EPRG WORKING PAPER

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EPRG Working Paper 1714

Cambridge Working Paper in Economics 1732

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Publication August 2017
Financial Support ESRC grant

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May 23, 2017

Abstract

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*My thanks are due to Toke Aidt, Robert Ritz, and numerous participants at the EAERE 2016 Conference in Zurich, and at the Empirical Microeconomics Workshop and Electricity Policy Research Group weekly seminar, both at the University of Cambridge. I also gratefully acknowledge the financial support of the ESRC (Grant number ES/J500033/1).

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1 Introduction

This paper aims to answer the question 'when might polluting firms support environmental protection, and what difference does this make?' Lack of political support is a major reason why environmental regulations are either delayed or permanently weak.[1] Political support for environmental protection can come from a number of places, but it is arguably most valuable when it comes from business. Many environmental policymakers would go so far as to say that this is almost a necessary condition for feasible environmental regulation - when there appears to be conflict between 'the economy' and the environment, the environment tends to lose.[2]

Firms spend significant resources on lobbying[3] and there is a general perception that polluting firms inevitably use their lobbying power to slow down, water down, or entirely block measures to protect the environment. This is indeed the case much of the time,[4] but there have been major and important exceptions to this rule. The following two examples motivate much of the paper.

The first is an unusually clear-cut case concerning protection of the ozone layer, the biggest environmental problem of its time. During the 1980s, regulators were attempting to draw up global rules to limit the production of ozone-depleting CFCs and encourage investment in cleaner alternatives. Until 1988, the major ozone-polluting firms had all opposed environmental regulation and successfully used their influence to limit protection of the ozone layer. The largest producer, US firm DuPont, had lobbied for decades against regulation, for example warning the US Senate that restrictions were unnecessary and would cause 'tremen-

[1]Oates and Portney (2003) review the literature on the political economy of environmental protection.

[2]Stern (2015).

[3]For example, in the US, energy and fossil fuel companies spent \$0.54 billion on lobbying over the 2013-14 Congress (according to the Center for Responsive Politics, opensecret.org, accessed on 29 Jan 2015). The EU is far less transparent, so financial flows are hard to obtain, but according to Dinan and Wesselius (2010) there are perhaps 30,000 lobbyists in Brussels, the same as the number of EU Commission employees.

[4]Oreskes (2010) details attempts to block environmental protection by polluting firms.

dous economic dislocation'.[5] However, in March 1988 DuPont abruptly announced that it no longer opposed regulation and in fact now wanted a complete phase-out of global CFC production. DuPont's new political support for regulation is widely seen as the key turning point in the story of ozone protection.[6] The European producers continued to lobby against reductions but were unsuccessful: the Montreal Protocol, and a series of subsequent treaties, achieved a total phase out of CFCs. It has been suggested that DuPont's lobbying for regulation may have been in its economic self interest. Since it had already made some investments in cleaner production technologies that would give it an advantage over its rivals in the clean substitute market, DuPont potentially stood to gain market share.[7] In the words of DuPont director Joseph Glass, 'when you have $3 billion of CFCs sold worldwide and 70 percent of that is about to be regulated out of existence, there is tremendous market potential.'[8] A key feature of DuPont's lobbying was for controls to be as strong and as international as possible, so that their major European rivals would be affected.

The DuPont example is perhaps particularly straightforward, but similar dynamics are also likely to be operating on various levels in the more complex case of climate change. In the run up to the Paris Agreement, a coalition of major oil and gas producers was among those calling for the introduction of a global carbon price. Europe's six largest oil and gas companies (BG, BP, Eni, Shell, Statoil and Total) argued in an open letter to the UN sent on 29 May 2015 for the introduction of a carbon price. If this were introduced, they argued, they could invest in reducing their emissions by, for example, increasing the proportion of gas they produce (which is relatively clean). The letter also hints at another effect of the carbon price: 'reduced demand for the most carbon intensive fossil fuels' - that is, coal, their biggest

[5]Benedick (1998) gives a definitive and first hand account of the history of ozone protection, as he was the lead US negotiator for the Montreal Protocol.

[6]See Barrett (2003) for further details.

[7]DuPont probably had several reasons for making this move; all that is argued here is that profit is likely to have been one of them. Smith (1998) gives a detailed discussion of DuPont's potential motives.

[8]Quoted in Gilding (2012).

competitor product, with a market share of global energy supply around 30%.[9] A moderately strong carbon price would almost certainly shift market share away from coal and towards gas, creating, in the words of the DuPont director, 'tremendous market potential'. It is hard not to see this lobbying, at least in part, as an attempt by the oil and gas companies to steal market share from the coal companies.[10] Although climate regulation is on-going, stronger political support from the private sector is considered by many policy makers to have helped achieve the Paris Agreement in 2015.[11]

Hence there are clear examples of major polluting firms lobbying for environmental regulation of their markets, and this political support can substantially increase the ability of governments to protect the environment.[12] This paper asks, by modelling these kinds of situations, when and how a firm like DuPont might choose to invest in a costly clean technology, knowing it will be able to influence the political process to get regulations passed that will result in increased market share and so greater profits.

An outline of the model and results presented here is as follows. In the baseline model there are two identical firms, each of which can invest in a new green production technology or keep their old polluting technology. A government then chooses the emissions tax they are subject to, and the firms can influence this choice through lobbying. The result is that, for a region of the model's parameter space, competition between the firms causes one

[9] IEA *Key World Energy Statistics* (2014).

[10] This lobbying probably had multiple aims. For example, by participating actively in the political process of carbon pricing, the oil and gas companies might be able to keep the carbon price from being too much higher than they would like, or by sorting it out sooner rather than later, they might be able to reduce uncertainty around long run demand for their product. It may also have been to improve the public image of these companies. All that is argued here is that stealing market share from coal could be one of the reasons for this kind of lobbying.

[11] For example, Nicholas Stern's response to the Paris Agreement included: '... businesses have been strongly represented at the Paris climate change summit and have played an important role in urging governments to achieve a strong agreement.' (New Climate Economy, newclimateeconomy.net, accessed on 29 Jan 2016.)

[12] Barrett (1992) details other instances of this kind of behaviour. For example, in response to concerns over the environmental impact of phosphates, the German firm Henkel invested in a phosphate-free detergent, lobbied for controls and gained market share in France and Germany in the 1980s. More generally, this process need not be limited to environmental regulation.

firm to choose to go green and lobby for strong environmental protection, so that it gains market share in the new regulated market, while the other keeps the old technology and opposes environmental regulation. The lobbying results in the equilibrium emissions tax being distorted above the Pigouvian level, and increasingly so as the government becomes more open to lobbying. The key result concerns the interaction between the political process and firms' green investment choices: there are situations where it is only because a firm can lobby, and therefore secure strong environmental protection, that it will see it as worthwhile to go green. At the same time, it is only because of a firm's political support that the government can take environmental action. Lobbying can therefore induce a transition to a greener economy.

This is the key result of the paper, but I go on to make five further points. First, for other regions of the parameter space (for example, when environmental damage is higher, or green investment costs lower), both firms choose to go green in equilibrium instead of just one. Here, although no lobbying conflict is observed over market share between the firms, the threat of loss of market share if a firm doesn't go green, intensified by lobbying, helps to sustain the equilibrium. Second, the welfare implications of these two types of lobbying-induced transitions to a greener economy are characterised, and I show that if lobbying induces a transition then it must also be welfare improving. Third, the model can be generalised to the case of n firms and variants of all the key results developed in the two firm case continue to hold, though now with coalitions of green and brown firms. The two firm model is therefore appropriate for examining situations with more than two firms, so the bulk of the paper focuses on this simpler set up. Fourth, the results are robust to various different product market assumptions. However, the extent to which lobbying makes the green investment more attractive to firms falls as demand becomes more elastic, because the market share effect is partially offset by the total market shrinking. Fifth, I discuss three reasons why lobbying-induced transitions to a greener economy are not always observed in practice.

The findings presented here are related to three broad strands of the economics literature. First, the paper sits within the wide literature on the political economy of environmental regulation. Stigler (1971) argued that across the economy regulation is ultimately largely the result of profit seeking by firms. Buchanan and Tullock (1975) pointed out that different environmental regulations often vary substantially in their distributional consequences, and suggested that firms will ensure the regulations that are chosen are those that most increase their profits. Barrett (1991) argues environmental regulation can give some firms competitive advantage, and that those firms will therefore attempt to get those regulations introduced. These early papers remain highly relevant today, though they lack a mechanism that explains how firms influence policy. Grossman and Helpman (1994) were the first to apply the common agency model of Bernheim and Whinston (1986) to lobbying, an approach that has now become standard.[13] Aidt (1998) and Fredriksson (1997) first applied it to environmental policy making, showing that an environmental lobby group can counter the influence of a polluters' lobby group and thereby bring about environmental protection. This remains an active and productive area of research: Damania (2001) shows that polluting firms can use dirty investments as a commitment device to aid their lobbying efforts; Eliste and Fredriksson (2002) look at the relationship between trade and environmental regulation when firms can lobby; Wilson and Damania (2005) explore the environmental impact of corruption at different levels of government; MacKenzie and Ohndorf (2012) show that lobbying considerations may, counterintuitively, make non-revenue raising environmental regulation the most preferred option for governments; Habla and Winkler (2013) show how national lobbying can play an important role in international environmental agreements. A feature common to all

[13]Lobbying can alternatively be thought of as a process of information transmission, and therefore an application of Crawford and Sobel (1982)'s model of strategic information transmission. Which of the two types of lobbying takes place in reality is context dependent (see Grossman and Helpman (2001) for a discussion). This paper focuses on buying influence.

these papers is that polluting firms will always lobby against environmental protection: for the externality to be adequately controlled, a lobby group with environmental preferences is needed. The model presented here, therefore, offers a complementary explanation of the political processes behind environmental regulation, by showing how environmental protection can sometimes be achieved even in the absence of a lobby group that cares about the environment.

