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DEPARTMENT OF ECONOMICS

Policy Incentives and Economic Outcomes:

Three Essays in Applied Microeconomics

Hélia Costa

Thesis submitted for assessment with a view to obtaining the degree of Doctor of Economics of the European University Institute

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European University Institute
Department of Economics

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Abstract

This thesis contributes to the understanding of how policy making shapes economic outcomes, and the role of individual decision and incentives in this process. It consists of three chapters, which focus on aspects of this general topic from an applied microeconomic perspective: (i) market mechanisms for environmental policy and their implications for firm investment, (ii) political incentives of pork barrel environmental expenditures, and (iii) strategic interaction in decision making among decentralized levels of government.

In the first chapter, entitled *Policy Uncertainty and Investment in Low-Carbon Technology*, which is joint work with Silvia Albrizio, we investigate how uncertainty over environmental policy affects firms' investment in low-carbon technology in the context of an emission trading scheme. We develop a three period sequential model combining the industry and electricity sectors and encompassing both irreversible and reversible investment possibilities for firms. Additionally, we explicitly model policy uncertainty in the regulator's objective function as well as the market interactions giving rise to an endogenous permit price. We find that uncertainty reduces irreversible investment and that the availability of both reversible and irreversible technologies partially eliminates the positive effect of policy uncertainty on reversible technology found in previous literature.

In the second chapter, entitled *Pork Barrel as a Signaling Tool: The Case of US Environmental Policy*, I investigate whether signaling is a driving force of pre-electoral pork barrel policies. I develop a two-period model of electoral competition where politicians use current policies to signal their preferences to rational, forward-looking voters. There exists an equilibrium where incumbents use pork barrel spending for signaling in majoritarian systems. Results show that pork spending is directed towards ideologically homogeneous groups and is mitigated if the incumbent is a "lame duck" or has a high discount rate. The predictions of the model are tested using data on US State level environmental expenditures. The results support the signaling motive as a central mechanism in generating pork barrel towards the environment.

In the third chapter, entitled *Interaction in Local Governments' Spending Decisions: Evidence from Portugal*, which is joint with Linda Veiga and Miguel Portela, we analyze the sources and the degree of interaction among Portuguese municipalities' expenditure levels by estimating a dynamic panel model, based on jurisdictional reaction functions. The analysis is performed for all 278 Portuguese mainland municipalities from 1986 to 2006, using alternative ways to measure neighborhood. Results indicate that local governments' spending decisions are significantly, and positively, influenced by the actions of neighboring municipalities. Attempts to identify the sources of interaction allow us to conclude that they are due to spillovers that require coordination in expenditure items and to mimicking behavior possibly to attract households and firms.

Aos meus pais

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Preface

This thesis contributes to the understanding of how policy making shapes economic outcomes, and the role of individual decision and incentives in this process. The thesis consists of three chapters, which focus on diverse aspects of this general topic from an applied microeconomic perspective: (i) market mechanisms for environmental policy and their implications for firm investment (ii) political incentives of pork barrel environmental expenditures, and (iii) strategic interaction in decision making among decentralized levels of government. The first focuses on issues relating to the current debate on the efficiency of market-based environmental mechanisms. The question of how firms respond to environmental policy in terms of investment has received considerable attention in recent years. This is of particular interest given the proliferation of market-based instruments designed to achieve a reduction of greenhouse gases, such as emission trading schemes. The following two address public choice aspects of policy making. Public choice theory is concerned with the application of economic principles to the study of political behavior. Contrary to the assumption of a benevolent social planner, it studies the welfare decreasing economic distortions caused by self-interested politicians and rent seeking groups. Assessing the mechanisms responsible for this kind of behavior, and the incentives for both voters and politicians to behave in this way is one of the goals of this thesis.

In the first chapter, entitled *Policy Uncertainty and Investment in Low-Carbon Technology*, which is joint work with Silvia Albrizio, we investigate how uncertainty over environmental policy affects firms' investment in low-carbon technology in the context of an emission trading scheme. To this end, we develop a three period sequential model combining the industry and electricity sectors, encompassing both irreversible and reversible investment possibilities for firms. We model policy uncertainty in the regulator's objective function as well as the market interactions giving rise to an endogenous permit price. We then calibrate the model with data for the United Kingdom, which takes part in the European Union emission trading. We find that, given a balanced proportion of the two regulated sectors, the effect of policy uncertainty depends on the nature of the investment and the relative preferences of the government. First, uncertainty decreases aggregate irreversible investment. Second, the effect of uncertainty on reversible technology varies according to the weight put by the regulating authority on the environment versus the economy. When policy makers are strongly biased towards economic activity uncertainty might increase investment in reversible technology, as it creates an option value for investing: firms use the investment to hedge against price uncertainty in the permit market. However, this positive effect is weakened by interaction with the irreversible technology. Finally, contrary to previous literature, we find that when policy makers are more environmentally concerned, uncertainty reduces reversible investment. This suggests that in the case of the European Union, where we observe a higher environmental awareness with clear long-run green policy goals, the introduction of commitment mechanisms that reduce long-term uncertainty might be beneficial for investment. Conversely, when policy makers are concerned primarily with economic expansion compared to environmental issues, as might be the case for developing countries, a small level of uncertainty might create the right incentives to increase reversible investment.

In the second chapter, entitled *Pork Barrel as a Signaling Tool: The Case of US Environmental Policy*, I investigate whether signaling is a driving force of pre-electoral pork barrel policies. This assignment of benefits to particular groups at the expense of others constitutes an efficiency loss when the budget is limited and fixed. I develop a two-period model of electoral competition where politicians use current policies to signal their preferences to rational, forward-looking voters. I prove the existence of an equilibrium where incumbents use pork barrel spending for signaling, and show that pork spending is directed towards ideologically homogeneous groups and is mitigated if the incumbent is a "lame duck" or has a high discount rate. The predictions of the model are then tested using data on US State level environmental expenditures from 1970 to 2000. Environmental policy is particularly prone to political pressure, as it triggers strong opinions from the electorate. To measure pork barrel I focus on systematic increases in environmental expenditures in election years relative to total expenditures, as well as deviations relative to the mean of all the other years of the politician's mandate. I create an indicator for voter environmental preferences and ideological dispersion with survey data. The results support the signaling motive as a central mechanism in generating pork barrel towards issues that elicit strong preferences. This implies in particular that environmental policy issues are subject to electoral cycle variations. Given that in order to be efficient environmental policy requires continued action across time, this has important implications for institutional design. For example, mechanisms restraining the discretionary power of politicians that limit the size of electorally driven cycles could increase the efficiency of environmental policy by shielding it from electoral incentives.

In the third chapter, entitled *Interaction in Local Governments' Spending Decisions: Evidence from Portugal*, which is joint with Linda Veiga and Miguel Portela, we analyze the sources and the degree of interaction among Portuguese municipalities' expenditure levels. Municipalities might affect each other's spending decisions due to competition to attract households, benefit spillovers, or yardstick competition. Local interactions are a major issue to understand the impact of budget decentralization policies. The institutional reforms that Portugal is implementing under the financial assistance program agreed with the IMF and the EU in May 2011 makes the topic even more relevant. In order to promote fiscal consolidation, it is important to gain new insights into public policy decisions at the local level. We estimate a dynamic panel model, based on jurisdictional reaction functions, where a municipality's spending decisions are allowed to depend on those of neighboring ones. We perform the analysis for all 278 Portuguese mainland municipalities from 1986 to 2006 and construct alternative geographic, demographic and political measures of neighborhood in order to account for possible sources of interdependence. We furthermore account for the possibility of spatial correlation in addition to serial correlation. Our results show that local governments do not make their spending decisions in isolation; instead, they are significantly influenced by the actions of geographically neighboring municipalities. We conclude that Portuguese municipalities react to each other's expenditures due to both spillovers that require coordination of public policies among geographically close municipalities and to mimicking behavior with the purpose of attracting households and firms.

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Chapter 1

Policy Uncertainty and Investment in Low-Carbon Technology

With Silvia Albrizio

1.1 Introduction

The question of how firms respond to environmental policy in terms of investment has received considerable attention.[1] This is of particular interest given the proliferation of market-based instruments designed to achieve a reduction of greenhouse gases (*GHG*), such as emission trading schemes. Currently, the biggest emission trading scheme (*ETS*) is the European one, although in 2012 both California and Australia introduced respectively the state *GHG* cap-and-trade programme, under the Global Warming Assembly Act, and the carbon price mechanism, in the context of the Clean Energy Future plan.
An emission trading scheme is a cap-and-trade system designed to create incentives for firms to invest in low-carbon technology, with the final goal of reducing carbon dioxide (CO_2) emissions. In practice, by allocating a certain amount of tradable emission permits for each of the energy-intensive installations covered by the scheme, the *ETS* places a limit on total CO_2 emissions. This system creates a market for these permits so that, given that firms have different marginal costs of abatement, some installations find it profitable to reduce their emissions and sell the unused allowances. This aggregate limit, or cap, and consequently the allocation of permits per each installation, is set by a regulatory authority periodically and at a decreasing rate. The periodicity of the cap decision allows the policy makers to update the limit according to the realized technology innovation path, to the actual investment process by firms and to possible government changes or priority revisions due to business cycles. Although this system entails a flexibility gain for the authority, it also leads to uncertainty over the future cap and the future market price of the allowances for the firms. As a consequence, given the long-term nature of investments

[1] See, for example, Zhao (2003) and Jung et al. (1996).

in low-carbon technologies, the return on investment in abatement is also unknown at the time of investing. Thus, how does uncertainty over the policy decisions, driven by the periodicity of the cap, affect firms' investment in low-carbon technologies? More specifically, is the *ETS* efficient when firms do not know future levels of the cap?
Previous literature has attempted to address similar questions. Blyth et al. (2007) study how environmental policy uncertainty affects power sector irreversible investment in low carbon technology, following a real option approach. According to what the theory predicts,[2] they find that uncertainty over the price of permits, i.e., the process that drives the future flow of profits, decreases irreversible investment. However this analysis presents several limitations. First of all, policy uncertainty is represented as an exogenous shock over the price of permits. This setting (an exogenous price and the absence of a policy objective function) rules out any consideration of the feedback effect from the firms to the policy maker, which is important from a policy design perspective. Secondly, it concerns only a portfolio choice: that is, the firms' production is held fixed, which eliminates a potential instrument to deal with future uncertainty. Finally, it focuses only on one of the sectors of the European scheme (*EU ETS*), the power sector, and only one possible kind of investment in low-carbon technology - the irreversible one.
We distinguish between two kinds of investment specific to the power sector: an irreversible one, which once made is used in production - such as renewable energy resources or energy efficiency - and a reversible one, which may or may not be used in production depending on *ex post* profitability - as is the case of fuel switching.[3]
Differentiating between these two options is of vital importance for this research. In fact, in the analysis by Chen and Tseng (2011), reversible investment is found to increase with uncertainty. The investment studied takes the form of building up a gas plant, which allows power companies to use gas for production when the price of coal (the input cost plus the permit price) is higher than the gas price and vice-versa (fuel switching). This investment provides electricity generators with a precautionary instrument that helps to hedge the fuel price risk. However, the same criticisms made of Blyth et al. (2007) can be directed at this contribution.

[2]See Dixit and Pindyck (1994).

[3]According to Shapiro and Varian (1999), a technology investment is comparable to an option when switching costs are high and therefore a technology lock-in effect comes into play. We extend this definition to the case where switching costs are not extremely high but firms simply do not find it profitable to switch back to previous technology solution after having invested in new one.

Finally, Colla et al. (2012) take a step further in modeling this market, by introducing an objective function for the authority and endogenizing the price of the permits. They study the optimal environmental policy for the *EU ETS* in the presence of speculators in the market for allowances. However, in their setting, firms are homogeneous, with only the choice of irreversible investment, and uncertainty regards future demand for the firms' product, and not the policy rule.

As in previous literature, we consider the current set up of the *EU ETS* as representative of a general scheme, although our results carry over to other cap-and-trade systems, such as the newborn California programme.[4] In fact, these two schemes share not only a comparable design of the cap, but also the type of sectors regulated.

We put forward a stylized but comprehensive setting where the two sectors regulated by the *EU ETS*, industry and electricity, have access to different low-carbon technologies. Industries have access only to an irreversible clean technology: energy efficiency and renewable energy sources. Conversely, power companies may use both irreversible clean technology and reversible technology, namely fuel switching: electricity generation firms can construct a gas plant, while keeping the option of producing with existing coal plant.[5]

We explore the final effect of the interaction of these firms in the market in terms of aggregate investment. For this purpose, we develop a three-period sequential model. In the first period, two firms, price takers in the market for emission permits and representative of the two sectors, decide whether to invest in CO_2 abating technologies; in the second period, uncertainty over the relative preference of the authority over economic activity versus environmental concerns is realized and the regulator chooses the aggregate cap. Finally, firms decide on their production levels and fuel choices; and the permits market clears.

