R. G., & Pizer, W. A. (2003). Regulating stock externalities under uncertainty. *Journal of Environmental Economics and Management*, *45*(2), 416–432.
46. Paris, Q. (1990). The Vonliebig hypothesis. *American Journal of Agricultural Economics*, *77*(4), 1019–1028.
47. Parry, I. W., Williams, R. C., & Goulder, L. H. (1999). When can carbon abatement policies increase welfare? The fundamental role of distorted factor markets. *Journal of Environmental Economics and Management, 37*(1), 52–84.
48. Paul, A., Myers, E., & Palmer, K. (2009). A partial adjustment model of US electricity demand by region, season, and sector. Resources for the Future: Discussion Paper 08-50, pp. 1–27.
49. Peltzman, S. (1976, August). Toward a more general theory of regulation. *Journal of Law and Economics*, *19*(2), 211–240.
50. Persson, T., & Svensson, L. E. O. (1989). Why a stubborn conservative would run a deficit: Policy with time- inconsistent preferences. *Quarterly Journal of Economics*, *104*(2), 325–345.
51. Persson, T., & Tabellini, G. (1999). The size and scope of government: Comparative politics with rational politicians. *European Economic Review,* *43*(4–6), 699–735.
52. Persson, T., & Tabellini, G. E. (2000). *Political economics: Explaining economic policy*. Cambridge, MA: MIT Press.
53. van der Ploeg, F. (2013). Cumulative carbon emissions and the green paradox. *Annual Review of Resource Economics, 5*(1), 281–300.
54. Pigou, A. C. (1932). *The economics of welfare*. London, UK: Macmillan.
55. Posner, R. A. (1974). Theories of economic regulation. *Bell Journal of Economics and Management Science*, *5*(2), 335–358.
56. Rausser, G. C., Swinnen, J., & Zusman, P. (2011). *Political power and economic policy: Theory, analysis, and empirical applications*. Cambridge University Press.
57. Rivers, N., & Jaccard, M. (2006) Choice of environmental policy in the presence of learning by doing. *Energy Economics,* *28*(2), 223–242
58. Ryan, S. P. (2012). The costs of environmental regulation in a concentrated industry. *Econometrica*, *80*, 1019–1061.
59. Rubin, E. S., Yeh, S., Antes, M., Berkenpas, M., & Davison, J. (2007). Use of experience curves to estimate the future cost of power plants with CO 2 capture. International journal of greenhouse gas control, 1(2), 188-197.
60. Sagar, A. D., & van der Zwaan, B. (2006). Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. *Energy Policy, 34*(17), 2601–2608.
61. Shahan, Z. (2014, September 4). *13 Charts on solar panel cost & growth trends*. Clean Technica. Retrieved from http://cleantechnica.com/2014/09/04/solar-panel-cost-trends-10-charts/.
62. Shapiro, J. S., & Walker, R. (2015). Why is pollution from US manufacturing declining? The roles of trade, regulation, productivity, and preferences (No. w20879). National Bureau of Economic Research.
63. Silk, J.I., Joutz, F.L. (1997). Short and long-run elasticities in US residential electricity demand: a cointegration approach. Energy Economics 19, 493–513.
64. Soubeyran, R., Tidball, M., Tomini, A., & Erdlenbruch, K. (2015). Rainwater harvesting and groundwater conservation: When endogenous heterogeneity matters. Environmental and Resource Economics, 62, 19–34.
65. Sunding, D., & Zilberman, D. (2001). The agricultural innovation process: Research and technology adoption in a changing agricultural sector. In B. L. Gardner & G. C. Rausser, (Eds.), *Handbook of agricultural economics*, Vol. 1 (pp. 207–261). Elsevier.
66. Tabellini, G., & Alesina, A. (1990). Voting on the budget deficit. *American Economic Review, 80*(1), 37–49.
67. Tombe, T., & Winter, J. (2015). Environmental policy and misallocation: The productivity of intensity standards. *Journal of Environmental Economics and Management*, 72, 137–163.
68. Torani, K., Rausser G., & Zilberman, D. (2016). Innovation subsidies versus consumer subsidies: A real options analysis of solar energy. *Energy Policy,* *92*, 255–269
69. Weitzman, M. L. (1974). Prices vs. quantities. *Review of Economic Studies*, *41*(4), 477–491.
70. Wu, J. J., Zilberman, D., & Babcock, B. A. (2001). Environmental and distributional impacts of conservation targeting strategies. *Journal of Environmental Economics and Management*, *41*(3), 333–350.