The second strand of literature this paper relates to is the Porter Hypothesis (the idea that firms often gain rather than lose from environmental regulation). The model gives rise to a version of the Porter Hypothesis without relaxing any of the optimising assumptions of standard economic theory.[14] Hence it suggests a new mechanism that can give rise to this familiar result.

Third, this model also shares various features with those in the literature on competitive R&D and endogenous technical change. In the competitive R&D literature,[15] firms undertake R&D in an imperfectly competitive market because doing so brings them a competitive advantage, usually lower relative costs, allowing them to gain market share. The approach taken here can be thought of as an extension of this literature by modelling two sequential investment choices. First, a standard R&D investment (in clean technology) that impacts firms' relative costs; second, a political investment (in a high emissions tax) that is highly complementary to the R&D. Looked at in this way, it is the complementarity of the investments that means that when offered together they will be undertaken, whereas in isolation they may not. Finally, this paper is relevant to the current literature on endogenous technical change.[16] For example, Acemoglu et al. (2016) present and estimate a dynamic model in

[14]Porter and Linde (1995) give the original statement of the argument, which holds that '$10 bills are waiting to be picked up', that is, in reality firms are not profit maximising. Other explanations consistent with optimising behaviour are based on market power, asymmetric information and R&D spillovers (see Ambec et al. (2013)).

[15]See, for example, Reinganum (1983).

[16]See, among others, Acemoglu et al. (2012) and Aghion et al. (2016).

which formerly polluting producers choose between investments in clean or dirty production methods. In the absence of significant R&D subsidies, very high carbon taxes are needed for the transition to clean technologies. The present paper can be seen as complementing this literature, by offering one explanation for how such taxes can be politically achieved.

The remainder of this paper is organised as follows. In Section 2 the baseline model is presented. Section 3 contains the key results: equilibria are characterised and discussed. In Section 4 examines the welfare consesquences of the results. In Section 5 the model is generalised to n firms, and robustness is considered. Section 6 concludes with a discussion of three potential reasons why the predictions of the model don't always hold in reality.

2 The baseline model

The baseline model contains two firms and a single government who play a three stage game. First the firms choose whether or not to invest in costly, but emissions-free production technology. Then in the second stage the government sets an emissions tax, which the firms attempt to influence through lobbying. In the third stage firms produce and earn profits.

2.1 The economy

There are two firms, 1 and 2. Each firm $i \in \{1, 2\}$ produces a quantity x_i of a single homogenous good. They each face an initial choice over their production technology $f_i \in \{G, B\}$. They can choose the clean, or 'green', production technology $f_i = G$, in which case production by the firm results in no emissions. Alternatively they can choose the dirty, or 'brown', production technology $f_i = B$, in which case production is polluting and each unit of output results in a unit of emissions. Choosing $f_i = G$ requires the firm to spend $s > 0$ on investment in the new green technology. This could represent the building of a new factory or power station, some kind of R&D, or any other step to reduce emissions. Choosing $f_i = B$

is free, reflecting the idea that the current technology is polluting and can continue to be used with no new investment required. Note that the cost structure of the firms is otherwise unaffected by this investment choice; the only purpose of investing in clean technology is to reduce emissions to zero.[17] Each firm has emissions per unit of output e_i given by:

$$e_i(f_i) = \begin{cases} 0 & \text{if } f_i = G \\ 1 & \text{if } f_i = B \end{cases} \tag{1}$$

The firms face an emissions tax τ, resulting in a tax bill of $\tau e_i x_i$. From the firm's point of view, the green investment can be thought of simply as a way to switch off emissions tax τ.[18]

The firms have identical and strictly convex production costs. Specifically, assume they have costs given by $\frac{1}{2}kx_i^2$, where for analytical simplicity I normalise k to $\frac{1}{2}$.[19] Given any pair of technology choices by the two firms $f \in \{G, B\}^2$ and emissions tax τ, each firm i chooses output x_i to maximise profits from production, given by:

$$\pi_i(x_i \mid \tau, f) = px_i - \frac{1}{4}x_i^2 - \tau e_i x_i \tag{2}$$

[17] In reality investment in new green technology does often have an impact on marginal cost, pushing it either up or down, and this can be a major investment incentive. Abstracting away from this allows the paper to isolate a separate reason for green investments.

[18] Given the set up of this model, the first best outcome would involve the government using an investment subsidy to reach the efficient outcome. The assumption here is that such a subsidy is not available, reflecting the fact that investment subsidies are rarely used to solve environmental problems - subsidies, taxes or quotas on outputs or inputs (together with performance standards) tend to be the instruments used in practice - even when the policy goal is to encourage investment.

[19] The only assumption here important for the results is that costs must be strictly convex, of which quadratic is the simplest, and $\sum k_i = 1$ gives the simplest analytical solutions. If firms have non-convex costs then the government would face no interesting tradeoffs following $f = (G, B)$; it would always simply set the tax to push the brown firm entirely out of the market.

The market structure is as follows. Demand is linear and given by:

$$x = 1 - bp \tag{3}$$

where $x = x_1 + x_2$, and $b \geq 0$. Many of the proofs and examples will begin with the case where $b = 0$, that is where demand is inelastic and equal to 1. Fixing the total size of the market in this way generates simple analytical solutions that are useful for understanding how competition for market share drives the key results. This low elasticity benchmark is then contrasted with a high elasticity case.

The second product market assumption is that firms are price takers. This ensures there is no strategic behaviour at the production stage, and so allows the model to focus cleanly on the strategic interactions between the firms at the investment and lobbying stages.[20] The results are robust to this assumption: in Appendix A.4 the model is resolved for Cournot competition, giving qualitatively equivalent but analytically less tractable results. The price taking assumption also fits naturally with the n firm generalisation of the model presented in Section 5.1.

2.2 The political process

After the investment choices have been made, the emissions tax τ is set by a government with two aims: to maximise social welfare and to collect political donations from lobbyists. Social welfare W is the utility of a representative citizen plus the impact of environmental damage. Demand curve (3) implies that the representative citizen has quasilinear utility of

[20] Any assumption other than price taking will lead to production market failures, and the government will therefore use the emissions tax partly as an instrument of competition policy, which would not be a desirable feature of the model.

the form $u(x,y) = \frac{1}{b}(x - \frac{1}{2}x^2) + y$, where y is wealth (or consumption of a numeraire good).[21] Wealth y is equal to total profits $(\pi_1 + \pi_2)$, minus expenditure on x (px), plus emissions tax revenue $(\tau \sum e_i x_i)$. Environmental damage is given by $\eta \sum e_i x_i$, where $\eta \geq 0$ gives marginal environmental damage.[22] Combining the above gives welfare:[23]

$$W(x, \tau, f) = \frac{1}{b}(x - \frac{1}{2}x^2) + \sum \pi_i - px + \tau \sum e_i x_i - \eta \sum e_i x_i \tag{4}$$

The government also cares about political contributions c_1 and c_2 from the two firms, who lobby the government over the level of τ. Bernheim and Whinston (1986) give an analysis of games of common agency, which Grossman and Helpman (1994) apply to lobbying, and I follow this now standard approach here. The problem is one of two firms (the principals) attempting to influence the actions of the government (the common agent). They do this through lobbying, which is represented by a contribution function $C_i(\tau)$ specifying how much firm i will pay as a political donation to the government for each level of τ. The government therefore seeks to maximise $W(\tau) + \lambda(C_1(\tau) + C_2(\tau))$, where $\lambda \geq 0$ determines the relative weight the government gives to political contributions compared to social welfare. λ is the openness to lobbying of the government: $\lambda = 0$ represents an incorruptible government only interested in social welfare; as λ rises the government and its policies become increasingly

[21] The above utility function is not defined for $b = 0$. A complete specification of the utility function for all $b \geq 0$ implied by demand equation (3) is: $u(x,y) = \begin{cases} \frac{1}{b}(x - \frac{1}{2}x^2) + y & \text{if } b > 0 \\ v(x) + y & \text{if } b = 0 \end{cases}$, where $v(x) = \begin{cases} 0 & \text{if } x = 1 \\ -\infty & \text{if } x \neq 1 \end{cases}$. This discontinuity in the utility function does not affect any real quantities in the economy, even for $b = 0$, because demand is continuous at $b = 0$. It matters only when calculating welfares in Section 4. A final assumption when inferring this quasilinear utility function from linear demand is that the consumer always has enough wealth to choose her ideal level of x, that is we have an interior solution to her utility maximisation problem.

[22] Linear environmental damage is likely to be a realistic assumption only for emissions within a limited range: most environmental damage functions are ultimately convex (see Ackerman et al. (2009) for a discussion). However the qualitative nature of the results would be the same in either case, so the simplest specification is used here.

[23] When $b = 0$ the utility component of this welfare equation is given by relevant part of footnote 21.

‘for sale’. This paper focuses on the case where λ is close to but not quite equal to 0, which (hopefully) represents many modern economies.[24]

2.3 The overall game

Combining the above components, the model can be summarised as a three stage game:

Stage 1: Investment

- Each firm i simultaneously chooses production technology $f_i \in \{G, B\}$.

Stage 2: Lobbying

- Each firm i simultaneously chooses contribution function $C_i(\tau)$,
- The government then chooses emissions tax $\tau \in \mathbb{R}$.

Stage 3: Production

- Each firm i simultaneously chooses output $x_i \in \mathbb{R}_{\geq 0}$.
- Prices are taken as given, the market clears, and each firm i earns profits π_i.