To the best of our knowledge, no other model has put together both carbon-intensive industries and electricity generators, which is essential to capture the final behavior of the aggregate level of investment - both reversible and irreversible - in low-carbon technology. We also allow for output effects in addition to substitution effects, by allowing firms to decide on production levels. Additionally, we clearly identify the uncertainty parameter

[4]Appendix 1.A provides a description of the *EU ETS* to the extent relevant for the purpose of this analysis and explains the concept of policy uncertainty in this context. For further information regarding the *EU ETS* see Ellerman et al. (2010) and Chevallier (2011).

[5]We exclude the reversible technology possibility for the industry sector as it is not a feasible option for industrial production.

in the regulator's objective function as the relative weight the authority puts on environmental concerns. This provides us with a feedback effect, since the regulator internalizes the effect of her choices on firms' fuel choices. Moreover, the political nature of uncertainty allows us to derive important policy implications regarding commitment incentives by policy makers. This is because this type of uncertainty can be directly influenced by the authority, as opposed, for instance, to demand uncertainty. Finally, our formulation allows us to derive a closed form solution and therefore to clearly identify the effects of the different forces that play a role in this complex picture. Our model can thus be used as a benchmark to further include additional features of interest of the different *ETS* and study how the outcome varies with them.

Our results show that, given a balanced proportion of the two regulated sectors, the effect of policy uncertainty depends on the nature of the investment and the relative preferences of the government. First, as in the real options approach, uncertainty decreases aggregate irreversible investment. Second, the effect of uncertainty on reversible technology varies according to the weight put by the regulating authority on the environment versus the economy. When policy makers are strongly biased towards economic activity uncertainty might increase investment in reversible technology, since it creates an option value for investing: firms use the investment to hedge against the uncertain prices in the permit market. However, this positive effect is partially nullified by the interplay with the irreversible technology. Finally, contrary to previous literature, when policy makers are more environmentally concerned, uncertainty reduces reversible investment. This is because in some cases it is more profitable for firms to face uncertainty by adjusting their output *ex post*.

The chapter is organized as follows. Section 1.2 introduces the model while section 1.3 presents the methodology and the results. In Section 1.4 the welfare analysis is presented and, finally, Section 1.5 concludes.

1.2 The Model

We develop a model of three sequential periods, which encompasses the key elements of a cap-and-trade system. As in the actual market for permits, firms have to decide on their investment strategy before knowing with certainty the future amount of permits they will be entitled to. Once the cap is set and firms decide on their production levels, the price is endogenously determined by the interplay of firms' supply and demand of allowances. We abstract both from temporal trading and speculation, which allows us to focus on the direct market interactions between the firms and the regulator. For the same reason, we do not include demand side effects, by assuming that firms can always sell their production at a constant price. The model considers three different agents: a regulatory authority, or policy maker, and one firm from each of the two regulated sectors. Firm 1 is representative of the power sector and firm 2 of the industrial sector. Given the large number of installations covered by this type of schemes (the *EU ETS* covers around 11 300 energy-intensive installations from 30 countries), and the fact that the allowances are traded on electronic platforms, it is difficult for any particular firm to exert significant market power in the market for permits. Therefore, we assume perfect competition amongst firms in this market.[6] Furthermore, we assume a continuum of homogeneous firms within each sector and therefore consider only a representative firm from each. This implies, in particular, that the price that prevails in the market will be determined, in our model, as the result of the interaction of the two firms, because it represents the actions taken by the entire market. Finally, all agents are risk neutral.

1.2.1 The regulator

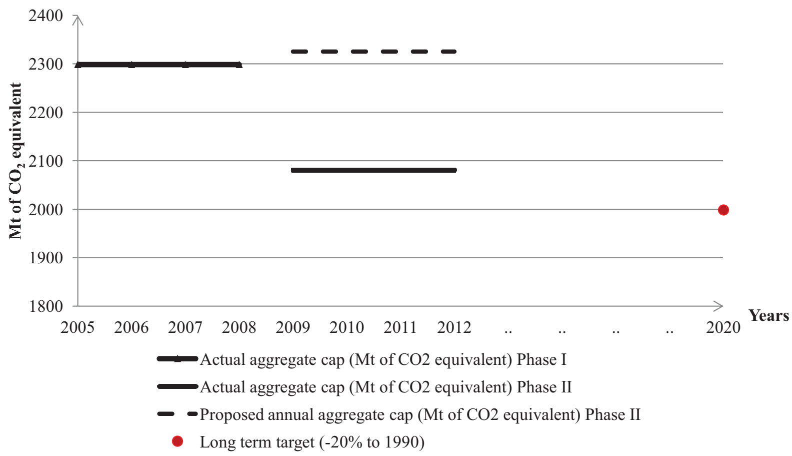
As laid out in the introduction, we focus on the effect of having uncertainty over the policy maker's preferences. Although a long term target for the cap is set out in advance, the policy maker decides period by period on the actual limit in effect for that given trading period (phase), which might be tighter or looser than the average, according to the importance she puts in environmental concerns versus economic outcomes. This difference in preferences might derive from priority revisions resulting from business cycles,[7] unexpected changes in the technological innovation path, different political preferences of changing governments, or even the presence and influence of political lobbies. Considering that a standard payoff period for a low-carbon investment is between 15 and 20 years, when firms make their investment decisions, their payoff is uncertain - particularly, investment in low-carbon technology is more profitable if the forthcoming emission cap is

[6] This is true even though allowances are not distributed equally amongst firms: in the *EU ETS*, power companies receive a much higher share of allowances. However, the model can be extended to include some market power amongst the firms in the electricity generating sector.

[7] In particular, whenever there is an economic recession, the government in power might choose to loosen the cap, so as to bolster the economy.

tighter, and vice-versa.
An example of policy uncertainty in the context of the *EU ETS* is presented in Fig.1.1. It

Figure 1.1: Annual aggregate cap as known in 2003. Source: European Commission.



depicts the information available to the firms in 2003 and the realized cap for the first and the second trading periods. In fact, in 2003 firms were aware of the aggregate cap level for the first trading period (2005-2007) and they had expectations on the second phase cap (the dashed line). In 2007 the European Commission announced a second-phase cap significantly lower than the expected one due to the unforeseen over-allocation of the first phase. The difference between the expected cap for 2008-2012 (dashed line) and the realized one (the solid line) proves evidence of the uncertainty around the future policy, namely the aggregate cap. A similar description for the other *EU ETS* periods can be found in Appendix 1.A.
We model this uncertainty through a parameter, $\tilde{\gamma}$, measuring the weight put by the policy maker on economic expansion, proxied by the firms' profits, while $(1-\tilde{\gamma})$ is the weight put on the disutility from CO_2 emissions. This preference parameter can take two values:

$$\tilde{\gamma} = \begin{cases} \gamma + \tau & \text{with probability } q \\ \gamma - \tau & \text{with probability } (1-q) \end{cases}$$

It can be high with probability q, or low with probability $(1-q)$. Firms know the value of q, γ and τ, but they do not know the exact realization of $\tilde{\gamma}$ *a priori*, namely when they make their investment decisions. This value becomes known to firms only in the second period, when uncertainty is realized. The regulator sets the cap so as to maximize the following objective function:

$$R(\bar{e};\tilde{\gamma}) = \tilde{\gamma}\left[\sum_{i=1}^{2}\pi_{i,s}\right] - (1-\tilde{\gamma})\,\phi\bar{e} \tag{1.1}$$

$$s = h, l; i = 1, 2$$

where $\pi_{i,s}$ is the profit in state s of firms 1 (power sector) and 2 (industry) and $\phi\bar{e}$ is the damage function that represents the disutility from CO_2 emissions, as described in Scott (1994) and Germain et al. (2004). This function consists of a parameter, ϕ, which quantifies not only the marginal immediate damage of CO_2 emissions, but also comprises a measure of their long-run social and economic cost, due to climate change,[8] and $\bar{e}$, the cap set by the policy maker, which therefore corresponds to the total amount of CO_2 emitted by firms. We assume that the damage is linear in the emissions, so that the parameter represents their actual marginal cost.[9] In principle, tightening the cap has two effects: a substitution effect, as firms substitute from the carbon-intensive input towards cleaner technologies, and an output effect, because firms might find it profitable to decrease their production in order to decrease emissions.

1.2.2 The firms

The representative firms differ in their productivity, α_i, their available choice of fuels, and their cost of investment in clean technologies, measured by k_i.[10] In particular, the firm in the electricity sector may choose to invest in two types of low-carbon technologies:

- An irreversible clean technology (such as renewable energy sources, *RES*, or energy

[8]Such as the damage from the intensification of natural disasters, the decrease in clean water resources, or migration and restructuring due to the sea level rise.

[9]A linear damage function has been used in similar analyses (see, for example, (Scott, 1994) and (Colla et al., 2012)).

[10]For now, we assume throughout that both sectors have the same size. However, the model can easily be extended to include different shares among sectors.

efficiency enhancing technologies) which we consider irreversible, since after investment takes place the firm is locked-in to its use.[11]

- A reversible technology, namely fuel switching in production, which requires building a second plant that produces using gas,[12] and paying a fixed cost, F. However, once the investment is made and uncertainty over the cap is resolved, the firm has the opportunity to switch back to the coal-using plant, if the realized cap was higher than the expected, given that operating costs of coal are always lower than those of gas. We assume the firm operates with only one of the plants at a time.[13] Accordingly, we consider the availability to switch between fuels a reversible technology. The investment decision is of a discrete nature: to build or not the new gas plant. We consider this option a low-carbon technology because gas releases only around 80% of the amount of CO_2 emitted by coal. This coupled with the fact that lower amounts of fuel are necessary, since the productivity of gas is usually much higher, leads to a much lower total level of emissions from production. The relevance of gas as energy source for power companies is illustrated in the table in Appendix 1.B.

On the contrary, firm 2 has only the option to invest in the irreversible clean technology.[14]
Both clean technologies are continuous variables.
The firms' profit functions can be described as:

$$\pi_1(a_1, e_1, G_1; \bar{e}) = \max\{\pi_{1,e}(a_1, e_1; \bar{e}), \pi_{1,G}(a_1, G_1; \bar{e})\} \tag{1.2}$$

$$\pi_{1,e}(a_1, e_1; \bar{e}) = \alpha_{1,e}(a_1 + \bar{a})e_1 - ce_1^2 - p_s\left(e_1 - \frac{\bar{e}}{2}\right) - k_1 a_1^2 \tag{1.3}$$

$$\pi_{1,G}(a_1, G_1; \bar{e}) = \alpha_{1,G}(a_1 + \bar{a})G_1 - gG_1^2 - p_s\left(\lambda G_1 - \frac{\bar{e}}{2}\right) - k_1 a_1^2 - F \tag{1.4}$$

[11] Regarding *RES*, since there are nearly no operating costs, once these investments take place, the firm always uses them.

[12] Almost all the existing coal plants burn pulverized coal in a boiler to generate steam which then drives a steam turbine. Replacing the existent coal-burners to burn gas would reduce consistently the efficiency of the gas plant. For instance, a retrofit gas plant would have an average of 37% efficiency whereas a new CCGT has on average 58% efficiency. Therefore almost all the companies build a new gas plant.

[13] That is, we assume that both plants are big enough so that the company operates with only one of them at a time according to the merit order.

[14] For example, a cooling system installed in a cement installation.

for firm 1, where the profit will be the maximum between the profit using coal for production and the profit using gas for production, and

$$\pi_{2,e}(a_2, e_2; \bar{e}) = \alpha_{2,e}(a_2 + \bar{a})e_2 - ce_2^2 - p_s\left(e_2 - \frac{\bar{e}}{2}\right) - k_2a_2^2 \tag{1.5}$$

for firm 2. Each firm has a two-input production function, where one of them is a fossil fuel - coal (e_2), for firm 2, and coal (e_1) or gas (G_1) for firm 1 - and the other is clean technology - a_2 for firm 2 and a_1 for firm 1. Our measure of coal has a one to one correspondence with carbon dioxide (CO_2) emissions. We assume that fossil fuels and clean technology are complementary inputs and for mathematical tractability we consider a multiplicative production function. This complementarity is justified by technological considerations.[15] Given that the profit is expressed in monetary terms, these functions imply that the firms' profits are given by the revenues from their sales, minus the costs of using gas or coal, which consist of the operating costs of the inputs plus the permits trading cost, and minus investment costs. The productivity of the combination of the inputs, which includes the price of the output, is given by α_i. Due to their physical properties $\alpha_{1,G} > \alpha_{1,e}$. Moreover, $\bar{a}$ represents the existing level of clean technologies for the two sectors. This formulation allows firms to set the level of investment in clean technology to zero, if optimal, still having a positive production level. We assume the same $\overline{a}$ for both sectors.

We assume convex costs of coal and gas, which assures that the profit functions are concave in the production inputs. This is satisfied as long as $4ck_i - \alpha_{i,e}^2 > 0, i = 1, 2$ (See Condition 1, Section 3.1). The cost structure captures not only the price of the fuels, but also the storage costs of these inputs, as well as their opportunity cost - both of which increase exponentially for high quantities of fuels. Because the price of gas is historically higher on average than the price of coal, we also consider $g > c$.