# Xepapadeas, A. P. (1992). Environmental policy design and dynamic nonpoint-source pollution. *Journal of environmental economics and management*, 23(1), 22-39.

# Zusman, P. (1976). The incorporation and measurement of social power in economic models. *International Economic Review*, 17, 447–462.

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3. The authors thank Kathleen Segerson for the conversations they had and comments she made on earlier drafts, which significantly improved this work and its presentation. The authors also thank Ujjayant Chakravorty, Ronald B. Mitchell, and JunJie Wu for comments and suggestions that significantly contributed to this paper, and thank participants of AERE 2016, WEAI 2016, and AAEA 2016 meetings. Any remaining errors are the authors’ doing. [↑](#footnote-ref-3)
4. Both Fuss (1978) and Dasgupta (1970) suggested that the putty–clay approach fits the energy sector well, and several studies have assessed the impact of energy regulation using the putty–clay specifications (see survey by Khanna & Rao, 2009). Moffitt, Zilberman, and Just (1978) applied the putty–clay approach to analyze waste-management regulation, and Sunding and Zilberman (2001) used it to assess the impact of water market reforms in California. Furthermore, studies by Paris (1990) and Berck and Helfand (1990), among others, showed that the fixed proportion Von-Liebig production function fits well agricultural production systems, thus justifying, for example, the approach taken by Babcock, Lakshminarayan, Wu, and Zilberman (1997) and Wu, Zilberman, and Babcock et al. (2001) who used putty–clay specifications to assess various payments for ecological service schemes. These and other empirical studies confirm the insight of Houthakker (1955) and Johansen (1972), who showed that the putty–clay approach results in aggregate production functions that are well behaved and simple to construct and analyze. [↑](#footnote-ref-4)
5. The US Environmental Protection Agency’s sulfur regulation programs resulted in altering the refined product value chain with some technologies being retired, others being adopted, and the US benefiting from cleaner internal combustion engines. [↑](#footnote-ref-5)
6. An alternative approach introduces adjustment costs to the capital markets (Davis & Haltiwanger, 1991; Cooper & Haltiwanger, 2006). However, we elected to employ the putty–clay approach and disallowed the redeployment of capital because it yielded a clear characterization of the implications from political uncertainty on the choice of environmental policy in industries embodied in capital-intensive technologies. [↑](#footnote-ref-6)
7. http://dwwind.com/project/block-island-wind-farm/ [↑](#footnote-ref-7)
8. To this end, the empirical literature estimates learning-by-doing through the quantification of the aggregated effect of technological development using the experience curve approach. This approach assumes that costs decline with a fixed percentage over each doubling in cumulative production (Chen & Khanna, 2012; Rivers & Jaccard, 2006). [↑](#footnote-ref-8)
9. Available at <https://www.epa.gov/climate-indicators/greenhouse-gases> [retrieved February 14, 2017]. [↑](#footnote-ref-9)
10. [*Federal Register, Volume 80, number 205*](https://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22842.pdf) (PDF), U.S. Government Printing Office, October 23, 2015, pp. 64661–65120, RIN 2060–AR33 [↑](#footnote-ref-10)
11. Baumol and Oates (1988) showed that when the number of polluting units is small (i.e., one firm pollutes) or the damage is affecting a small number of consumers (i.e., the pollution is negatively affecting one firm), the Pigovian tax does not result in the optimal solution. [↑](#footnote-ref-11)
12. Under this functional form, when and the density function is a uniform distribution function where for and 0 otherwise. However, when (), the density function places more weight on low-polluting (efficient) firms. On the other hand, if (), then the density function places more weight on high-polluting (inefficient) units. [↑](#footnote-ref-12)
13. Data is available at http://www.eia.gov/electricity/data/browser/. [↑](#footnote-ref-13)
14. Data for employment in the utility sector is available at http://www.energy.gov/sites/prod/files/2016/03/f30/U.S.%20Energy%20and%20Employment%20Report.pdf. [↑](#footnote-ref-14)
15. To this end, solar costs have fallen during the last five years by more than 40% (Shahan, 2014). [↑](#footnote-ref-15)
16. Data is available at http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-2-Trends.pdf. [↑](#footnote-ref-16)
17. These estimates are similar to other learning rates found by authors investigating large-scale energy technologies (Grubler, Nakicenovic, & Victor, 1999; McDonald & Schrattenholzer, 2002), with solar being an exception. To this end, solar costs have fallen during the last five years by more than 40% (Shahan, 2014). [↑](#footnote-ref-17)