Payoffs at the end of the game for government and firms are

$$U_{gov} = W + \lambda(c_1 + c_2) \tag{5}$$

$$U_i = \pi_i - c_i - s(1 - e_i) \qquad \text{for each } i \in \{1, 2\} \tag{6}$$

[24]Goldberg and Maggi (1999), among many others, estimate Grossman and Helpman’s trade protection model. They estimate, for the US, openness to lobbying λ to be positive but small, around $\lambda = 0.02$.

3 Equilibria

The relevant solution concept for a sequential game of this kind is the subgame perfect Nash equilibrium.[25] It is found by backward induction, starting at stage 3.

Stage 3: Production

Taking as given the investment choice f and emissions tax τ chosen earlier in the game, each firm maximises profits (2) and prices adjust so that supply equals demand (3). This gives, for each firm $i \in \{1, 2\}$, equilibrium output $x_i^*(\tau, f)$, price $p^*(\tau, f)$ and profits $\pi_i^*(\tau, f)$ (13) as a function of choices made earlier in the game. Appendix A.1 contains a complete summary of the analytical solutions to this and subsequent stages of the game.

Given the symmetry of the two firms, there are three different technology choices to consider: $f \in \{(G, G), (G, B), (B, B)\}$.[26] The production subgame following $f = (G, G)$ is the simplest. Both firms have made the clean technology investment, so produce no emissions: $e_i = 0$. The emissions tax therefore has no effect, and output is high and split evenly between the two firms.

Next, consider the (G, B) investment, where one firm goes green by investing in the clean technology and the other stays brown by keeping the old technology. Denote, with some abuse of notation, outcomes for the firm that chose $f_i = G$ with a subscript G, and outcomes for the firm that chose $f_i = B$ with a subscript B. The green firm causes no emissions, $e_G = 0$, but the brown firm continues to pollute, $e_B = 1$, and so must pay emissions tax τ for every unit of production. This gives interior[27] equilibrium output, price

[25] Throughout the paper, I restrict my attention to pure strategies only.

[26] Because the two firms are ex ante identical, the (G, B) and (B, G) outcomes are equivalent.

[27] The solution to the game will be an interior equilibrium if, given the tax rate, each firm chooses non-negative production. We will see a corner solution following (G, B) if the tax is pushed up to the point where the brown firm ceases production. Throughout the main text I focus on the interior solution, with the corner solution given in Appendix A.5.

and profits, which depend on the emissions tax τ as follows:

$$\frac{d}{d\tau}x_G^*(\tau,(G,B)) > 0, \qquad \frac{d}{d\tau}x_B^*(\tau,(G,B)) < 0, \qquad \frac{d}{d\tau}p^*(\tau,(G,B)) > 0, \tag{7}$$

$$\frac{d}{d\tau}\pi_G^*(\tau,(G,B)) > 0, \qquad \frac{d}{d\tau}\pi_B^*(\tau,(G,B)) < 0, \qquad \frac{d}{d\tau}\sum \pi_i^*(\tau,(G,B)) > 0 \tag{8}$$

Increasing the emissions tax τ has two effects on the goods market: shifting market share from the brown firm to the green firm, and increasing the price. The green firm would like a high emissions tax τ since it will gain both market share and the environmental rents contained in the price rise. These gains to the green firm can be thought of as a kind of first mover advantage. Similarly the brown firm would like a low τ since this lowers its loss of market share, and limits the fall in its net of tax price. The sum of profits is increasing in τ since production is shifted to the firm receiving a higher net of tax price. This means that the green firm benefits more from an emissions tax increase than the brown firm loses. This result is an important feature of this production subgame, and one that will underpin many of the final results, so is summarised in the following lemma:

Lemma 1. *Following investment $f = (G,B)$, total profits are increasing in the emissions tax τ, $\frac{d}{d\tau}\sum \pi_i^*(\tau,(G,B)) > 0$. That is, the green firm gains more from increasing τ than the brown firm loses.*

Proof: see Appendix A.2.

Finally, consider $f = (B,B)$. Both firms keep the old technology, so both pay emissions tax τ. The firms produce equal output $x_B^*(\tau,(B,B))$ and earn profits $\pi_B^*(\tau,(B,B))$. For any $b > 0$, both output and profits decrease as the government increases the emissions tax, which shrinks total output in the usual way. For $b = 0$, demand is inelastic, so total output is fixed, and the tax has no effect on each firm's output or profits.

Stage 2: Lobbying

In this stage, each firm seeks to influence the emissions tax, while the government balances its two objectives of maximising social welfare and collecting political contributions from each firm. Following the common agency approach of Bernheim and Whinston (1986), this situation is characterised by the decision of a single agent (the government) affecting two principals (the firms). Each firm announces a contribution function $C_i(\tau)$ which specifies how much it will donate to the government for any level of τ that might be chosen.[28] Each firm designs its contribution function $C_i(\tau)$ to encourage the government to distort the tax in the direction that increases its own profits. The government observes the contribution functions and chooses τ to maximise $W(\tau) + \lambda \sum C_i(\tau)$.

An outcome of this lobbying subgame will be an equilibrium if the government cannot choose a better tax rate given the contribution functions it faces, and if each firm cannot offer a contribution function that gives it a better payoff, given the function offered by the other firm. More formally, given any f, a subgame perfect equilibrium of this lobbying game is a tax rate τ^*, and pair of contribution functions $(C_1^*(\tau), C_2^*(\tau))$ such that:

(i) For the government τ^* is a best response to $(C_1^*(\tau), C_2^*(\tau))$. That is, $\tau^* \in \arg\max_{\tau \in \mathbb{R}} W(\tau) + \lambda(C_1^*(\tau) + C_2^*(\tau))$.

(ii) For each firm $i \in \{1, 2\}$, $C_i^*(\tau)$ is a best response to $C_j^*(\tau)$. That is, there is no other τ' and $C_i'(\tau)$ such that τ' is a best response to $(C_i'(\tau), C_j^*(\tau))$ and $\pi_i(\tau', f) - C_i'(\tau') > \pi_i(\tau^*, f) - C_i^*(\tau^*)$.

With no restrictions on $C_i(\cdot)$ this game has many equilibria. Following the now standard approach in Grossman and Helpman (1994), equilibria are limited to those where firms offer contribution functions of the form $C_i(\tau) = \pi_i(\tau) + a_i$, where a_i is a constant. Bernheim

[28] The contribution function is formally equivalent to the kind of standard incentive contract offered in the context of performance related pay. In reality lobbyists do not normally offer explicit contracts in such a transparent way, but an implicit contract of this type underpins their use of political contributions to secure favourable policies (see Grossman and Helpman (2001) for further discussion).

and Whinston (1986) term such strategies 'truthful strategies' and show that the resulting equilibria are focal among the set of all possible equilibria, since only they are stable to non-binding communication.

I can now find the equilibria of the lobbying subgame following each choice of $f \in \{(G,G),(G,B),(B,B)\}$. First, consider the game following $f = (G,G)$. As mentioned above, the production outcomes (13) are independent of an emissions tax in this case, so no firm will spend resources lobbying and the government can choose any tax, which has no impact on welfare. The equilibrium outcomes are therefore $\tau \in \mathbb{R}$, $c_G^*(G,G) = 0$.

Now consider the lobbying subgame that follows $f = (G,B)$. Substituting profit functions (13) into truthful contribution functions $C_i(\tau) = \pi_i^*(\tau,(G,B)) + a_i$, equilibrium condition (i) gives the equilibrium emissions tax $\tau^*(G,B)$. Condition (ii) gives the level of contribution $c_i^* = C_i^*(\tau^*)$ from each firm needed to maintain this as an equilibrium. The equilibrium tax rate and two of its properties are:

$$\tau^*(G,B) = \frac{8\eta + b(6\eta + b\eta - \lambda)}{8(1-\lambda) + b(6 - 4\lambda - b\lambda + b)}, \quad \tau^*(G,B)|_{\lambda=0} = \eta, \quad \frac{d}{d\lambda}\tau^*(G,B) > 0 \tag{9}$$

The contributions $c_i^*(G,B)$ are given by equation (14) in Appendix A.1. To understand this result, consider initially the case when openness to lobbying $\lambda = 0$. The government maximises social welfare and ignores potential lobbying, giving outcome $\tau^* = \eta$ and $c_i^* = 0$ for each i; we see Pigouvian taxation and no political contributions.[29] As λ increases, and so the government becomes more open to lobbying, τ^* rises and so the tax rate increasingly exceeds the Pigouvian level. This result is a consequence of Lemma 1 (that $\sum \pi_i$ is increasing in τ following $f = (G,B)$). The green firm would like a higher τ and so chooses a contribution function that rewards the government for increasing τ, and the brown firm will likewise reward the government for reducing τ. But by Lemma 1, the green firm gains more than the

[29] We would expect the Pigouvian tax because there is one market failure (environmental damage) and an instrument (the emissions tax) which can implement the first best solution given the chosen technology f.

brown firm loses from an increase in τ, so the green firm lobbies harder than the brown. That is, the sum of the contributions will be increasing in τ and so in equilibrium the lobbying distorts it upwards: the more the government is open to lobbying the more the green firm gets its way. This result can be generalised in the following Lemma:

Lemma 2. *Lobbying will distort emissions tax τ above the Pigouvian level if and only if total industry profits are increasing in the emissions tax, that is $\tau^*(f) > \eta \iff \frac{d}{d\tau}\sum \pi_i^*(\tau, f) > 0$.*

This result is very general since it holds for any f, any number of firms and any market structure. A proof of Lemma 2 follows almost immediately from contribution functions being truthful, so that $\sum C_i(\tau) = \sum \pi_i^*(\tau) + a$, where a is a constant. If the sum of profits is increasing in τ then the sum of contributions will be too, so including it in the government's objective function (condition (i) above) will therefore increase the equilibrium tax above the level optimal for social welfare alone. Lemma 2 also identifies when lobbying would distort the emissions tax below the Pigouvian level: in any situation where the market structure is such that $\sum \pi_i^*(\tau)$ is decreasing in τ.