The second part of the profit concerns the permit trading part which is the net demand for permits ($(e - \overline{e}/2)$ or $(\lambda G - \overline{e}/2)$) multiplied by the endogenous permit price ($p_s = p(\overline{e}_s)$), which is a function of the total amount of allowances ($\overline{e}_s$). The cap is assumed to be shared equally amongst the firms,[16] and λ is the proportion of CO_2 emitted by one unit

[15] Renewables are intermittent energy resources and very difficult or costly to store, hence the aggregate supply of electricity always uses a mix of fossil fuels and *RES*. *EF*, on the other hand, are investments that make these fuels more productive, by reducing the energy wasted during the cycle, and must, therefore, always be used along with the latter.

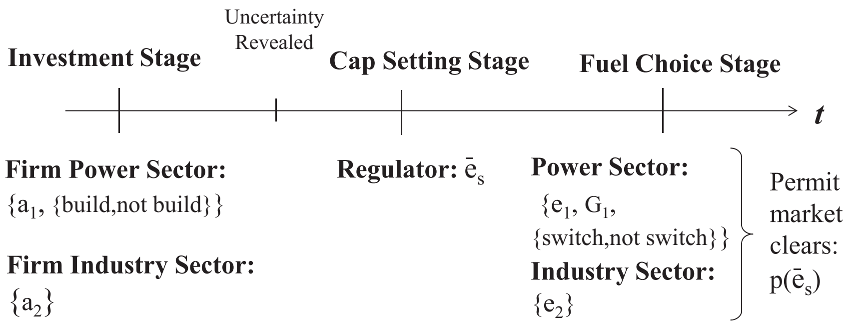
[16] The *ex-ante* allocation does not affect efficiency, as the permit trading reallocates them efficiently; what matters is the aggregate level.

of gas, as compared to that of one unit of coal. If the net demand is positive, the firm is emitting more than what it is entitled to, and therefore is a net buyer of allowances. On the contrary, if a firm manages to decrease its emission level below its allocation of permits, then it is a net seller in the market for allowances.
Finally, $k_i a_i^2$ is the cost of investing in the irreversible technology. We assume, as it is standard in the literature,[17] that the cost of investing in this technology is convex.

1.2.3 Timing

The agents' actions take place as follows: in the first period, the two firms make their investment decisions, according to their expectation of the forthcoming cap; in the second period uncertainty is realized and the policy maker decides on the aggregate amount of permits, by maximizing her objective function; and in the last period, firms set their production levels, so as to maximize profits, by adjusting their fuel choices. They trade permits and the market clears, giving rise to the equilibrium price of allowances. This timeline is set out in Fig.1.2.

Figure 1.2: Timeline



1.3 Methodology and Results

In order to better isolate the mechanisms in effect, we first explore two reduced settings: one where only the irreversible investment (the choice of a_i) is available, which means that

[17] After the seminal contribution of Montgomery (1972), several papers have assumed convex abatement costs - for example, Fell and Morgenstern (2009).

firms can improve their energy efficiency or invest in RES, and the alternative situation where only reversible investment for the electricity sector - investment in a gas plant - can be made.

1.3.1 Irreversible Investment in Isolation

We start with the first case. When only irreversible investment is available, the firms' profit functions reduce to:

$$\pi_{i,e,s}(e,a;\bar{e_s}) = \alpha_{i,e}(a_i+\bar{a})e_{i,s} - ce_{i,s}^2 - p_s\left(e_i - \frac{\bar{e}_s}{2}\right) - k_i a_i^2 \qquad i=1,2; s=h,l \tag{1.6}$$

where s stands for the realization of the state, which can be high ($\tilde{\gamma}_h = \gamma + \tau$) or low ($\tilde{\gamma}_l = \gamma - \tau$). In this reduced setting firms differ only on their productivity, α_i and their cost of abatement parameter, k_i.
We solve the model by backward induction.[18] In $t = 3$, after the cap has been set and uncertainty is revealed, the firms decide on their output levels by adjusting their fuel (which consists here of coal, e_i), according to the observed cap. They do so by maximizing their last period profit, given by (6) net of sunk costs, with respect to the coal level, taking the price, the allocation and their first period choices as given. The resulting optimal level of coal is, then, given by:

$$e_{i,s}^*(p_s) = \frac{-p_s + \alpha_i(a_i+\bar{a})}{2c} \tag{1.7}$$

for $i = 1, 2; s = h, l$, where the star indicates an equilibrium level and $p_s = p(\bar{e}_s)$. This optimal quantity depends positively on the productivity parameter $\alpha_{i,e}$, on the investment in clean technology a_i, and on its starting level $\bar{a}$. This happens because the marginal productivity of e_i is given by $\alpha_{i,e}(a_i+\bar{a})$, which makes the complementarity effect between inputs to be larger than the substitution effect.[19] Lastly, the optimal coal level depends negatively on the price for permits, p_s, and on the parameter measuring operating costs, c.
The two firms then exchange permits, according to their production needs, and the market

[18] As firms do not act strategically, the model could also be solved by forward induction.
[19] This is true for any other choice of production function which embodies any (even very small) degree of complementarity between inputs.

clears. The equilibrium price is given by the following market clearing condition, for each of the two s states:

$$e^*_{1,s}(p_s) + e^*_{2,s}(p_s) = \bar{e}_s \tag{1.8}$$

which, solving for p_s, gives us the price that clears the market:

$$p^*_s = \frac{1}{2}\left[\alpha_1(a_1 + \bar{a}) + \alpha_2(a_2 + \bar{a}) - 2c\bar{e}_s\right] \tag{1.9}$$

This price depends negatively on $\bar{e}_s$ and c, and positively on the average productivity of coal. Intuitively, exogenous increases in the productivity of coal make it more profitable and so boost the demand for permits, thereby increasing its price. On the contrary, a decrease in operational costs c diminishes coal demand and consequently reduces the allowances' price. Finally, increases in the total amount of available permits $\bar{e}_s$ reduce their price, and vice-versa. This negative relation between $\bar{e}_s$ and p^*_s means, in particular, that the price level associated with $\tilde{\gamma}_h$, p_h, will be lower (or equal) than that associated with $\tilde{\gamma}_l$, p_l.

Next, we study the policy maker's behavior. In $t = 2$, she chooses the cap by maximizing her objective function, according to her type s, taking into account her effect on the firms' last period choices. Her objective function is given by:

$$R_s(\bar{e_s}) = \tilde{\gamma}_s \left[\sum_{i=1}^{2} \pi_{i,s}(a_i, e^*_i; \bar{e}_s)\right] - (1 - \tilde{\gamma}_s)\,\phi\bar{e}_s \tag{1.10}$$

$$s = h, l$$

where firms' profits are given by (1.6), substituting in the equilibrium values $e^*_{i,s}$.

The resulting equilibrium cap is a function only of the parameters describing the economy and a_i:

$$\bar{e}^*_s = \frac{(a_1 + \bar{a})\alpha_1\tilde{\gamma}_s + (a_2 + \bar{a})\alpha_2\tilde{\gamma}_s + 2\phi(\tilde{\gamma}_s - 1)}{2c\tilde{\gamma}_s}, s = h, l \tag{1.11}$$

The optimal cap $\bar{e}^*_s$ depends positively on the weight the regulator puts on the economy, $\tilde{\gamma}_s$, and negatively on the marginal damage of emissions, ϕ, since $\tilde{\gamma}_s - 1 > 0$. Re-arranging the expression, it can be seen that the existence of a positive cap is guaranteed by the following maximum for the marginal damage parameter:

$$\phi < \frac{\gamma}{(1-\gamma)} \frac{1}{2} [\alpha_1(a_1 + \bar{a}) + \alpha_2(a_2 + \bar{a})] \tag{1.12}$$

which means the marginal damage has to be smaller than the average coal productivity in the market weighted by the relative preference of the regulator for the economy.
As in Colla et al. (2012), if the marginal damage of emissions is too large, the regulator is better off setting the cap to zero and having no production (and zero emissions). Therefore, for the rest of the analysis, we assume that ϕ is smaller than the threshold, and incorporate this condition in the following maximizations.
Finally, we study firms' investment decision in the first period. In $t = 1$, firms face uncertainty regarding the policy maker's preference parameter $\tilde{\gamma}$, and therefore regarding the cap and the market price for permits. They expect, with probability q, that the regulator is of a high type (i.e., more concerned about the economy), and therefore sets the associated cap, $\bar{e}_h$, and with probability $(1 - q)$ that she is of a low type (more environmentally biased), and thus sets the associated cap, $\bar{e}_l$.[20] Therefore, they choose their investment levels by maximizing the following expected profit function with respect to a_i:

$$\begin{aligned} E(\pi_{i,e}(a_i; \bar{e})|\gamma, \tau, q) = q[\alpha_{i,e}(a_i + \bar{a})e^*_{i,h} - ce^{*2}_{i,h} - p(\bar{e}_h)(e^*_{i,h} - \frac{\bar{e}_h}{2}) - k_i a_i^2 t] \\ +(1-q)[\alpha_{i,e}(a_i + \bar{a})e^*_{i,l} - ce^{*2}_{i,l} - p(\bar{e}_l)((e^*_{i,l} - \frac{\bar{e}_l}{2}) - k_i a_i^2] \\ i = 1, 2 \end{aligned} \tag{1.13}$$

In doing so, for each of the two states they take into account the last period optimal levels of coal, the prices and the caps. Solving the first order conditions for a_i, we get the optimum investment level in clean technology, as a function of the expected price:

$$a_i^*(p_h, p_l) = \frac{\alpha_1[\bar{a}\alpha_1 - qp_h - (1-q)p_l]}{4ck_1 - \alpha_1^2}$$

[20]Although firms act as price takers and do not take into account their own effect on the price or the cap, they can assess exactly how these depend on the policy maker's preferences. So, they associate with each state s a certain level of permits, $\bar{e}_s$, and price $p(\bar{e}_s)$.

Substituting in the equilibrium price we have:

$$a_i^* = \frac{(\alpha_{i,e}(-\alpha_{j,e}^2 \hat{\hat{e}} + 2k_j[\overline{a}(\alpha_{i,e} - \alpha_{j,e}) + 2c\hat{\hat{e}}]))}{16ck_ik_j - 2\left(k_j\alpha_{i,e}^2 + k_i\alpha_{j,e}^2\right)} \tag{1.14}$$

for $i = 1, 2, j = 3 - i$, where $\hat{\hat{e}} = [q\bar{e}_h + (1-q)\bar{e}_l]$. This quantity is always positive as long as the following two conditions are maintained:

$$4ck_i - \alpha_{i,e}^2 > 0, i = 1, 2 \tag{1.15}$$

$$[q\bar{e}_h + (1-q)\bar{e}_l] \geq \frac{-2k_j\bar{a}(\alpha_i - \alpha_j)}{(4ck_2 - \alpha_j^2)} \tag{1.16}$$

for $i = 1, 2, j = 3 - i$. The first condition regards the comparison between marginal costs and marginal productivity of a_i and e_i. The second one means that for a_i^* to be non-negative the expected cap cannot be too tight. This is because under such a cap level firms are better off setting e_i to zero, and consequently not producing. As long as these conditions are maintained, existence and uniqueness of a_i^* and e_i^* are guaranteed.
The derivative of a_i^* with respect to the expected cap, $[q\bar{e}_h + (1-q)\bar{e}_l]$, is always positive under the first condition. This effect takes place due to the complementarity with e_i, and means that also a_i^* depends negatively on the price of $e_{i,s}$. However, these effects are larger for $e_{i,s}^*$ than for a_i^*, so that the clean technology to coal ratio actually increases with increases in the price.[21] Additionally, a_i^* depends negatively on k_i, so that the firm with lower costs of abatement invests more in equilibrium, and *vice-versa*.
Substituting the equilibrium cap in the optimal levels of inputs and *vice-versa*, we find that both inputs increase with an increase in $\tilde{\gamma}_s$ and decrease with increases in ϕ, which carries over from their effect on the cap. The same substitution in conditions (1.12) and (1.16) shows (1.12) is always more binding, so that we take only this one. Thus, the conditions guaranteeing existence and uniqueness of non-negative equilibrium quantities are the following:

Condition 1

$$4ck_i - \alpha_{i,e}^2 > 0, i = 1, 2$$

[21] Similar to the workings of the capital to labor ratio in most production functions.

Condition 2

$$\phi \leq \frac{\bar{a}\alpha(\gamma^2 - \tau^2)}{\gamma - \tau(1 - 2q) - (\gamma^2 - \tau^2)}$$

where $\alpha = min\{\alpha_1, \alpha_2\}$.
We finally investigate the effect of uncertainty on investment in clean technology. We do so by studying the effect of an increase in the spread of $\tilde{\gamma}_s$, which essentially means an increase in τ. We first assume that uncertainty parameter follows a mean preserving spread (MPS) process, so that each of the possible states occurs with the same probability (i.e., $q = \frac{1}{2}$). Comparing the optimal values of a_i in the case of full information ($\tau = 0$) with those of uncertainty ($\tau \neq 0$), we find the that both at an aggregate level ($A = \sum_{i=1}^{2} a_i$) and at installation levels investment is always lower in the latter case. Additionally, we find that $\frac{\partial a_i^*}{\partial \tau} < 0$, so that the investment levels monotonically decrease with uncertainty. This result is perfectly in line with the predictions of the Real Option Theory and derives from the fact that a higher level of irreversible investment implies less flexibility to deal with future uncertainty. Lastly, we consider a non-MPS, and find that, whenever $q < \frac{1}{2}$ the results are maintained, and for $q > \frac{1}{2}$, they only change whenever $\tau > \hat{\tau} = \gamma(2q - 1)$. This means that increases in τ only have a positive effect on irreversible investment for the particular case where the probability that the realization is $\tilde{\gamma}_h = (\gamma + \tau)$ is very high, so that increases in τ mean increases in the average cap. Increasing uncertainty in this case would simply increase the expected cap because the probability of a high realization is so large. Our results so far are summarized in the following propositions.