The interior equilibrium contributions c_G^* and c_B^* are strictly positive for $\lambda > 0$, and other than this depend ambiguously on various parameters. This is because as λ rises, though the firms have more influence and therefore are prepared to pay more to get a better outcome, the government also needs less 'compensation' from firms for losses in social welfare resulting from distortions in τ. In other words distorting the tax becomes cheaper. These two effects tend to respectively increase and decrease c_i^* as λ rises, hence overall the effect is ambiguous.

Now consider the lobbying subgame following $f = (B, B)$. Following the same procedure as above, equilibrium condition (i) gives the equilibrium emissions tax $\tau^*(B, B)$ and condition

(ii) gives the level of contributions. The tax rate is:

$$\tau^*(B,B) = \frac{4\eta + b\eta - \lambda}{4 + b - b\lambda}, \quad \tau^*(G,B)|_{\lambda=0} = \eta, \quad \frac{d}{d\lambda}\tau^*(G,B) \leq 0 \tag{10}$$

and the contributions $c_B^*(B,B)$ are given in equation (14). As in the previous case, in the absence of lobbying we see the government implement a Pigouvian tax. However, now the firms gain from a lower tax, so as the government becomes more open to lobbying, the firms push the tax below the Pigouvian level: $\frac{d}{d\lambda}\tau^*(G,B) \leq 0$.

Stage 1: Investment

Now consider the initial subgame, where each firm decides whether to invest in the new green technology or keep the old brown technology, given their knowledge of how the game will go following each decision.

Substituting profits (13) at tax rate and political contributions (14) into firm payoffs (6), gives the reduced form payoffs for each firm following each investment outcome. The payoffs are summarised in Table 1, and a full analytical description given in Appendix A.1.

		Firm 2	
		G	B
Firm 1	G	$\pi_G^*(G,G) - s$ $\pi_G^*(G,G) - s$	$\pi_G^*(G,B) - c_G^*(G,B) - s$ $\pi_B^*(G,B) - c_B^*(G,B)$
	B	$\pi_B^*(G,B) - c_B^*(G,B)$ $\pi_G^*(G,B) - c_G^*(G,B) - s$	$\pi_B^*(B,B) - c_B^*(B,B)$ $\pi_B^*(B,B) - c_B^*(B,B)$

Table 1: Payoff matrix for the investment subgame. See Appendix A.1 for the full analytical results.

The Nash equilibria of this reduced form game, along with quantities τ^* and $\{c_i^*, x_i^*\}_{i\in\{G,B\}}$, are the subgame perfect Nash equilibria of the whole game. An intuitive summary of the possible equilibria is as follows. If firms choose (G, G), then profits are high and symmetric, no political contributions are made, and both firms pay green investment cost s. If firms choose (B, B) then profits are low and symmetric, both firms lobby the emissions tax below the Pigouvian level and both firms avoid the investment cost s. If firms choose (G, B), then the green firm gains profits from increased market share and higher prices $(\pi^*_G(G, B) > \pi^*_B(B, B))$, it must pay a political contribution $(c^*_G(G, B))$ to push the tax up and stop its opponent firm from pushing it down, and it must pay green investment cost s. The brown firm loses profits from loss of market share and lower net of tax prices $(\pi^*_B(G, B) < \pi^*_G(G, G))$, it must pay a political contribution $(c^*_B(G, B))$ to keep the emissions tax from being even higher, but it avoids investment cost s.

The equilibria of the investment subgame can now be found. The focus is on two equilibria: (G, B) and then (G, G).

3.1 The (G, B) equilibrium

The asymmetric equilibrium (G, B) is of particular interest,[30] since this features political conflict between the firms. Using the payoff matrix in Table 1, the no-deviation conditions for the two firms are:

$$s \leq \pi^*_G(G, B) - \pi^*_B(B, B) - c^*_G(G, B) + c^*_B(B, B) \tag{11}$$

$$s \geq \pi^*_G(G, G) - \pi^*_B(G, B) + c^*_B(G, B) \tag{12}$$

The (η, λ, b, s) parameter space that gives rise to the (G, B) equilibrium can now be characterised. For any (η, λ, b), let S be the set of values of investment cost s that satisfy no-deviation conditions (11) and (12). That is, let $S = \{s \in \mathbb{R} : \text{inequalities (11) and (12) hold}\}$. Denote by $|S|$ the absolute size of S, so that it is the range of investment costs that leads to

[30]Given the symmetry of the firms, if (G, B) is an equilibrium then (B, G) will also be an equilibrium.

(G, B) in equilibrium, and is a function of the remaining parameters, (λ, η, b). The following proposition gives the first key results.

Proposition 1 (Existence of (G, B) equilibrium)**.** *For η sufficiently large, and b sufficiently close to 0:*

(i) The (G, B) equilibrium exists, that is S is non-empty.

(ii) The (G, B) equilibrium becomes more likely as the government becomes more open to lobbying, that is $\frac{d}{d\lambda}|S| > 0$.

Proof: see Appendix A.2.

Proposition 1(i) confirms the intuition outlined in the Introduction that market share considerations can indeed lead to one firm going green and the other staying brown. That such an asymmetric equilibrium exists is not a foregone conclusion in a model like this, and is therefore of interest. The setup of the model is symmetric in that the two firms are ex ante identical, and yet in equilibrium they behave differently.[31] Hence a firm needs no initial technological advantage (or head start of any other kind) over their rival to find it profitable to go green and lobby for increased market share.

Proposition 1(ii) shows that as λ rises, (G, B) becomes more likely, in the sense that a greater range of parameters support this equilibrium. The intuition for this is that the ability of firms to lobby makes green investment more attractive. The green firm is willing to lobby harder than the brown firm for the emissions tax to rise, so τ is increasing in λ. This extra lobbying results in an increase in profits that outweighs the increased lobbying bill, so the green investment becomes more attractive. Hence, the firm will be willing to make the green investment at higher costs s, tending to increase $|S|$. The brown firm's behaviour

[31] The intuition for this is that the gain in market share from going green is decreasing in the number of firms going green. Hence it may be profitable for a firm to choose G if the other has chosen B, but not if the other has chosen G. Hence (G, B) is an equilibrium.

will be impacted by rising λ too, since staying brown involves an ever larger loss of market share, tending to decrease $|S|$. However, this loss is smaller than the green firm's gain, so the overall effect is an increase in $|S|$. Put another way, we find that corruption can increase environmental protection.

These same results can be understood graphically, as shown in Figure 1a. The Figure shows the regions of the (λ, s) parameter space that give rise to different investment choices in equilibrium (holding η and b fixed). The solid line is the indifference curve of a firm whose competitor has stayed brown (condition (11)). At points below the line, green investment costs are low enough that it is profitable to go green, above the line it is better to stay brown. The dashed line is the indifference curve of a firm whose competitor has gone green (condition (12)), with optimal technology choices likewise above and below the line. As expected, when green investment cost s is low, both firms prefer to go green since this requires only a small investment and avoids market share being stolen by their competitor. As s rises one firm will at some point find it profitable to stay brown, and eventually s will be so prohibitively high both firms will prefer to stay brown.

Proposition 1(i) is demonstrated by the fact that the indifference curves lie one above the other in the order they do: $|S|$ is the vertical distance between the two lines. Proposition 1(ii) is demonstrated by the fact that the vertical space between the lines grows with λ.

These results indicate that there are situations where is it only because of lobbying that the economy ends up in the (G, B) equilibrium. This insight can be formalised by defining a new set. For any (η, λ, b), let $S'(\lambda) = S(\lambda) \setminus S(0)$. That is, $S'(\lambda)$ is the set of investment costs that result in (G, B) when openness to lobbying is λ, but would not have given (G, B) if λ were 0. It captures those situations were the outcome is (G, B) only because firms can lobby. The following results can now be given.

Proposition 2 (Lobbying-induced transitions to (G, B))**.** *For η sufficiently large and b sufficiently close to 0, there exist investment costs s such that:*

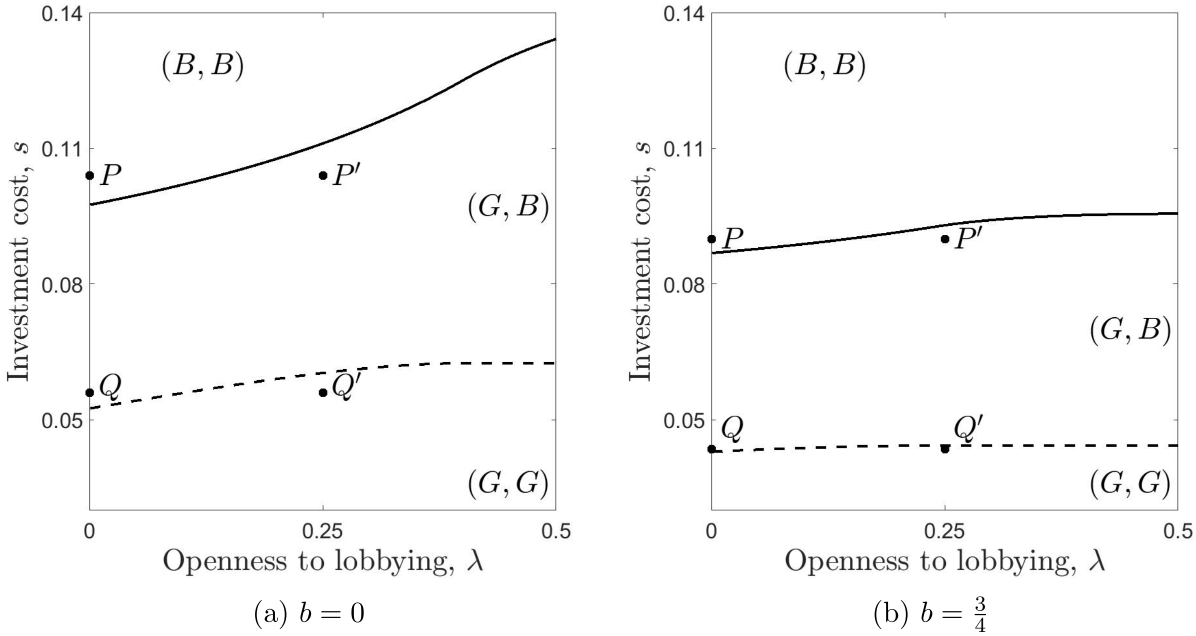

Figure 1: Equilibrium investment outcomes as a function of the parameter space (λ, s), for $\eta = 0.3$. The solid line shows the indifference curve of a firm whose competitor has played B, the dashed line likewise if the competitor has played G. Panel 1a is plotted for $b = 0$ and has an interior solution for $\lambda \leq 0.4$. Panel 1b is plotted for $b = 0.75$ and has an interior solution for $\lambda \leq 0.24$.

(i) It is only because of lobbying that the economy is in equilibrium at (G, B) *and not* (B, B)*, that is* S' *is non-empty.*

(ii) A lobbying-induced transition from (B, B) *to* (G, B) *becomes more likely as the government becomes more open to lobbying, that is* $\frac{d}{d\lambda}|S'| > 0$.

Proof: see Appendix A.2.

The graphical representation of this Proposition in Figure 1a would be to draw a horizontal line out from the $\lambda = 0$ point on the solid indifference curve. The wedge between this line and the curve represents the set of investment costs for which the economy is tipped into (G, B) only because of the ability of firms to lobby. Proposition 2(i) is demonstrated by such a wedge existing, and Proposition 2(ii) is demonstrated by the size of the wedge increasing with λ.

In order to summarise these results and illustrate the importance of lobbying, consider first an economy where the government is not at all open to lobbying, that is $\lambda = 0$, and suppose green investment cost s is such that the economy is at point P in Figure 1a. A firm thinking of going green knows that if it were to do so it would gain market share and increase its profits due to the introduction of an emissions tax. But it also knows this emissions tax ($\tau^* = \eta$) will not be high enough to compensate it for the large green investment cost s, hence the equilibrium is for all firms to stay brown and no environmental protection is achieved. If, however, the government were to be somewhat open to lobbying, say $\lambda = \frac{1}{4}$, with the same green investment cost the economy would be at point P'. Now the firm considering going green would reason that, if it were to invest in the green technology, it could use the political process to push up the emissions tax (to $\tau^* = \frac{4}{3}\eta$), and this would be sufficient to cover the investment cost plus the political contribution needed to push up the tax. The other firm would lobby too, in order to stop the emissions tax from being even higher, but it would prefer to lose some market share rather than pay the green investment cost itself and so will stay brown. Hence, it is only the ability of a firm to influence the political process and secure a high emissions tax that enables it to invest in the green technology, and it is only because of the firm's political support that the government takes strong action on the environment. The welfare implications of this are given in Proposition 4 below.

3.2 The (G, G) equilibrium

So far I have focused on the asymmetric (G, B) equilibrium, since it involves firm conflict in the lobbying subgame. However the model may also help describe situations where all firms make the green investment together and no market share ends up being fought over, that is (G, G) is the equilibrium outcome. In this case, it is the threat of having its market share stolen that will make each firm more likely to go green. Using a similar approach to Section 3.1, the properties of this equilibrium can be characterised. Let T be the set of investment costs that lead to (G, G) in equilibrium. That is, for any (η, λ, b), let $T = \{s \in \mathbb{R}$: inequality (12) holds$\}$. Unlike in the previous case, the existence of the (G, G) equilibrium should not itself be a surprising result: given small enough green investment costs, each firm will prefer to make the small green investment in order to avoid emissions tax τ. I therefore move straight to the question of whether lobbying makes the (G, G) outcome more likely, in the sense that it expands the parameter space that supports this equilibrium.

For any (η, λ, b), let $T'(\lambda) = T(\lambda) \setminus T(0)$. That is, let $T'(\lambda)$ be the set of investment costs that result in (G, G) when openness to lobbying is λ, but would not have given (G, G) if λ were 0. T captures those situations where (G, G) is the outcome only because firms can lobby. The following results can now be given.

Proposition 3 (Lobbying-induced transitions to (G, G))**.** *For any η, and b sufficiently close to 0, there exist investments costs s such that:*

(i) It is only because of lobbying that the economy is in equilibrium at (G, G), that is T' is non-empty.

(ii) A lobbying-induced transition from (G, B) to (G, G) becomes more likely as the government becomes more open to lobbying, that is $\frac{d}{d\lambda}|T'| > 0$.

Proof: see Appendix A.2.

Proposition 3 shows that there are situations where it is only because firms can lobby that the economy ends up in (G, G) rather than (G, B), and that these situations become more likely as the government becomes more open to lobbying. The intuition for this is as follows. The more firms can lobby, the further the tax will be distorted above the Pigouvian level following (G, B), and hence the more market share a firm will lose if it stays brown while its rival goes green. The threat of an increasingly damaging emissions tax means firms become increasingly willing to go green as λ rises. This point is made graphically in Figure 1a. An economy with no lobbying is shown at point Q, and is in equilibrium at (G, B). An otherwise identical economy except that the government is more open to lobbying is shown at point Q', and is in equilibrium at (G, G). This result formalises the idea that, even when all firms in an industry go green together in a seemingly 'cooperative' way, it may well be that it is only the threat of losing substantial market share that keeps each individual firm from deviating. The welfare consequences of this are given in Proposition 5 below.

3.3 The high elasticity case

The above results are derived analytically and shown graphically in Figure 1a using the case where $b = 0$. Since all the relevant expressions are continuous in b at $b = 0$ (see Appendix A.2), the results continue to hold analytically for b close to 0. The length of the relevant analytical expressions when $b \neq 0$ (see Appendix A.1) makes closed form versions of the above and subsequent results more difficult to work with, but I argue here that all the results do continue to hold as b rises, though for increasingly narrow parameter spaces.

First, note that Lemma 1 holds for all b, but that $\frac{d}{db}\frac{d}{d\tau}\sum \pi_i^*(\tau, (G, B)) < 0$. Hence, at higher b the tax does still increase total profits, but by a smaller amount. Intuitively, when the total size of the market is very price sensitive, the green firm has less to gain from a price rise because the corresponding fall in quantity is large: the market stealing effect is somewhat offset by a market size effect. This means the equilibrium tax $\tau^*(G, B))$ falls in b, and approaches the Pigouvian level. Hence the ability of firms to lobby becomes less important as b rises.

This point in made graphically in Figure 1b, which is plotted for $b = \frac{3}{4}$. The (G, B) equilibrium still exists and becomes more likely as λ rises (Proposition 1), though for a smaller parameter space than in the $b = 0$ case. Likewise, lobbying-induced transitions to (G, B) and to (G, G) exist and become more likely as λ rises (Propositions 2 and 3), though for a smaller parameter space than in the $b = 0$ case.

These results demonstrate that lobbying that supports environmental regulation is most likely to occur in industries where the demand elasticity is low. If it is too high, strong environmental protection shrinks the market too much, offsetting any firm's potential gain in market share and therefore making green investments less attractive.

4 Welfare

Section 3 showed that the ability of firms to lobby can cause the economy to end up in a greener equilibrium than in the absence of lobbying. In this section I ask whether these lobbying-induced transitions are welfare improving. In each case there are trade-offs between increased environmental protection on the one hand, and investment costs and distortions to the production profile of the economy as a result of lobbying on the other.

Using equilibrium outcomes (13) and taxes and contributions (14) in welfare equation (4), define an indirect welfare function $W(f)$ that depends only on technology profile f. Then define social preference $\succ$ over technology profiles $f \in \{G, B\}^2$ as follows: for any two technology profiles $f, f' \in \{G, B\}^2$, $f \succ f'$ if and only if $W(\cdot)$ minus any green investment costs is higher for f than f'.

4.1 The (G, B) equilibrium

It can now be asked when transitioning from (B, B) to (G, B), for example from P to P' in Figure 1a, is socially preferable. Using the above definitions, $(G, B) \succ (B, B)$ if and only if $W(G, B) - s > W(B, B)$. For any (η, λ, b), let $Y = \{s \in \mathbb{R} : (G, B) \succ (B, B)\}$. Y is the set of investment costs for which the greener (G, B) is socially preferred to the dirtier alternative (B, B). Recall that S' is the set of investment costs for which the economy transitions to (G, B) from (B, B). Hence, all such lobbying-induced transitions will be socially preferable if any economy in S' is also in Y, that is if $S' \subset Y$.

Proposition 4 (Welfare of lobbying-induced transitions to (G, B))**.** *For b sufficiently close to 0, any lobbying-induced transition from (B, B) to (G, B) is socially preferable, that is $S' \subset Y$.*

Proof: see Appendix A.2.

To understand this result, consider the social costs of moving from (B, B) to (G, B). In the (B, B) equilibrium, firms produce an equal share of output but they lobby the tax below the Pigouvian level, resulting in too much environmental damage. In the (G, B) equilibrium, lobbying distorts the tax above the Pigouvian level, which reduces environmental damage. But it also distorts the production profile of the economy, both by giving the green firm more than its efficient market share (convex cost functions making this socially undesirable) and also by shrinking total output below the optimal level (for $b > 0$).

Proposition 4 shows that if the green investment cost s is large enough to induce a transition from (B, B) to (G, B), then the net gain in welfare, from reduced environmental damage plus increased product market distortion, more than compensates for s. All such transitions are therefore socially preferable.