Proposition 1 *If the stochastic process follows a mean-preserving spread, irreversible investment is always lower under uncertainty than with full information, both at an aggregate level and at an installation level. Moreover, the higher the uncertainty, the lower the the investment.*

Proposition 2 *If the stochastic process does not follow a mean-preserving spread, and* $q < \frac{1}{2}$ *the results are maintained. If* $q > \frac{1}{2}$*, irreversible investment is lower in than in the certainty case if and only if* $\tau > \hat{\tau}$.

1.3.2 Reversible Investment in Isolation

In the second scenario we explore, firms do not have the option of investing in the irreversible technology, but the electricity generating company may take advantage of fuel switching. In this case, firm 1 and firm 2's profit functions are given by equations (1.2) to (1.5) setting a_i to zero.[22] The profits when using coal and gas for production are, respectively, given by:

$$\pi_{i,e}(e_i;\bar{e}) = \alpha_{i,e}e_i - ce_i^2 - p(\bar{e})\left(e_i - \frac{\bar{e}}{2}\right), i = 1, 2 \tag{1.17}$$

$$\pi_{1,G}(G_1;\bar{e}) = \alpha_{1,G}G_1 - gG_1^2 - p(\bar{e})\left(\lambda G_1 - \frac{\bar{e}}{2}\right) - F \tag{1.18}$$

Since this problem involves not only continuous decisions (the optimal levels of e_i and G_1), but also discrete choices by firm 1 (whether to invest in the gas plant in $t = 1$ and which plant to use in $t = 3$) we follow a somewhat different methodology for solving it.
To begin with, we distinguish the possible behavior of the electricity company, with respect to its discrete choices. While with full information (i.e. price and cap known in $t = 1$) the power company invests in the new plant only if in the last period it is profitable to use gas instead of coal, under uncertainty this condition is maintained only under certain values of the fundamentals (τ, γ and ϕ). For other values, however, the company might not find it profitable to use gas, after having invested, depending of the realization of $\tilde{\gamma}$. In the latter case, if the regulator is more biased towards the environment ($\tilde{\gamma} = \tilde{\gamma}^l$), the cap is tighter, the permits' price is higher and, for given fuel prices, it is more profitable for the firm to produce by using gas, which requires it to hold a lower quantity of permits.[23] On the contrary, if the regulator is more willing to boost the economic activity $\tilde{\gamma} = \tilde{\gamma}^h$, the cap is higher, the allowances' price is lower, and the firm prefers to use the option to switch back to coal, given that $c < g$. Consequently, we distinguish between three possible cases, which correspond to the two discrete decisions of firm 1:

- *Case 1 (NI):* Firm 1 does not invest;

[22]Since $\bar{a}$ is fixed, it becomes just an increase in productivity. So, we can set it to 1 without loss of generality, leaving the firms with a one-input production function.
[23]Recall from Section II that gas emits less CO_2 than coal and it is also more productive.

- *Case 2 (INS):* Firm 1 invests and never switches;
- *Case 3 (IS):* Firm 1 invests and

$$\begin{cases} \text{switches} & \text{if } \tilde{\gamma} = \tilde{\gamma}_h \\ \text{does not switch} & \text{if } \tilde{\gamma} = \tilde{\gamma}_l \end{cases}$$

Note what differentiates the last two cases are the fundamentals, namely the values of γ,τ and q, which are known by all agents from the first period, while what matters for the switching decision of the firm in the third case is particular realization of $\tilde{\gamma}$. We start by studying the two investment conditions: one assuming the fundamentals are such that firm 1 never switches after having invested - and so we compare firm 1's profit in the first two cases (*INS versus NI*); and another assuming that firm 1 might switch after the investment - for which we perform the comparison between firm 1's profit in third and first cases (*IS versus NI*).

The most interesting case, however, is the latter, since it involves the situation where the firm switches and takes advantage of the reversibility of the technology. Thus, we assume the conditions are such that if the firm invests, it will switch to coal when $\tilde{\gamma} = \gamma + \tau$, and solve the model for this case. In order to find an equilibrium, we first assume it is not optimal for the firm to invest, and calculate the optimal quantities in a similar fashion to the case of only irreversible technology. The policy maker's cap is, thus, her best response to the quantities in the case where the firm is not investing in the gas plant, according to her type (h or l). We then assume it is optimal to invest and repeat the procedure.[24] All the equilibrium quantities, $e^*_{i,s}$, $\bar{e}^*_s$ and p^*_s, for each of the two cases (*NI* and *IS*), have the same properties as the ones derived above, and $G^*_{1,s}$ is analogous to the optimal level of coal. Additionally, we find that in equilibrium, firm 2's choices of $e^*_{2,s}$ are equal for both

[24]Notice that the cap set by the regulator in equilibrium is different depending on whether the firm invested or not. Due to market interactions, the optimal level of coal resulting from firm 2's profit maximization in this case might also be different from that of the case where firm 1 does not invest.

the *NI* and *IS* cases. The resulting expected profits for firm 1 are, therefore,

$$E[\pi_{1,NI}(e_s^*;\bar{e}_{s,NI}^*)] = q[\alpha_{1,e}e_h^* - ce_h^{*2} - p_{h,NI}^*(e_h^* - \frac{\bar{e}_{h,NI}^*}{2})] \\ + (1-q)[\alpha_{1,e}e_l^* - ce_l^{*2} - p_{l,NI}^*(e_l^* - \frac{\bar{e}_{l,NI}^*}{2})] \quad (1.19)$$

$$E[\pi_{1,IS}(e_h^*, G_l^*;\bar{e}_{s,IS}^*)] = q[\alpha_{1,e}e_h^* - ce_h^{*2} - p_{h,SI}^*(e_h^* - \frac{\bar{e}_{h,SI}^*}{2})] \\ + (1-q)[\alpha_{1,G}G_l^* - gG_l^{*2} - p_{l,SI}^*(\lambda G_l^* - \frac{\bar{e}_{l,SI}^*}{2})] \quad (1.20)$$

for $s = h, l$.[25]

In order to explore the firm's investment decision, we need to compare the two expected profits. However, since the firm is a price taker, it does not take into account its own effect on the price and the cap. Therefore, when the company makes its investment decision it does not compare the two expected profits described above directly.

Our equilibrium is, therefore, constructed in the following manner. We first assume it is an equilibrium for the representative firm to invest. This means all the continuum of firms invest, so that the equilibrium cap and price are $\bar{e}_{s,IS}^*$ and $p_{s,IS}^*$. Then, we check if this is the case; that is, if there does not exist any profitable deviation. We do so by comparing the profit of the representative firm when investing (and switching) with that of not investing, when the cap and the price are those prevailing assuming the firm is investing:

$$E[\pi_{1,IS}(e_h^*, G_l^*;\bar{e}_{s,IS}^*, p_{s,IS}^*)] - E[\pi_{1,NI}(e_h^*, e_l^*;\bar{e}_{s,IS}^*, p_{s,IS}^*)] > 0, s = h, l \quad (1.21)$$

We then repeat the procedure assuming it is an equilibrium not to invest, and compare:

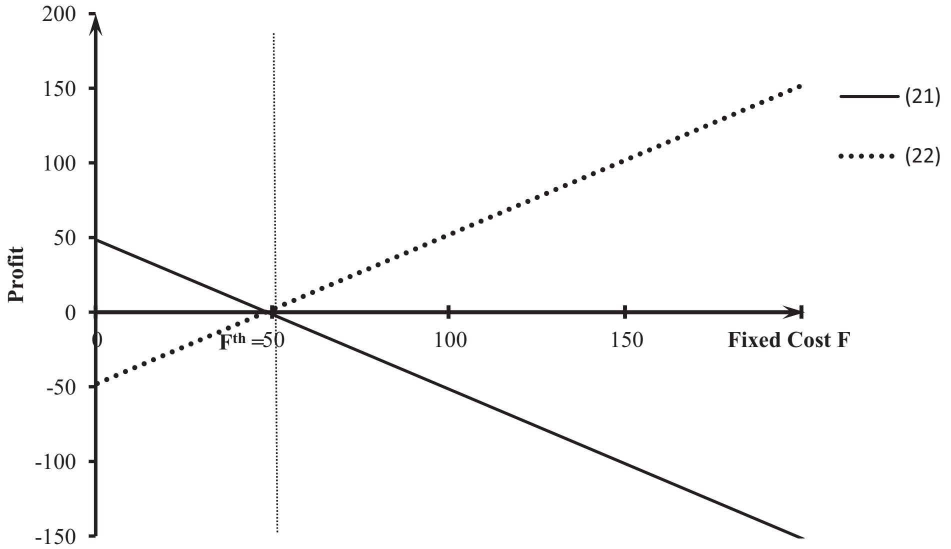
$$E[\pi_{1,NI}(e_h^*, e_l^*;\bar{e}_{s,NI}^*, p_{s,NI}^*)] - E[\pi_{1,IS}(e_h^*, G_l^*;\bar{e}_{s,NI}^*, p_{s,NI}^*)] > 0, s = h, l \quad (1.22)$$

Considering, once again, a MPS we find that there is a threshold on F, F^{th}, such that, for $F < F^{th}$ firm 1 is better off investing, both when the cap is $\bar{e}_{s,IS}^*$ and $\bar{e}_{s,NI}^*$, and prices

[25]The expected profit for firm 2 is analogous to the previous case.

are $p^*_{s,IS}$ and $p^*_{s,NI}$. The opposite is true when $F > F^{th}$.[26]
We therefore find a unique equilibrium, given the fundamentals of the economy, consisting of the equilibrium quantities above, the system of beliefs of firms, given by q, the threshold for investment and the condition for switching, determined further below.
Finally, for easiness of interpretation, we analyze the equilibrium imposing restrictions on some of the parameters that are not central to our analysis. The calibration procedure is described in Appendix 1.C. With these values, we plot equations (1.21) and (1.22). In Fig.1.3 we present the graph for the particular case of $\gamma = 0.5$ and $\phi = 280$, which in our framework describe a policy maker with balanced preferences. The figure shows that, for

Figure 1.3: Investment decision for firm 1



$F < F^{th}$, the firm has a higher profit when investing in the gas plant, both when the cap is set optimally for this choice (positive part of the curve representing (1.21)) and when the cap is set optimally for NI (negative part of curve (1.22)). For $F > F^{th}$ the firm no longer has an incentive to invest: equation (1.21) becomes negative, and (1.22) positive, meaning that for any of the two caps, the firm is better off not investing.
The same procedure was followed to find an equilibrium in the case where the firm never switches to coal, once it has invested (INS). We find that the threshold for investing is

[26] We assume that, when indifferent, i.e., $F = F^{th}$, the firm invests.

larger since the company is willing to pay more for an investment that it is sure it will use. In a similar graph to that of Fig.1.3, this corresponds to a jump of the two curves to the right.
To complete the analysis for the reversible technology case, we find the conditions under which the firm switches. We proceed in the same manner as before, by assuming an equilibrium in the last period, and then checking for profitable deviations. Additionally, and since the regulator can influence the firm's decision to switch because the cap is set before this, we compare her utility under each of the cases, to find unique conditions.

We find that the switching decision depends on a the relative environmental preference of the regulator weighted by the marginal emission damage:

$$\varphi = \frac{(1-\gamma)}{\gamma}\phi \tag{1.23}$$

In particular, we find a critical point, φ^{th}, for which the switching decision depends on τ. Specifically:

1. If $\varphi < \varphi^{th}$, $\forall\tau$ whenever firm 1 invests it switches for a high realization;
2. If $\varphi > \varphi^{th}$, the firm switches only if $\tau > \tau^{th}$ (i.e., if the spread of the uncertainty parameter is very high).

The effect of uncertainty on this reversible investment depends on the region of these parameters:

- If we are in the first case ($\varphi < \varphi^{th}$) and the firm always switches, then increases in the spread of $\tilde{\gamma}_s$ (τ) increase the threshold for investing, F^{th}, so that there is more investment in equilibrium. This effect can be seen in Fig.1.3 as a movement of all the curves to the right.
- Whenever $\varphi > \varphi^{th}$, and $\tau < \tau^{th}$, the firm does not switch, and, therefore, investing in the gas plant is equivalent to an irreversible investment.[27] Therefore, the effect of uncertainty is negative.[28]

[27] This result is in line with the analysis of Blyth et al. (2007).