4.2 The (G, G) equilibrium

The same welfare analysis can be conducted on the transition from (G, B) to the greener (G, G) equilibrium. $(G, G) \succ (G, B)$ holds if and only if $W(G, G) - s > W(G, B)$. For any (η, λ, b), let $Z = \{s \in \mathbb{R} : (G, G) \succ (G, B)\}$. Recall T' is the set of investment costs for which lobbying induces the economy to be in (G, G) rather than (G, B). Hence any lobbying-induced transition will be socially preferable if all economies in T' are also in Z, that is if $T' \subset Z$.

Proposition 5 (Welfare of lobbying-induced transitions to (G, G))**.** *For b sufficiently close* *to 0, any lobbying-induced transition from (G, B) to (G, G) is socially preferable, that is $T' \subset Z$.*

Proof: see Appendix A.2.

This result is perhaps less surprising than the previous proposition. As outlined above, the (G, B) outcome features product market distortions, both in the firms' shares of production and total output. In contrast, there is no product market distortion in the (G, G) case, since both firms have clean production technologies and so output is shared evenly and at the socially optimal level. Moving from (G, B) to (G, G), therefore, reduces both environmental damage and product market distortions. Hence, if the investment cost is such that a lobbying-induced transition occurs, it will be more than compensated for by the above two welfare gains.

5 Extensions and robustness

5.1 Generalisation to n firms

In this section I generalise the model by allowing the number of firms to be any $n \in \mathbb{N}$. The results for the special case of $n = 2$ characterised in the previous sections are shown to qualitatively hold in the more general case. Let n_G be the number of firms that chose $f_i = G$ in stage 1. Solving the model in an analogous way to the $n = 2$ case in Section 3 gives equilibrium outcomes as a function of n_G at each stage. The details are given in Appendix A.3. For simplicity, I consider the $b = 0$ case.

Proposition 6 (n-firm equilibrium existence)**.** *For any η, λ sufficiently close to 0, and any $n \in \mathbb{N}$:*

(i) Any number of green firms can be supported as the unique equilibrium. That is, for all $n_G \in \{0, ..., n\}$ there exist regions of (η, λ, s) space such that $S(n_G)$ is non-empty.

(ii) The equilibrium number of green firms n_G^* decreases with the green investment cost s.

Proof: see Appendix A.2.

The results in the above proposition are demonstrated graphically in Figure 2, plotted with $n = 5$. Like Figure 1a, this shows which regions of the (λ, s) parameter space give rise to different n_G^* equilibria. Proposition 6(i) is demonstrated by each number of green firms $n_G \in \{1, ..., n\}$ being supported by some different green investment s for small λ. Proposition 6(ii) is demonstrated by the number of firms going green in equilibrium falling as the green investment becomes more expensive, for intuitively straightforward reasons. Analogous comparative statics to those given in many of the Propositions 1-5 can also be derived in the n-firm case, and some are illustrated graphically in Figure 2.

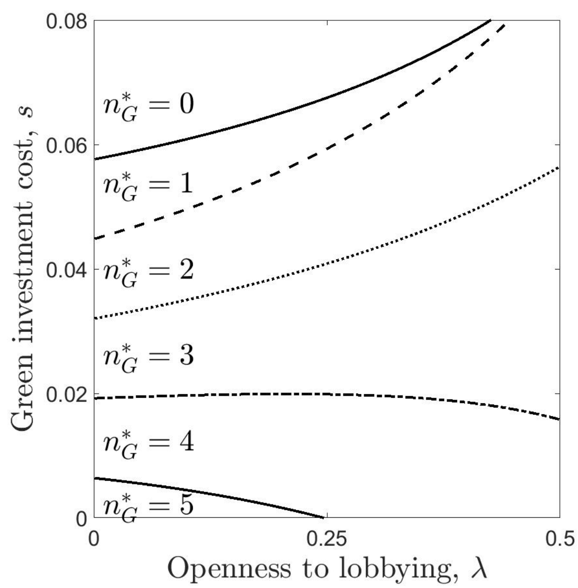

Figure 2: Equilibrium outcomes as a function of the parameter space (λ, s), plotted for $n = 5$ and with $\eta = 0.2$ and $b = 0$.

The n-firm case more closely describes the real world examples discussed in the Introduction. In the case of the ozone layer and DuPont, $n_G^* = 1$ and $n \approx 5$, with just DuPont lobbying for environmental protection and a handful of others opposing. In the case of climate change and the European oil and gas companies, $n_G^* = 6$ and n is large. However, the key insights gained from the two-firm model remain largely unchanged in the n-firm case.

5.2 Cournot and other models of competition

The baseline model assumes firms take prices as given. As discussed, by abstracting away from strategic product market behaviour, this allows the model to focus cleanly on the political and investment stages of the game. The results, however, are robust to this assumption. In this section I outline the solution to the model with Cournot competition in the production stage. Appendix A.4 contains further details.

Consider the setup outlined in Section 2, and now suppose firms know that prices depend on quantity according to demand equation (3). Substituting this into their profit equations and maximising gives equilibrium outputs such that Lemma 1 continues to hold. In the lobbying stage, compared to the previous case, the equilibrium taxes are distorted downwards, as the government addresses the market failure resulting from Cournot competition. This use of an environmental tax as an instrument of competition policy complicates the solutions, but they retain the key properties needed for the final results: $\tau^*(G,G) \in \mathbb{R}$, $\frac{d}{d\lambda}\tau^*(G,B) > 0$, and $\frac{d}{d\lambda}\tau^*(B,B) < 0$. Solving the investment stage establishes that the (G,B) equilibrium exists and becomes more likely as λ increases. The remaining results are best obtained graphically.[32]

A final point to make about market structure is a more general one. Abstracting away from specific assumptions, the results found here will qualitatively hold so long as total profits are increasing in the government's environmental protection instrument. Instead of a tax, this instrument could most obviously be a reduction in permits under a cap and

[32] The model can be re-solved for other competitive environments. Hotelling competition gives particularly concise analytical solutions. Again, the results continue to hold, though they are inevitably made more complex by the government using the emissions tax as an instrument of competition policy as well as environmental policy.

trade scheme. Hepburn et al. (2013) characterise quite general conditions under which the equivalent of $\frac{d}{d\tau}\sum \pi_i^* > 0$ holds. That it does often hold should not be too surprising a result: environmental protection frequently involves putting a price on externalities where previously there was none, generating environmental rents which can at least partially accrue to firms. Hence, though environmental regulation can sometimes shrink markets, getting a share of the new rents often ensures the winners gain more than the losers lose. Therefore Lemma 1 or its equivalent is arguably a more general property of economies than might initially be supposed.

6 Conclusion

This paper presented a simple model of environmental protection in a situation where firms can lobby the government over the level of an emissions tax and use it as a means to potentially steal market share from their competitors. The paper focused on the equilibrium where one firm goes green, lobbies for a high emissions tax and gains market share from its rival, who stays brown and lobbies to try to lower the tax. The equilibrium tax is increasingly distorted above the Pigouvian level as the government becomes more open to lobbying. I show there are situations where it is only because of lobbying that the economy ends up with one green firm instead of none. The equilibrium where both firms go green is also characterised, and here the threat of loss of market share helps to sustain the equilibrium. In both cases, lobbying-induced transitions to a greener economy are welfare improving.

The findings in this paper illustrate some broader points concerning the political economy of environmental protection. First, and rarely discussed, is that we ought to think more carefully about why there might be conflict between corporate interests and environmental protection, and whether it is inevitable. Certainly profit maximising behaviour, particularly when it comes to minimising costs,[33] can mean these two forces pull in opposite directions. But the creation of environmental rents and the opportunity to use regulation to gain a competitive advantage over a rival are both powerful reasons for profit maximising firms to support environmental protection. Such political support can have a major impact on the extent to which the environment is protected.

Second, the market share considerations explored in this paper may be important in a international context too. If one of the two firms in the (G, B) case were foreign owned, then the welfare component of the government's objective function would clearly change. This could explain the especially strong US support for regulation in the case of ozone, or the reluctance of the US to agree to stronger climate policies given that EU firms often made more substantial investments in low-carbon technologies than US firms.

I have argued this model explains some otherwise puzzling examples of environmental lobbying by polluting firms. However, the model is also a bad predictor of the political economy of environmental protection much of the time - since polluting industries are often united in opposing regulation - a fact which is itself interesting since it suggests that there may be other important effects at work. Three potentially plausible frictions that would generate this result are as follows.

The first, and perhaps most interesting, explanation could be collusion. Firm collusion in the product market has been extensively studied, but it is not the only arena in which firms may be more or less competitive. The model presented here features a competitive political stage (in the sense that lobbying is non-cooperative), but perhaps in reality the firms collude, at least to some extent. The determinants of political collusion by firms might perhaps be similar to the determinants of product market collusion. It may therefore be expected that concentrated, established industries that cooperate on other matters might

[33] The 1984 Union Carbide chemical leak in Bhopal was a particularly deadly and long lasting environmental disaster (see Dhara and Dhara (2002)). Aggressive cost cutting is often said to be its cause, as it was with the 2010 BP oil spill in the Gulf of Mexico.

here collude politically and stay brown rather than maximise their individual profits and go green. Conversations I have had with both industry and environmental lobbyists often emphasise the practical importance of Trade Associations, the industry-wide lobby groups through which much of each firm's lobbying in reality takes place. In order to function, these institutions foster consensus and cooperation among their members, or, in other words, collusion. Firms' lobbyists are often not keen to deviate from a collusive outcome, either for rational repeated game-type reasons, or perhaps for ingrained social and institutional ones.[34]

A second plausible explanation could be due to uncertainty over government policy. The green firm needs the tax to stay in place and not be changed by future governments, which is the case by construction in the simple model presented here. In reality, however, governments behave less predictably and newly elected governments, for example, often cancel taxes or subsidies introduced by their predecessors. Going green is therefore a risky investment, and companies may decide they don't want the uncertainty in their revenues and may rationally choose to stay brown. Third, it may be that (due to small asymmetries not modelled above) the firms that stand to lose are large incumbents, and those that stand to gain are either small incumbents or entrants. Such firms are likely to be liquidity constrained in their lobbying activities, and may face other barriers to lobbying such as less developed networks with policymakers. Under such constraints, lobbying would not in equilibrium produce a large enough environmental tax for a firm to choose to go green. Whatever the exact mechanism, some additional friction or imperfection is needed before it can be shown that corporate lobbying inevitably harms the environment. Given this may often have large consequences, further, perhaps empirical, work in this area may be fruitful.

[34] Wider social and cultural factors may also play a role in determining the extent of collusion, for example in explaining why European oil and gas producers lobbied for a carbon price in 2015 when their US counterparts did not.

A Appendix

A.1 Full analytical solutions to the subgames

	x_1	x_2	p	π_1	π_2
(G,G)	$\frac{2}{b+4}$	$\frac{2}{b+4}$	$\frac{1}{b+4}$	$\frac{1}{(b+4)^2}$	$\frac{1}{(b+4)^2}$
(G,B)	$\frac{4\tau+2}{b+4}$	$\frac{2-(2+b)2\tau}{b+4}$	$\frac{2\tau+1}{b+4}$	$\frac{(2\tau+1)^2}{(b+4)^2}$	$\frac{(1-(2+b)\tau)^2}{(b+4)^2}$
(B,B)	$\frac{2(1-b\tau)}{b+4}$	$\frac{2(1-b\tau)}{b+4}$	$\frac{4\tau+1}{b+4}$	$\frac{(1-b\tau)^2}{(b+4)^2}$	$\frac{(1-b\tau)^2}{(b+4)^2}$

Production subgame equilibrium outcomes (13)

	τ^*	c_1^*	c_2^*
(G,G)	$\in \mathbb{R}$	0	0
(G,B)	$\frac{8\eta+b(6\eta+b\eta-\lambda)}{8(1-\lambda)+b(6-4\lambda-b\lambda+b)}$	$\frac{4\lambda(b+2)(2\eta-\lambda+1)^2}{(b-2\lambda-b\lambda+4)(8\lambda-6b+4b\lambda+b^2\lambda-b^2-8)^2}$	$\frac{\lambda(b+2)^2\left(2\lambda-b+4\eta+4b\eta+b^2\eta-2\right)^2}{(b^2+6b-4\lambda+8)(8\lambda-6b+4b\lambda+b^2\lambda-b^2-8)^2}$
(B,B)	$\frac{4\eta+b\eta-\lambda}{4+(1-\lambda)b}$	$\frac{b\lambda(b\eta-1)^2}{(2b-b\lambda+8)(b-b\lambda+4)^2}$	$\frac{b\lambda(b\eta-1)^2}{(2b-b\lambda+8)(b-b\lambda+4)^2}$

Lobbying subgame equilibrium outcomes (14)

	G	B
G	$\frac{1}{(b+4)^2} - s$ $\frac{1}{(b+4)^2} - s$	$\frac{(b+2)(2\eta-\lambda+1)^2}{-(b-2\lambda-b\lambda+4)(8\lambda-6b+4b\lambda+b^2\lambda-b^2-8)} - s$ $\frac{\left(2\lambda-b+4\eta+4b\eta+b^2\eta-2\right)^2}{(-6b+8\lambda+4b\lambda+b^2\lambda-b^2-8)(-6b+4\lambda-b^2-8)}$
B	$\frac{\left(2\lambda-b+4\eta+4b\eta+b^2\eta-2\right)^2}{(-6b+8\lambda+4b\lambda+b^2\lambda-b^2-8)(-6b+4\lambda-b^2-8)}$ $\frac{(b+2)(2\eta-\lambda+1)^2}{-(b-2\lambda-b\lambda+4)(8\lambda-6b+4b\lambda+b^2\lambda-b^2-8)} - s$	$\frac{2(b\eta-1)^2(b+4)}{(2b-b\lambda+8)(b-b\lambda+4)^2}$ $\frac{2(b\eta-1)^2(b+4)}{(2b-b\lambda+8)(b-b\lambda+4)^2}$

Investment subgame payoff matrix (15)

A.2 Proofs

Lemma 1

Proof. Using production equilibrium outcomes (13), we find $\frac{d}{d\tau}\sum\pi_i(\tau,(G,B)) = \frac{2(8\tau-b+4b\tau+b^2\tau)}{(b+4)^2}$, which is positive if $\tau > \frac{b}{4b+b^2+8} \in [0, \frac{\sqrt{2}-1}{4}]$ for all $b \in \mathbb{R}_{\geq 0}$. The results from the next stage verify that, in the equilibria of interest, τ always satisfies the above inequality. $\square$

Proposition 1

Proof. (i) There are parameters for which S is non-empty if $|S|> 0$. Let $\overline{s}_s = \max S$, obtained by substituting values from payoff matrix (15) into no-deviation condition (11). Likewise let $\underline{s}_s = \min S$, obtained by substituting values from payoff matrix (15) into no-deviation condition (12). $|S|= \overline{s}_s-\underline{s}_s$, but the full analytical expression for $|S|$ and subsequent quantities is long, so I proceed in this and the next two proofs as follows. First, I demonstrate the relevant result at $b = 0$. Second, if the relevant expression is continuous in b at $b = 0$, then any result true at $b = 0$ must also be true for b close to 0. Proceeding in this way, $|S|_{b=0}= \frac{\lambda^2-\lambda+8\eta^2}{8(1-\lambda)(2-\lambda)}$, which is positive if $\eta > (\frac{\lambda(1-\lambda)}{8})^{\frac{1}{2}}$. $\eta > \frac{\sqrt{2}}{8} \approx 0.18$ guarantees $|S|> 0$ for all $\lambda \in \mathbb{R}_{\geq 0}$ that give an interior solution. Finally, $\lim_{b\to 0}(|S|) = |S|_{b=0}$, so $|S|$ is continuous in b at $b = 0$.

(ii) Differentiating gives $\frac{d}{d\lambda}|S|\big|_{b=0} = \frac{(12-8\lambda)\eta^2-(1-\lambda)^2}{4(1-\lambda)^2(2-\lambda)^2}$ which is positive for $\eta > \frac{1-\lambda}{2(3-2\lambda)^{1/2}}$. $\eta > \frac{\sqrt{3}}{6} \approx 0.29$ guarantees $\frac{d}{d\lambda}|S|> 0$ for all $\lambda \in \mathbb{R}_{\geq 0}$ that give an interior solution. Finally, $\lim_{b\to 0}(\frac{d}{d\lambda}|S|) = |S|_{b=0}$, so $\frac{d}{d\lambda}|S|$ is continuous in b at $b = 0$. $\square$

Proposition 2

Proof. (i) S' is non-empty if $|S'|> 0$, where $|S'(\lambda)|= \overline{s}_s(\lambda) - \overline{s}_s(0)$. Using maximum investment cost $\overline{s}_s(\lambda)$ from the above proof, $|S'|_{b=0}= \frac{8\eta+\lambda^2-\lambda+8\eta^2-8\lambda\eta}{16(1-\lambda)(2-\lambda)}$. Hence $|S'|> 0$ if $\eta > \frac{\lambda-1+\sqrt{2}\sqrt{-3\lambda+\lambda^2+2}}{2(3-\lambda)}$; $\eta > \frac{1}{6}$ ensures this holds for all $\lambda \in \mathbb{R}_{\geq 0}$ that gives an interior solution. Finally, $\lim_{b\to 0}(|S'|) = |S|_{b=0}$, so $|S'|$ is continuous in b at $b = 0$.

(ii) Differentiating and then setting $b = 0$ gives $\frac{d}{d\lambda}|S'|\Big|_{b=0} = \frac{(2\eta+1-\lambda)(\lambda+6\eta-4\lambda\eta-1)}{8(1-\lambda)^2(2-\lambda)^2}$. This is positive if $\eta > \frac{1-\lambda}{2(3-2\lambda)}$; $\eta > \frac{1}{6}$ ensures this holds for all $\lambda \in \mathbb{R}_{\geq 0}$ that gives an interior solution. Finally, $\lim_{b\to 0}(\frac{d}{d\lambda}|S'|) = \frac{d}{d\lambda}|S'|\Big|_{b=0}$, so $\frac{d}{d\lambda}|S'|$ is continuous in b at $b = 0$. □

Proposition 3

Proof. The form of the proof is the same as for Proposition 2. (i) T' is non-empty if $|T'|> 0$, where $|T'(\lambda)|= \overline{s}_T(\lambda) - \overline{s}_T(0)$ and $\overline{s}_T = \max T'$. Substituting payoff matrix (15) into no-deviation condition (11) gives $\overline{s}_T$, which then gives $|T'|_{b=0}= \frac{\lambda(4\eta-\lambda-12\eta^2-4\lambda\eta+4\lambda\eta^2+1)}{16(1-\lambda)(2-\lambda)}$. Hence $|T'|> 0$ if $\eta > \frac{1-\lambda+\sqrt{2}\sqrt{(1-\lambda)(2-\lambda)}}{2(3-\lambda)}$, which holds for all $(\lambda, \eta) \in \mathbb{R}^2_{\geq 0}$ that give an interior solution. Finally, $\lim_{b\to 0}(|T'|) = |T|_{b=0}$, so $|T'|$ is continuous in b at $b = 0$.
(ii) Differentiating and then setting $b = 0$ gives $\frac{d}{d\lambda}|T'|= \frac{(1-\lambda+6\eta-4\lambda\eta)(1-\lambda-2\eta)}{8(1-\lambda)^2(2-\lambda)^2}$. Again this is positive if $\eta < \frac{1-\lambda}{2}$, which holds for all $(\lambda, \eta) \in \mathbb{R}^2_{\geq 0}$ that give an interior solution. Finally, $\lim_{b\to 0}(\frac{d}{d\lambda}|T'|) = \frac{d}{d\lambda}|T'|\Big|_{b=0}$, so $\frac{d}{d\lambda}|T'|$ is continuous in b at $b = 0$. □