[28] In the analogous graph to the one in Fig.1.3, but for the comparison between NI and INS, which we do not present due to space restrictions, the two curves move to the left as τ increases, decreasing the threshold for investment.

- Finally, in the case where $\varphi > \varphi^{th}$ and $\tau > \tau^{th}$, the firm switches under the high realization of uncertainty, but increases in τ lead to decreases in investment.

Our results differ from those of Chen and Tseng (2011), where reversible investment always increases with uncertainty, due to the output effect: because firms are able to adjust their fuel quantities after uncertainty is resolved, they find it more profitable to decrease production than investing in a gas plant, if there is the possibility of a very low level of the cap, which follows from the existence of an environmentally-biased regulator ($\varphi > \varphi^{th}$) and a high level of uncertainty ($\tau > \tau^{th}$).

Proposition 3 *If firms are allowed to vary their output, reversible investment increases with uncertainty only for some values of the fundamentals of the economy.*

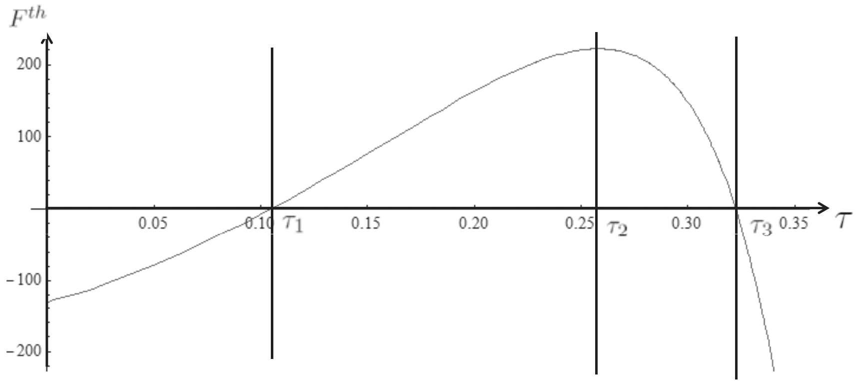
In a nutshell, if the authority is more biased towards the economy (either because the marginal damage is high, or γ is low), then uncertainty may have a positive effect on reversible investment, when it is considered in isolation. On the other hand, when the policy maker is more environmentally-oriented (either because γ is very high, or ϕ is low), uncertainty is never beneficial for investment.

1.3.3 Complete Environment

We now turn to the complete model, where both reversible and irreversible investments are available for the power generating firm, and the latter for the firm representative of the industrial sector. The procedure for solving is similar to that of subsection *1.3.2*, but incorporating the first period choices of a_i, as determined in subsection *1.3.1*.
Firms now have different optimal decisions on the level of clean technology according to the discrete reversible investment choice of firm 1: a_j^*, $j = INS, IS, NI$. This is because the power sector company adjusts its level of the irreversible technology, so as to maximize its profit, according to the productivity associated to the fuel it expects to use. Then, due to market interactions that affect the prevailing cap, we also allow firm 2 to decide on diverse levels of investment according to the fuel choices of firm 1, although in equilibrium, we find that they do not differ. This gives rise, in equilibrium, to three different levels of irreversible investment for firm 1, one for each of the three cases (*NI, IS, INS*) and only one for firm 2. When comparing these results with those of the model in subsection *1.3.1*,

we find that $a^*_{1,INS} > a^*_{1;IS} > a^*_{1,NI} = a^*_{1,isol}$.[29] This means that the higher the probability of the firm using gas in production, the higher is the level of a^*_1.[30]
All the comparative statics for the equilibrium levels of the continuous variables above are maintained. In particular, aggregate investment in the irreversible technology always decreases with uncertainty.
As for the discrete choice of switching, we follow the procedure described before to find a threshold on $\frac{(1-\gamma)}{\gamma}\phi$, call it $\varphi^{th'}$, for which the decision to change fuels once invested depends on τ. Our results confirm that, also in the full setting, when the government is more biased towards the environment, $\varphi > \varphi^{th'}$, the power company switches whenever $\tau > \tau^{th}$, and uncertainty always decreases investment in the reversible technology. However, in the case of a government more incline towards economic activity, i.e. $\varphi < \varphi^{th'}$, where firm 1 decides to switch for any $\tau > 0$ after investing, the results change when the choice of the irreversible technology is included in the model. The present scenario is characterized by two features: firstly, for low levels of uncertainty the firm never invests; secondly, the positive effect of uncertainty on the reversible investment level, observed in isolation, vanishes for high levels of τ. Fig.1.4 depicts the threshold for investment, F^{th}, as a function of τ for a given $\varphi < \varphi^{th'}$ and it allows to identify these outcomes.[31] There are

Figure 1.4: Investment in Reversible Technology



[29]The level of a^*_2 remains unchanged.
[30]This is because, on average, a_1 represents an addition to the productivity of the fuel, as the two inputs are complements.
[31]We again use the calibration described in Appendix 1.C. We set again $\gamma = 0.5$ and now $\phi = 150$, such that the constraint on φ is satisfied.

four regions of interest and, consequently, three additional thresholds for τ. For low levels of uncertainty, $\tau < \tau_1$, reversible investment increases with uncertainty as in subsection 3.2 but firms never invest. This is because, even if $F = 0$, the firm always has a lower profit investing in the gas plant than not investing. This effect can be traced to the equilibrium behavior of the regulator: the introduction of the possibility of a_i in the firms' production functions allows the policy maker to lower the cap, since the same level of production can be attained emitting less CO_2. This lower limit on emissions, in turn, decreases both the equilibrium levels of $e_{1,s}$ and $G_{1,s}$ which, as set out before, decrease the firm's expected profit in different ways. Specifically, the firm's profit function $\pi_{1,G}$ is much more responsive to changes in $G_{i,s}$ than $\pi_{1,e}$ is to changes in $e_{1,s}$, so that $\frac{\partial \pi_{1,G}}{\partial \bar{e}} > \frac{\partial \pi_{1,e}}{\partial \bar{e}}$. Additionally, this relationship is not linear in $\bar{e}$: for higher values of the cap, the variation in profits is higher than for lower ones. Consequently, the introduction of a_i leads an economically biased authority to set a cap for which it is no longer profitable for the firm to invest in a gas plant. In the case of the more environmental policy maker described above, however, this effect is not enough to eliminate investment, due to the lower expected cap associated with this regulator type.

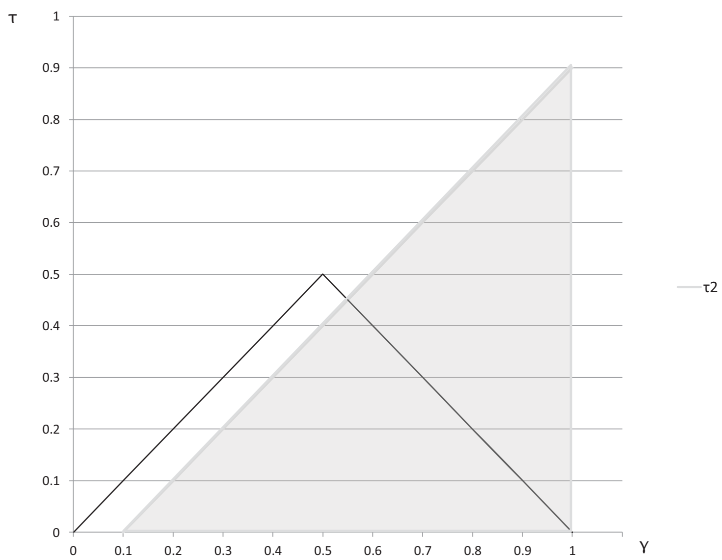
The second region refers to $\tau_1 < \tau < \tau_2$, where the power company invests in the reversible technology and uncertainty maintains the positive effect on investment found in subsection 3.2 as it represents a means to insure itself against future potential high permits price.

When $\tau > \tau_2$, however, uncertainty has a negative effect over investment in the reversible technology. This is derives from the negative impact of uncertainty over the irreversible investment. Since the profit of the firm using gas is more sensitive to changes in the level of the clean technology, a_{IS}, than the the profit when using coal, it decreases faster as a_{IS} diminishes. This effect now prevails over the hedging motive and reversible investment decreases with uncertainty. Thus for $\tau_2 < \tau < \tau_3$, the firm still invests but the higher the uncertainty the less the investment made is. Additionally, for $\tau > \tau_3$ the firm does not find it profitable to invest, for any fixed cost F. The following proposition summarizes this result:

Proposition 4 *In a comprehensive setting with output variation the introduction of irreversible investment decisions partly eliminates the possibility of a positive effect of uncertainty on reversible investment found for governments biased towards the economy.*

We further study the second threshold for τ, which is derived as the value for which $\frac{\partial \pi_{IS}}{\partial \tau} = 0$, and captures the point where there is a change in the sign of the effect that uncertainty has over reversible investment. Fig.1.5 plots this threshold for different levels of γ and for a given marginal damage $\phi = 50$. If τ is below the threshold, namely within

Figure 1.5: Threshold for positive effect



the shaded area, uncertainty leads to a higher investment level. On the contrary, for τ higher than the threshold uncertainty has a negative effect on investment. The triangle delimitates the maximum τ possible for each value of γ, so that τ has a positive effect on reversible investment only in the shaded area under the triangle. Note that τ_2 is increasing with γ. This means that for policy makers more biased towards the economy,[32], the higher their bias, measured by γ for given ϕ, the higher the maximum level of uncertainty that stimulates investment.

The main results of the complete model can be summarized in Table 1.1.

[32]Recall that we are in the case of $\varphi < \varphi^{th'}$

Table 1.1: Final effect of uncertainty on investment

Parameters	**Preferences**	**Uncertainty Reversible**	**Uncertainty Irreversible**
$\varphi > \varphi^{th'}$	Environment	Negative	Negative
$\varphi < \varphi^{th'}$	Economy	Positive if $\tau < \tau_2$	Negative
		Negative if $\tau > \tau_2$	Negative

In a setting which mimics the real world interaction in investment decisions, these results mean that if the authority has clear long run environmental goals such as the Kyoto Protocol, policy uncertainty is not likely beneficial for any type of investment in low-carbon technology. On the contrary, for an emerging country clearly prioritizing economic growth or for a developed one with a strong industrial lobby, such as the United States of America, some level of uncertainty might stimulate the development of a low-carbon economy. In fact, this uncertainty will allow for a transition period through the use of a less carbon-intensive fuel (gas), towards the implementation of clean technology, such as renewable energy and energy efficiency.

1.4 Welfare Analysis

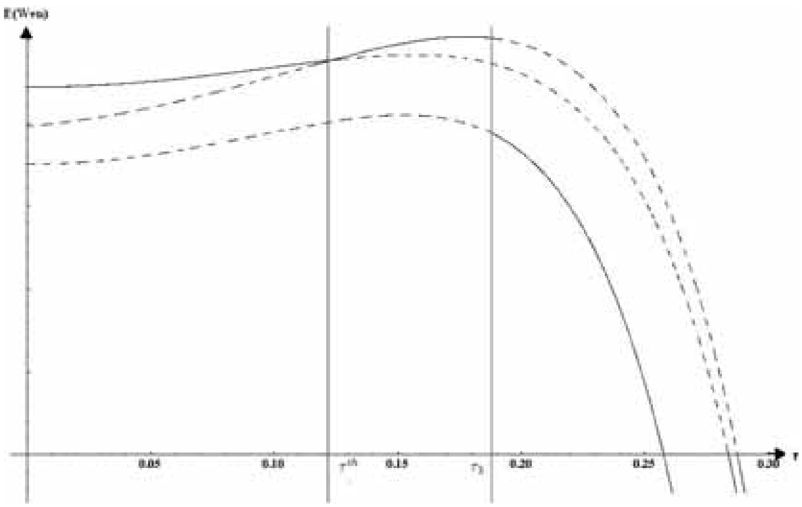
In the previous sections we focused solely on understanding the channels through which uncertainty affects investment in low-carbon technology. We now turn to the question of how much uncertainty, and therefore investment, is optimal from a welfare perspective.
Following Colla et al. (2012) and Germain et al. (2004) in similar analysis, we use the regulator's objective function as a measure of aggregate welfare. This means that ex-ante welfare is a weighted average of the profits in the economy and the disutility of the environmental damage from emissions. We therefore perform a partial welfare analysis that does not consider other uncertainties that might interact with the optimality of the decision-making process - for example, policy uncertainty may be beneficial in terms of welfare if it acts as a stabilizer for the economy, of if the flexibility it entails allows the policymaker to adjust the stringency cap to the current state of technological process.
As in the investment analysis, our results differ depending on the parameter regions that define the optimal choices of the firms - that is, on φ. Accordingly, expected welfare for

an environmentally concerned government, $E(W_{en})$, becomes the following discontinuous function:

$$E(W_{en}) = \begin{cases} qR\left(G^*_{1,h}, e^*_{2,h}, a^*_1, a^*_2, \bar{e}^*_{h,INS}\right) + (1-q)R\left(G^*_{1,l}, e^*_{2,l}, a^*_1, a^*_2, \bar{e}^*_{l,INS}\right) & \text{if } \tau < \tau^{th} \\ qR\left(e^*_{1,h}, e^*_{2,h}, a^*_1, a^*_2, \bar{e}^*_{h,IS}\right) + (1-q)R\left(G^*_{1,l}, e^*_{2,l}, a^*_1, a^*_2, \bar{e}^*_{l,IS}\right) & \text{if } \tau^{th} < \tau < \tau_3 \\ qR\left(e^*_{1,h}, e^*_{2,h}, a^*_1, a^*_2, \bar{e}^*_{h,IS}\right) + (1-q)R\left(G^*_{1,l}, e^*_{2,l}, a^*_1, a^*_2, \bar{e}^*_{l,IS}\right) & \text{if } \tau > \tau_3 \end{cases}$$

The resulting welfare can be seen in Fig.1.6 using the calibration described in Appendix 1.C and $\varphi > \varphi^{th'}$.

Figure 1.6: Welfare function: environmentally biased authority.



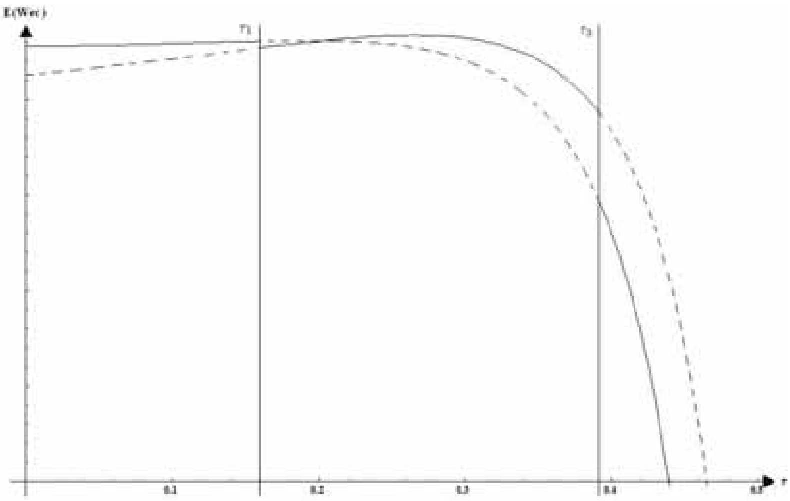
The welfare function is represented by the solid lines, and the two vertical lines correspond to the τ thresholds for switching and investing. When $\tau < \tau^{th}$ the electricity firm chooses to invest in a gas plant and never switches back to coal. Even though the higher the uncertainty (τ) the smaller the investment (see Section 3.3), welfare is a concave function of uncertainty. In fact, faced with higher uncertainty, firms will decrease not only clean technology investment but also output, and therefore emissions. The consequent positive effect of lower emissions on welfare more than offsets the losses in terms of output. When $\tau^{th} < \tau < \tau_3$, the electricity firm invests in the reversible technology but switches to coal whenever there is a high realization of the cap. Here, the previous effect is intensified because the emission reduction is higher given that coal is more carbon-intensive than gas. Finally, for $\tau > \tau_3$, the power sector representative firm is no longer investing in low-carbon technology, and the decreases in production driven by very low levels of the clean technology overcome the gains from lower emissions, leading to a rapidly decreasing welfare. Thus, for environmentally concerned governments, even though any level of uncertainty decreases all types of investment in low-carbon technology, expected welfare is maximized for a positive level of τ. This partial equilibrium analysis excludes however any long-run benefits of boosting investment in the short-run, both in environmental terms and in terms of technological development.

Finally, when the government is more economically biased the firms' optimal decisions change and the expected welfare is defined accordingly:

$$E(W_{ec}) = \begin{cases} qR\left(e^*_{1,h}, e^*_{2,h}, a^*_1, a^*_2, \bar{e}^*_{h,IS}\right) + (1-q)R\left(G^*_{1,l}, e^*_{2,l}, a^*_1, a^*_2, \bar{e}^*_{l,IS}\right) & \text{if } \tau_1 > \tau > \tau_3 \\ qR\left(e^*_{1,h}, e^*_{2,h}, a^*_1, a^*_2, \bar{e}^*_{h,NI}\right) + (1-q)R\left(e^*_{1,l}, e^*_{2,l}, a^*_1, a^*_2, \bar{e}^*_{l,NI}\right) & \text{otherwise} \end{cases}$$

This is depicted by the solid lines in Fig.1.7, for the same calibration and $\varphi < \varphi^{th'}$. As the figure shows, also here the expected welfare is maximum for a positive level of

Figure 1.7: Welfare function: economically biased authority.



uncertainty. Only in the extreme case of a very low damage of emissions (ϕ) welfare would be higher for the minimum uncertainty - here, low uncertainty and cheaper permits would allow for a high level of output without the cost of reversible investment for hedging purposes.

1.5 Conclusion

In the context of a carbon dioxide Emission Trading Scheme, we study how uncertainty over the policy rule, driven by periodicity of the aggregate cap, affects firms' investment in low-carbon technologies. We formulate a three period sequential model that puts together the two sectors regulated by the European scheme and encompasses both irreversible and reversible investment possibilities for the firms. Additionally, we explicitly model the policy uncertainty as the relative priority the regulator puts on economic activity with respect to environment concerns and we assume that it follows a mean preserving spread process. The results of previous literature carry over to our enlarged framework as far as irreversible investment is concerned. Namely, we find uncertainty always reduces investment levels. Regarding reversible investment taken in isolation, our results differ with respect to previous literature. Specifically, allowing firms to change their production *ex post* provides them with an additional instrument to cope with uncertainty (output effect), which mitigates to some extent the positive effect of uncertainty in reversible investment. Finally, in a complete setup, we show that introducing the additional possibility of irreversible investment partially eliminates the potential positive effect of policy uncertainty on reversible technology. The negative effect of uncertainty on irreversible investment carries over to the profitability of the reversible one, so that for higher levels of uncertainty this effect becomes negative.
To sum up, we find that only when policy makers are concerned primarily with economic expansion, relative to environmental issues, a small level of uncertainty might increase reversible investment, by making it a profitable opportunity. This situation might take place in developing countries, where often growth concerns relegate environmental issues to the background. On the contrary, in the case of the European Union, where we observe a higher environmental awareness, with clear long run green policy goals, policy uncertainty most likely has a negative effect on all investment in low-carbon technology. In this case the introduction of commitment mechanisms that reduce long-term uncertainty

would help to create the right incentives to reach the CO_2 reduction target of the policy. These could consist, for example, of the setting of a long-term limited range for the cap, which would be enforceable by law, thereby binding future governments. These mechanisms should however guarantee the minimum flexibility required to adjust to unforeseen changes of the technological process or to stabilize economic shocks.

Our analysis abstracts from features of permit markets that might have considerable impact on our analysis. The first is that we assumes a constant demand and prices for firms' output. As input prices increases and demand is constant, prices are likely to adjust thereby increasing the firms' profitability. If this is the case the effect of policy uncertainty might be substantially buffered. The second is that we do not consider the possibility of permit banking introduced in the third phase of the *EU ETS*. Banking endows firms with another instrument to hedge against uncertainty, thereby constituting an important substitute to both reversible and irreversible investment. An interesting extension to our model would be to analyze the final effect in terms of both investment and emissions.

Appendix

1.A The EU ETS and Policy Uncertainty

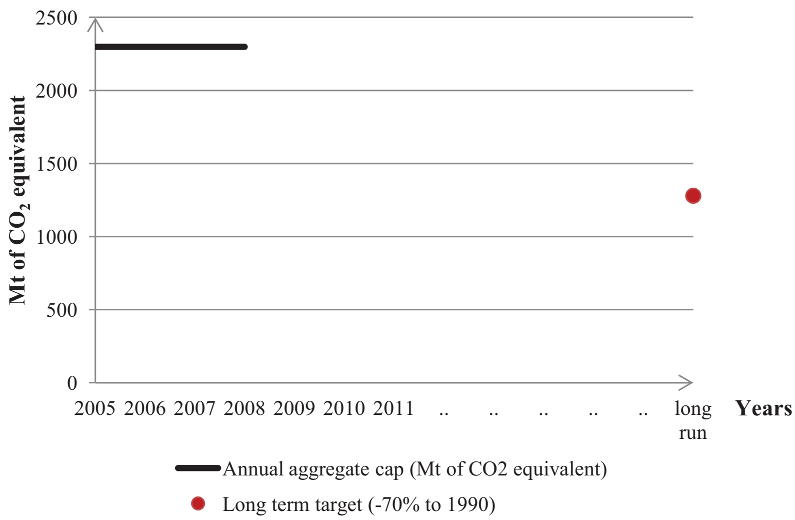
Launched in 2005, the *EU ETS* is a market based approach that relies on the companies' cost differential of reducing emissions. The current scheme involves two sectors: power companies and carbon-intensive industries. Industries covered include factories producing cement, lime, glass, brick, pulp and paper, oil refineries, coke ovens, iron and steel.[33] Each of these installations receives annually an allocation of permits which corresponds to the total amount of CO_2 it is entitled to emit during the production processes. At the end of a specified trading round, each participant is required to hold permits representing its total emissions for the period.[34] Companies that exceed their quotas are allowed to buy unused permits from those that have excess supply, as a result of investment in abatement or of reduction in their production level. These permits are called European Union Allowances

[33]Petro-chemical and aviation will be part of the scheme in 2012-2013.

[34]From the second phase of the scheme, firms are allowed to bank and borrow their permits among different periods and phases of the scheme, namely to smooth the usage of their permits inter-temporally.

(EUA) and are traded in a specific platform, one EUA corresponding to the right to emit one ton of CO_2. Participants who do not meet this requirement are subject to financial penalties.
Until 2008 the authority opted for a grandfathering type of allocation, namely based on historical emissions levels, but from 2013 the scheme will move towards an allocation rule based on benchmarking and auctioning.[35] The total amount of the allocated permits constitutes the cap. Both the cap and the allocation are set by the regulatory authority. Until 2008 the allocation decision was made by national authorities through the National Allocation Plans, while from 2013 this decision has been centralized at the European level. The authority decides on the level of the cap period by period but considering long run targets. These periods are called *phases* and they differ in length. Fig.1.8-1.10 depict for each of these phases the information available to firms regarding the future aggregate cap. Directive *2003/87/EC* set the goal of achieving an 8% reduction in emissions of

Figure 1.8: Annual aggregate cap as known in 2003. Source: European Commission.

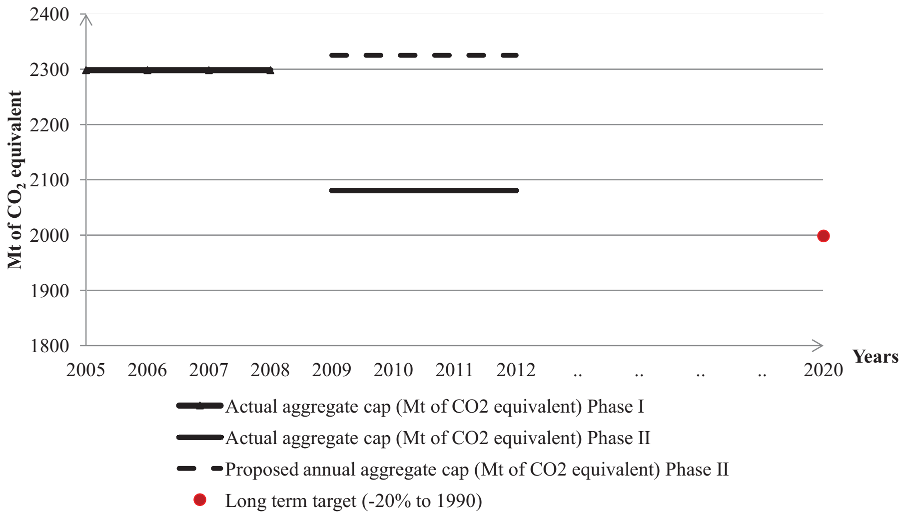


greenhouse gases by 2008 to 2012 compared to 1990 levels, and established a long-run goal of reducing emissions of greenhouse gases by approximately 70% compared to 1990 levels.

[35]This additional feature should not change our results. In fact, assuming that the auction revenues are redistributed by the authority as lump sum to the same firms, the regulator's objective function is not affected.