Proposition 4

Proof. Let $\overline{s}_Y = \max Y$, that is $\overline{s}_Y$ is the largest investment cost for which $(G, B) \succ (B, B)$. $S' \subset Y$ when $\overline{s}_Y > \overline{s}_S$. Using indirect welfare function $W(f)$, we can calculate $\overline{s}_Y = W(G, B) - W(B, B)$. The limits as $b \to 0$ are $\lim_{b\to 0}(\overline{s}_Y) = \frac{\eta(-2\lambda+\eta+\lambda^2-2\lambda\eta+1)}{2(\lambda-1)^2}$ and $\lim_{b\to 0}(\overline{s}_S) = \frac{(\lambda^2-\lambda+8\eta^2)}{8(\lambda^2-3\lambda+2)}$. Using these results, in the $b \to 0$ limit, $\overline{s}_Y(\lambda) > \overline{s}_S$ holds if $(16\lambda^2 - 32\lambda + 8)\eta^2 + (24\lambda^2 - 8\lambda^3 - 24\lambda + 8)\eta + (\lambda^3 - 2\lambda^2 + \lambda) > 0$. Solving for η, it can be shown that this holds for any $(\lambda, \eta) \in \mathbb{R}^2_{\geq 0}$ that give an interior solution. Note that at $b = 0$, for welfare analysis we must use the part of the utility function specified in footnote 21. This then ensures continuity in all the relevant expressions at $b = 0$. □

Proposition 5

Proof. Let $\overline{s}_Z = \max Z$, that is $\overline{s}_Z$ is the largest investment cost for which $(G, G) \succ (G, B)$. $T' \subset Z$ when $\overline{s}_Z > \overline{s}_T$. Using indirect welfare function $W(f)$, we can calculate

$\overline{s}_Z = W(G,G) - W(G,B)$. The limits as $b \to 0$ are $\lim_{b\to 0}(\overline{s}_Z) = \frac{\eta(-2\lambda-\eta+\lambda^2+2\lambda\eta+1)}{2(1-\lambda)^2}$ and $\lim_{b\to 0}(\overline{s}_T) = \frac{\lambda-\lambda^2-8\lambda\eta-8\eta^2+8\eta}{16(1-\lambda)(2-\lambda)}$. Using these results, in the $b \to 0$ limit, $\overline{s}_Z > \overline{s}_T$ holds if $\eta \in [\frac{(1-\lambda)(-4\lambda+2\lambda^2+1-\sqrt{2}L(\lambda))}{4(2\lambda^2-4\lambda+1)}, \frac{(1-\lambda)(-4\lambda+2\lambda^2+1+\sqrt{2}L(\lambda))}{4(2\lambda^2-4\lambda+1)}]$ where $L(\lambda) = \sqrt{-9\lambda + 16\lambda^2 - 10\lambda^3 + 2\lambda^4 + 2}$. Any η giving an interior solution lies in the above interval. Note that at $b = 0$, for welfare analysis we must use the part of the utility function specified in footnote 21. This then ensures continuity in all the relevant expressions at $b = 0$.

□

A.3 Generalisation to n firms

Stage 3: Production

Let n_G be the number of firms that chose $f_i = G$ in stage 1. The investment profile $f \in \{G, B\}^n$ is therefore summarised by n_G. Given n_G and tax τ chosen in stages 1 and 2, firms choose their level of output x_i to maximise their profits. Assuming all firms that made the same investment choice behave in the same way, and denoting as before variables for a firm that chose $f_i = G$ with a G subscript and those that chose $f_i = B$ with a B subscript, the stage 3 equilibrium is given by outputs $x^*_G(\tau, n_G), x^*_B(\tau, n_G)$, with corresponding prices and profits $p^*(\tau, n_G), \pi^*_G(\tau, n_G), \pi^*_B(\tau, n_G)$. As before, any firm that has gone green gains from a higher tax and those that stayed brown gain from a lower tax. Lemma 1 continues to hold since the sum of all firms profits is increasing in τ.

Stage 2: Lobbying

Knowing how a tax will impact their profits and taking n_G as given, the firms non-cooperatively choose their lobbying contribution functions $C_i(\tau)$.[35] The government maximises a weighted sum of social welfare and political contributions as before. The equilibrium

[35] For example, all the green firms don't form a special interest group and coordinate their lobbying. This implicitly assumes the firms have not solved the collective action problem that prevents them from colluding at the lobbying stage. This issue is briefly discussed in Section 6.

is an emissions tax τ^* and pair of contribution functions $(C_G^*(\tau), C_B^*(\tau))$ that satisfy the two equilibrium conditions set out in Section 3. When $b = 0$, solving gives $\tau^*(n_G) = \frac{\eta}{1-\lambda}$, and values of $c_i^*(n_G)$ that are generalisations of the $n = 2$ case. As in the two firm case, lobbying results in the emissions tax being increasingly distorted above the Pigouvian level. This is a consequence of Lemma 2, which it was previously noted holds for any n and therefore applies in this setting.

Stage 1: Investment

Having shown that green firms will successfully lobby to distort the emissions tax above the Pigouvian level, it only remains to show that some firms will in equilibrium choose to go green in the investment stage. An equilibrium of the investment subgame is a profile of choices $f \in \{G, B\}^n$, or equivalently a value of $n_G \in \{0, ..., n\}$, such that no firm gains from unilaterally deviating. That is, given the choices of the other firms, no firm choosing G could gain from deviating to B and no firm choosing B could gain from deviating to G, as given respectively by

$$\pi_G^*(n_G) - c_G^*(n_G) - s \geq \pi_B^*(n_G - 1) - c_B^*(n_G - 1) \tag{16}$$

$$\pi_B^*(n_G) - c_B^*(n_G) \geq \pi_G^*(n_G + 1) - c_G^*(n_G + 1) - s \tag{17}$$

An equilibrium is a value of n_G that satisfies both equations. In principle all the results in the propositions in Section 3 can be replicated using the equations derived in this section, but most of the analytical solutions are not tractable. I therefore present, in the main body of the article, the small λ case analytically, and then give a graphical example of the more general case to demonstrate the comparative statics. Following Section 3, define set $S(n_G) = \{s \in \mathbb{R}_{\geq 0} : n_G$ satisfies (16) and (17)$\}$. That is, $S(n_G)$ is the set of investment costs that supports n_G firms going green in equilibrium. Proposition 6 can now be stated.

Proposition 6

Proof. Part (i): Consider the case where $\lambda = 0$, giving $|S(n_G)|= \frac{2\eta^2}{n^2}(n-1)$, which is independent of n_G. $|S(n_G)|> 0$ therefore holds for all n_G and any $n \geq 2$. $\lim_{\lambda \to 0}(|S(n_G)|) = |S(n_G)|_{\lambda=0}$, so $|S(n_G)|$ is continuous in λ at $\lambda = 0$, hence the above results continue to hold for small λ. Part (ii): follows from $|S(n_G)|= \frac{2\eta^2}{n^2}(n-1)$ when $\lambda = 0$, and $|S(n_G)|$ being continuous in λ at $\lambda = 0$. $\square$

A.4 Cournot competition

Consider a set up identical to that in Section 2, except that each firm maximises its profits believing that its own and the other firm's output affects prices according to demand equation (3). For analytical simplicity, consider the $b = 1$ case. Solving in exactly the same way as in Section 3, we get:

$$\overline{s}_s = \frac{\begin{array}{c}11\,005\lambda + 13\,836\eta + 14\,375\lambda^2 - 53\,125\lambda^3 + 15\,625\lambda^4 + 582\eta^2 - \\ 33\,750\lambda^2\eta^2 - 83\,260\lambda\eta + 17\,880\lambda\eta^2 + 112\,500\lambda^2\eta - 12\,500\lambda^3\eta - 3168\end{array}}{5(\lambda-1)(\lambda-2)(145\lambda-47)(125\lambda-47)}, \tag{18}$$

$$\underline{s}_s = \frac{25(-400\lambda^2 - 4900\lambda\eta + 605\lambda - 6125\eta^2 + 5390\eta - 744)}{49(47-145\lambda)(47-20\lambda)} \tag{19}$$

Using these and subsequent expressions, we can obtain the results in the Propositions in the main text, though given the analytical length of these expressions, numerical examples are the easiest way to establish many of the existence results.

A.5 Corner solutions

A corner solution in the production subgame is a possibility following $f = (G, B)$. If the emissions tax τ is high enough then the brown firm will want to choose negative output by

(13) when $\tau > \frac{1}{b+2}$. Given equilibrium tax rates (14) from the lobbying stage, we have a corner solution if $\eta > \frac{b-2\lambda+2}{4b+b^2+4}$. Intuitively, if the environmental problem is too severe, the government will want to set a tax that entirely prohibits polluting production. The corner solution to the production and lobbying subgames is given by:

$$\begin{aligned} x_G^*(G,B) &= \frac{2}{b+'2}, \quad x_B^*(G,B) = 0, \quad \pi_G^*(G,B) = \frac{1}{(b+2)^2}, \quad \pi_B^*(G,B) = 0 \\ \tau^*(G,B) &= \frac{1}{b+2}, \quad c_G^*(G,B) = \frac{(2\eta + b\eta - 1)^2}{\lambda(b+2)(b-2\lambda-b\lambda+4)}, \quad c_B^*(G,B) = 0 \end{aligned} \tag{20}$$

These results can then be substituted into production outcomes (13) and welfare equation (4) to give investment subgame reduced form payoffs. The corner solutions do not feature in the analytical results, but they are shown in the graphical results.

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