The only cap set precisely was that of the first phase, 2005-2007 (Fig.1.8). This means that each regulated firm had to plan its long term investment, which has a payback period estimated in around 15 years, without knowing the aggregate cap level, and therefore its allocation of allowances, from 2008 onwards, but assuming a tighter cap in the future given the long term reduction goal (-70% compared to 1990 levels). In 2007, the cap for the

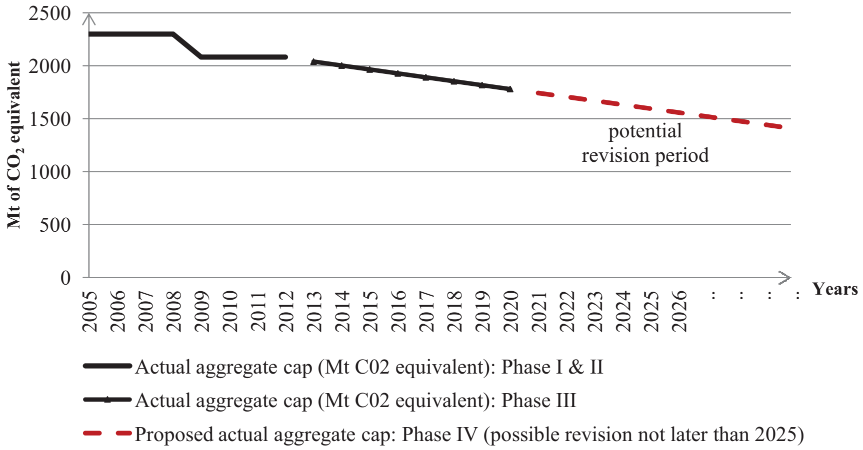
Figure 1.9: Annual aggregate cap as known in 2007. Source: European Commission.



period 2008-2012 was set to 2177MtCO_2, thereby correcting the previously announced one (dashed line in Fig.1.9). As reported by the EU Press Release IP/07/1614 of 26/10/2007, the European Commission also made a unilateral commitment that Europe would cut its emissions by at least 20% of 1990 levels by 2020, to be implemented "through a package of binding legislation". Although this implies a higher commitment of authorities towards lower emissions, also in this phase economic agents were uncertain about the cap level after 2012. Moreover the unexpected revision dictated by the over-allocation from the first phase increased even more the perceived volatility of the future cap level.

Finally, as shown in Fig.1.10, for the period 2013-2020, the cap corresponds to a trajectory. Specifically, it "will decrease each year by 1.47% of the average annual total

Figure 1.10: Annual aggregate cap as known in 2010. Source: European Commission.



quantity of allowances issued by the Member States in 2008-2012", according to directive *2010/634/EU*, starting with a cap of 2039MtCO_2. However, after 2020, the cap level is still unclear: it is stated that "this annual reduction will continue beyond 2020 but may be subject to revision not later than 2025". As underlined above, given the long term nature of low-carbon investments (around 15 years), this uncertainty over the policy instrument, the cap, may affect aggregate investment.

1.B Gas transition in the European power sector

For the choice of reversible investment we used the possibility for electricity generating firms to produce with gas or coal, according to which is more profitable. The following table reports the percentage of coal and gas used in the production mix of the power sector in different European countries in 1990 and 2010, as evidence of the relevance of gas as a production output. Coal is clearly substituted out, mostly by gas, in all the countries considered. This is not only a feature of the European Union, but a worldwide trend of employing gas in the electricity generation process.

Table 1.2: Coal and gas in the energy mix. Source: Enerdata and IEA.

Percentage of coal and gas in the energy mix (1990-2010)				
	Coal		Gas	
	1990	2010	1990	2010
Germany	58%	44%	7%	13%
Italy	17%	14%	19%	53%
Spain	40%	11%	1%	32%
United Kingdom	65%	28%	1%	46%

1.C Calibration

We present the parameter restrictions used for the interpretation of the results. As previously pointed out, this calibration exercise is dictated by the complexity of the analytical solutions.

Given the richness of information provided by the UK Government Department of Energy and Climate Change, we take the British market as a benchmark for the calibration of the parameters that are country dependent.

Productivity. We calibrate three different productivity parameters: one for the power sector when the plant is run by using coal ($\alpha_{1,e}$), one when the plant produces by using gas($\alpha_{1,G}$), and, finally, one for the industries sector which produces always by using coal (α_2). We consider the productivity of gas (output per 1000 cubic meters), adjusted for the thermodynamic efficiency of an average gas power plants, to be equal to 11 MWh/dam^3 (calorific value=40). For the coal, the adjusted productivity is set at 6.68 $MWh/tonne$. As mentioned in Section III, these parameters include also the price of the output. This means, for instance, that to calibrate ($\alpha_{1,e}$) we have to multiply the productivity of a power plant using coal by the retail price of electricity. For the first two parameters, ($\alpha_{1,e}$) and ($\alpha_{1,G}$), we use the Energy Prices and Taxes Statistics of the International Energy Agency, and take the annual average UK retail prices excluding taxes (in pounds per kWh) as a proxy for the price of electricity. Specifically, the annual average of UK end-of-use electricity price from 2006 to 2010 is 137 Euro per MWh (applying the current exchange rate). For the industrial sector we choose four industries regulated by the *ETS*: Steel, Cement, Pulp and Aluminium,[36] and we construct an industrial sector productivity

[36]The latter will be included in the scheme in 2013.

index. Therefore (α_2)is the defined as $\sum_{j=1}^{4} p_j \nu_j$, where j is the industry index, p_j is the output price of industry j, and ν_j is the output per ton of coal ratio for industry j. Industry data is taken from sector associations while average output prices are collected from London Metal Exchange. The particular values follow. Cement UK industry: $\nu = 0.78$, $p = 70$ Euro/t; Steel UK industry: $\nu = 1$, $p = 400$ Euro/t; Aluminium UK industry: $\nu = 0.7$, $p = 1800$ Euro/t; Pulp EU industry:[37] $\nu = 0.83$, $p = 480$ Euro/t. Summing up, the three adjusted productivity parameters are the following: $\alpha_{1,e} = 339.9$, $\alpha_2 = 528.25$, $\alpha_{1,G} = 509.6$, and they are consistent with the observed fact that gas is more productive than coal.

Inputs Cost. As mentioned in previous sections, $C(e)$ and $C(G)$ are the operating costs of the fuels and we assume them to be convex in order to comprise not only the price of fuels, but also the storage and opportunity costs. As a proxy for c and g, we use UK government statistics on average prices of fuels purchased by the major UK power producers:[38] $c = 62$ $Euro/t$ and $g = 185.9$ $Euro/dm^3$.

Emission Factor. λ is the proportion of CO_2 emitted by one unit of gas, as compared to that of one unit of coal. Given that the amount of CO_2 generated by one unit coal equals 2.86 ton and the CO_2 emitted by gas is 0.0019 t/m^3, after the required measurement transformations, we get that the relative emission produced by one cubic meter of gas is 0.8.

Investment Costs for Irreversible Investment. k_2 and k_1 represent the cost that industries incur in to improve their energy efficiency and that power companies have to pay to invest in renewables, respectively. As evidence suggests that these values differ considerably depending on the technology, we do not assign any value to these parameters and we let them be restricted only by the conditions indicated in the Section IV.

Finally note that, given the stylized three period nature of the model, most of the model parameters do not have a direct correspondent to reality, where the time horizon is more extend and involves several repetitions of investment and production decisions.

[37]Due to absence of pulp production in the UK we use EU data as the ETS is a European Market.

[38]Given that the average annual prices of coal purchased by the manufacturing industry in the UK is very close to the cost of coal paid by power producers, we use the same average for both sectors.

Chapter 2

Pork Barrel as a Signaling Tool: The Case of US Environmental Policy

2.1 Introduction

It is a well documented fact that economic decisions are distorted by electoral competition, across a variety of issues.[1] One particular tool used by politicians in order to obtain political advantage is the assignment of benefits to particular groups, geographically or otherwise determined. These benefits, typically called pork barrel,[2] might take the form of increases in highly visible local public goods, approval of particular projects, or even transfers from the central government. Pork barrel is often used in legislatures as a "currency" to build coalitions that allow to pass general interest legislation, but it is also an instrument in electoral competition used by incumbent politicians to gain the voters' support. And while in the former case it might generate benefits, by *greasing the wheels* of the legislative process (Evans, 2004), election-motivated changes in the composition of spending are widely accepted as constituting efficiency losses: by distributing pork when the budget is limited and fixed, politicians deviate from the welfare maximizing level of collective goods (Hicken and Simmons, 2008). Assessing the mechanism that is behind them, and the incentives to perform these policies is, therefore, of significant importance. This chapter aims at providing an insight into the mechanism generating election-year pork barrel policies, particularly regarding expenditures in goods or services likely to have strong support from some citizens, by deriving theoretical implications from a simple model and testing them empirically. It evaluates whether signaling is a driving force behind pre-electoral pork, where *signaling* refers to the conveying of preferences of the politician, true or not, through enacted policies. The idea is that politicians cannot commit to implement policies that they do not favor, and in the absence of this commitment,

[1] See Brender and Drazen (2005) for an empirical study on a large panel of countries.

[2] The expression is said to have originated in the pre civil war United States, when barrels of salt pork were given to slaves, who were required to compete for a share of it.

they use current policies to signal preferences, which are persistent over time, to the electorate. The implications of the model are tested on United States (US) environmental policy. Environmental policy is particularly prone to political pressure. The fact that it triggers strong opinions from the electorate renders it particularly suitable to test the current model.

I develop a two-period model of electoral competition, based on the framework of Persson and Tabellini (1999), where an incumbent divides a fixed budget between a national public good and expenditures on three "particularistic" issues - one of which is environmental spending - that assign extra benefits for those voters with strong preferences for them. Here, however, the politician is both policy and office motivated, and there is no commitment. Politicians are citizens who have themselves preferences for different types of expenditures. Thus the incumbent in the first period chooses her policy so as to maximize her utility, which depends on her policy preferences and the probability of being re-elected. Voters are rational, forward-looking, and informed about economic policies but imperfectly informed about the preferences of the politician. So they use current policies to infer them through bayesian updating: an increase in expenditures might mean the politician is performing pork barrel or that she has a genuine preference for them. The concept of probabilistic voting is used to solve the model. Finally, all agents are also ideologically biased.

The model generates conditions under which pork barrel arises as a political equilibrium for signaling purposes, that it, when pork is credible or *effective* in changing imperfectly informed voters' beliefs. I find that this occurs less when the politician's discount factor is higher than a threshold, and when she cannot be re-elected (she is a "lame duck"). These findings are consistent with previous results of downsian models. The former occurs because a high discount rate decreases the incentives of an incumbent to seek re-election through pork. So for example establishing terms limits should decrease the amount of pork, even if these are not binding in a given election. The latter is straightforward to understand - in the absence of re-election incentives, the politician does not have incentives to signal. Finally, I find that pork spending with signaling purposes occurs less towards the most ideologically dispersed group. This happens because in practice pork shifts the identity of the swing voter in the group receiving it towards the ideology of the incumbent. So by targeting voters more densely concentrated ideologically the incumbent is able to shift more votes with the same amount of expenditures. Intuitively, it means that it is easier to sway more homogeneous groups.

I test these predictions using a panel of state level data for the US from 1970 to 2000, including public expenditure and revenue, demographic characteristics, electoral data, and voters' preferences for the environment. To measure the latter I create an indicator, based on surveys, that measures the ideological dispersion of environmentally biased voters in each state. To measure pork barrel I focus on systematic increases in environmental expenditures in election years, relative to total expenditures, as well as deviations on these years relative to the mean of all the other years of the mandate of the same politician. US state policy is a particularly relevant laboratory to test the predictions of the model, since environmental expenditures are decided at the state level with a large degree of independence and strong policy preferences of voters are known to politicians before elections. Additionally, the large amount of years available and detail of the data facilitate the identification strategy.

The empirical results indicate that environmental expenditures in the US are in fact subject to pre-electoral pork barrel with signaling purposes. Particularly, I find that election-year increases in environmental expenditures occur more in states where term limit legislation is in place, implying a higher discount factor for incumbents, when the politician is not up for re-elections, and that they do not happen systematically for states where environmentally biased voters are more ideologically dispersed. The latter result more directly corroborates the signaling framework, as it is predicted by the present model but is not explained by other pre-electoral pork generating theories. These distortions remain visible and even stronger when restricting the analysis to elections less likely to be decided on the basis of ideology and close elections.

The analysis thus provides an insight into the mechanism behind distortionary policies with electoral incentives, particularly regarding policies generating strong support from some groups of the population, and contributes to the literature on the political economy of environmental policy in countries with elected governments. These insights have implications for theoretical studies of electoral distortions, interest group power, and governance discussions around mechanisms to prevent inefficient behavior. These are discussed in the conclusion.

The remainder of the chapter is organized as follows. The next section briefly revises some of the related literature. Section 2.3 describes and solves the theoretical model, and sets out the testable hypothesis it generates. Section 2.4 describes the empirical strategy and Section 2.5 its results. Finally, Section 2.6 concludes the chapter and puts forward implications of the analysis.

2.2 Literature

Large part of the existing theory on the use of pork distribution as an instrument to seek voter support focuses on models with full commitment by downsian politicians: following Downs (1957), candidates are purely office-motivated, and make binding promises as to the amount of pork spending they offer to voters. Some examples are Lizzeri and Persico (2001) and Persson and Tabellini (1999). However, politicians as citizens are likely to care not only about being in office but also about the policies performed, such that full commitment cannot be guaranteed. This idea is explored in citizen-candidate models (Osborne and Slivinski, 1996 and Besley and Coate, 1997), where politicians are citizens who decide to apply for office in order to implement their preferred policy. A model of pork spending where politicians have policy preferences is developed by Bouton et al. (2013), who use a retrospective probabilistic voting model to determine when politicians cater to a secondary issue, gun control, that a minority cares about, or a primary issue. However, a large body of research has found that prospective evaluations are important determinants of voting choices, in some cases more so than retrospective ones.[3]

Pre-electoral distortions are conciliated with forward-looking voters by political business cycle models, where incumbent politicians signal their competence by increasing expenditures or decreasing taxes, at the expense of the lately observed deficit.[4] The main idea is that, because information is costly, rational forward looking voters infer incumbent's quality by the amount of expenditure they can provide, for a given level of taxes, and vote for the ones perceived as competent. However, these models imply voters do not observe some economic variable prior to elections, which is less likely to happen in developed democracies where more and better information is available.[5] In established democracies distortions are more likely to arise from incomplete information regarding preferences of the incumbent. If these persist over time, current policy can be used as an indicator of

[3] See for example Lewis-Beck, 1990, Lockerbie, 1992, and Erikson et al. (2000).

[4] The seminal work by Nordhaus (1975) was later extended to include rational expectations by Rogoff and Sibert (1988) and Rogoff (1990).

[5] Brender and Drazen (2005) find that political budget cycles tend to disappear in established democracies, as voters become better at collecting and reporting relevant data.

future actions. This idea is used to evaluate how a politician may signal preference for expenditures that benefit the population instead of herself, by Drazen and Eslava (2010), with an empirical application evaluating the increase of highly visible expenditures in election years in Colombian municipalities. Redistribution between issues that population groups value differently, however, may also arise for signaling purposes. Preferences for different groups or issues has been studied in two papers. Focusing on preferences for different groups, Morelli and Van Weelden (2013) develop a theoretical framework to study politicians' incentives to focus effort on issues where they can best signal their preferences to voters, and the effects of increased transparency on this allocation. Drazen and Eslava (2012), in turn, study programmatic targeting of different groups of population, finding that politicians target with expenditures larger groups and those with more swing voters, and do not often target to mobilize groups into going to vote. However, none of the previous papers offers an empirical analysis of the validity of the framework of signaling preferences for issues that given groups value but others do not.

Finally, recent literature has focused on many aspects of the political economy of environmental policy. In particular, environmental expenditures in the US have been the subject of empirical analysis of political economy theories, mostly related to lobbying, but also to a lesser extent to electoral incentives. An example of the latter is List and Sturm (2006), who test how a secondary policy issue is affected by electoral incentives. In their model voters do not observe an economic shock happening prior to the election, as well as the politician's type. In another study, Fredriksson et al. (2011) use regression discontinuity approaches to test whether elected politicians are mostly office or policy motivated. Both analyses address differences between terms where incumbents can be re-elected and those she cannot (she is a "lame duck"). Instead I focus on election year behavior, giving rise to electoral cycles, while testing hypothesis from a different underlying behavior.

2.3 The Model

The model in this section fits the citizen-candidate framework (Osborne and Slivinski, 1996, and Besley and Coate, 1997), in the sense of having politicians who, as citizens, have intrinsic policy preferences. Thus, they cannot credibly commit to a given platform. However, in this model, the politicians' preferences are not observed by the voters prior to elections. I will abstract from the entry decision, by assuming there is only one challenger, selected randomly from the pool of citizens, conditional on ideology. The model also borrows from the Downsian framework (Downs, 1957), in the sense that candidates, in addition to having policy preferences, are office-motivated, which means that they obtain an additional payoff solely for being in power. Additionally, the model incorporates the possibility of using changes in current policies as a signaling tool for incumbents' unobserved characteristics, set out in the models of Rogoff and Sibert (1988) and Rogoff (1990). The distribution of the agents' policy and ideological preferences is the one in Persson and Tabellini (1999).

2.3.1 Setup

The economy is composed by a continuum of citizens, divided into three groups of equal size, $i = 1, 2, 3$, that differ in two dimensions: their preferences regarding fiscal policies (how the budget is divided) and their ideology. There are two time periods, $t = 1, 2$, with a single election taking place at the end of period 1, between an incumbent politician (I) and a randomly selected challenger (C). The incumbent in each period decides on what will be called the fiscal policy: how to allocate a fixed budget, T, between expenditures targeted at one of three particular issues, $g_{i,t}$, and a bundle of national level expenditures, which benefit all the population equally, G_t. The targeted expenditures are expenditures on issues for which voters care in different ways - namely, voters who have a preference for certain issues derive utility from those expenditures, while the others do not. A good example is spending in environmental protection, for which some citizens with environmental concerns have strong preferences and so they value them, while others do not. In particular, I assume voters in each of the three groups derive utility from only one of the three expenditures: voters in group i derive utility from $g_{i,t}$. Politicians, as citizens, also have policy preferences - i.e., they derive utility from one of the targeted expenditures. Policy preferences are not known to voters, but only the distribution of preferences of the population. Politicians also derive utility simply from being in office, from extracted rents or prestige.

The agents in the model also have ideological preferences, which are known and separate from their policy preferences, and include for example their position on issues like abortion or drug policy. The model further assumes the incumbent belongs to a party that is on one side of the ideological spectrum and the challenger to the one on the opposite. Theoretical results for downsian models with slightly policy-motivated politicians and some uncertainty on voters' behavior show that parties locate symmetrically around the median voter.[6] Finally, ideological preferences include a shock to general popularity shock: the incumbent may be more or less popular before the election, because of some personal factor.[7] The realization of the popularity shock is not known to the incumbent prior to the election.

The timing of the model is the following: in period zero nature chooses the policy preferences and ideology of the incumbent, challenger and voters, and during the first period, the incumbent chooses the allocation of the budget, which voters observe. At the end of period one, the challenger is chosen from the population, the popularity shock is realized, and the citizens vote. In the second period the candidate who is elected, according to the majoritarian voting rule, chooses the policy to be implemented.

The budget constraint

In a given period t the incumbent politician faces the following budget constraint:

$$\sum_{i}^{3} g_{i,t} + G_t = T \tag{2.1}$$

where T is a fixed value, equal for each period, G_t is continuous, with $0 < G_t < T$, and expenditures targeted at each issue $g_{i,t}$ are for simplicity assumed to be of a discrete nature: $g_i = \{1, 0\}$. They each have an equal cost, with the cost of spending on all adding to T, such that spending on one of them would take up one third of the budget.[8] The incumbent's fiscal policy can then be summarized as a vector $q_t^I = \left[\{g_{i,t}\}_{i=1,2,3}, G_t\right]$, where the superscript I indicates that it is the incumbent's choice. As is standard in the pork barrel literature,[9] G_t is by assumption the efficient choice, which benefits all groups equally. However, $g_{i,t}$ can be targeted to a specific group, thereby increasing the

[6] See, for example, Calvert (1985).

[7] Voters may be more inclined to vote for a politician if she is perceived as respectful or competent in the latest public appearances or news reports.

[8] The case with continuous choices would require additional assumptions on the shape of utility functions, but for given characteristics the main results would not change qualitatively.

[9] See, for example, Lizzeri and Persico (2001).

probability of getting the votes of the particular group more sharply. So the incumbent faces a trade-off between efficiency and targetability.

Voters

Voters are divided into three groups, $i = 1, 2, 3$, each with a continuum of citizens with unit mass, where preferences over fiscal policy are identical for all members of each group. The one-period utility, derived from fiscal policy, of a voter from group i in time t if policy q_t^I is being performed can be written as:

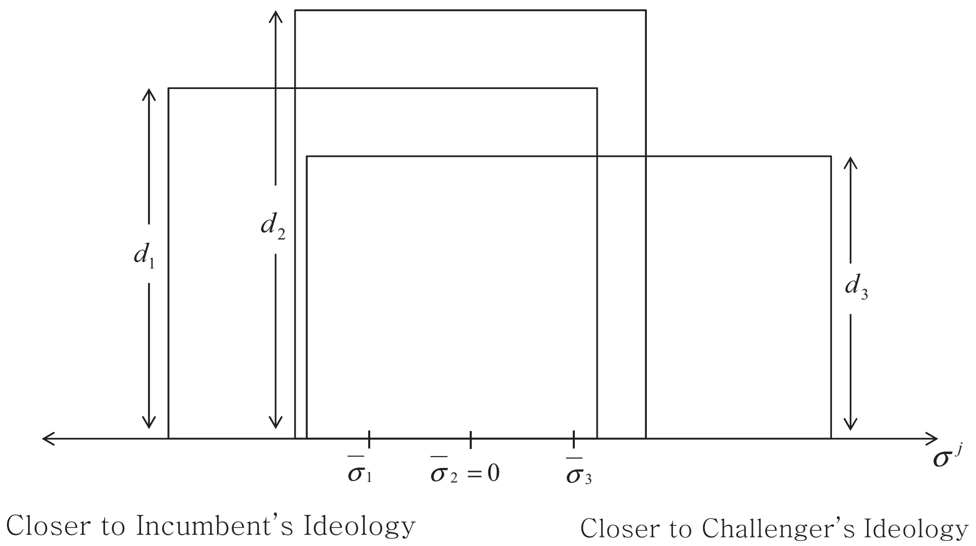
$$U_{i,t}(q_t^I) = \mu_i g_{i,t} + v(G_t), g_i = \{1, 0\} \tag{2.2}$$

where μ_i is a markup measuring the increase in utility from having expenditures in the preferred issue made, $g_{i,t}$ is equal to 1 if these expenditures are made and 0 otherwise, and $v(.)$ is monotonically increasing and concave. The fact that μ_i varies across groups accounts for the intensity of preferences, as some issues elicit stronger positions.
In addition to deriving utility from fiscal policy, voters have preferences over other aspects of political decision making ("ideological preferences"), which include individual ideologies and the general popularity of the incumbent. The ideological distribution used here is the one in Persson and Tabellini (1999), but adapted to the signaling structure of the present model. A voter j in group i has an ideological preference for the challenger, which can be positive of negative, given by $(\delta + \sigma^j)$. Here, δ is the general popularity of the challenger,[10] due to some personal characteristic or charisma, and is a random variable with uniform distribution with expected value zero and density z. That is, $\delta \sim U\left[-\frac{1}{2z}, \frac{1}{2z}\right]$. The shock is realized at the end of the first period, before the election, so the incumbent decides on first period policies under uncertainty. In turn, σ^j is the individual ideology of voter j of group i, which is distributed according to a uniform distribution with expected value $\overline{\sigma}^i$ (group i's specific mean), and density d^i. That is, $\sigma^j \sim U\left[-\frac{1}{2d^i} + \overline{\sigma}^i, \frac{1}{2d^i} + \overline{\sigma}^i\right]$. The distributions are common knowledge, but only the agent j observes her own parameter σ^j. As in Persson and Tabellini (1999), I assume $\overline{\sigma}^1 < \overline{\sigma}^2 < \overline{\sigma}^3$, and $\overline{\sigma}^2 = 0$. That is, group 2 is the one with more ideologically neutral, or swing, voters. Additionally, as they do, I assume group 2 is the one with the highest density $(d^2 > d^1, d^3)$, that $d^1 > d^3$ and that $\overline{\sigma}^1 d^1 + \overline{\sigma}^3 d^3 = 0$. The assumptions on the ordering of densities are made without loss of

[10]The general popularity of the incumbent is the symmetrical opposite of the challenger's popularity.

generality: the results do not change qualitatively for any ordering.[11] The last assumption, along with $\overline{\sigma}^2 = 0$, is made for simplicity, and means that the number of voters to the right and the left of the ideologically neutral ones is the same. If this assumption was to be relaxed, the ordering of densities would have an effect, as one of the politicians would have an ideological advantage (which would be larger the higher the density of the group with the same ideology). However, this analysis is beyond the scope of the chapter. The ideological distribution of voters can be summarized in Figure 2.1.

Figure 2.1: Ideological distribution of voters



The figure shows that all the groups have ideologically neutral voters. However, according to the density distribution, group 2 has the most, followed by 1, and finally, group 3 has the least swing voters. The main idea is that, if $\delta = 0$, an ideologically neutral voter will cast her vote solely on basis of her fiscal utility (i.e., vote for the incumbent if $E\left[U_i(q^I_{t+1})\right] > E\left[U_i(q^C_{t+1})\right]$).

[11] As will be clear from the equilibrium conditions, changing the ordering of densities will only affect the type of incumbent that plays a given strategy, but not the qualitative results.

The Politicians

The politician's utility in period t is analogous to that of a citizen, but includes the payoff from being in office, γ. For an incumbent with a preference for issue k, $k = 1, 2, 3$:[12]

$$w^I_{k,t}(q^I_t) = U^I_{k,t}(q^I_t) + \gamma = \mu_k g_k + v(G) + \gamma, g_k = \{1, 0\} \tag{2.3}$$

where $w^I_{k,t}(q^I_t)$ is the total utility of an incumbent in period t, and $U^I_{k,t}(q^I_t)$ stands again for the utility derived solely from fiscal policy q^I_t. The incumbent chooses current policy in order to maximize her two-period utility, W^I_k, which depends on the utility in equation (2.3) and the probability of being re-elected, π, which is defined later:

$$W^I_k = U^I_{k,t}(q^I_t) + \gamma + \beta \left[\pi \left(U^I_{k,t}(q^I_t) + \gamma\right) + (1 - \pi) \left(E \left[U(q^C_{t+1})\right]\right)\right] \tag{2.4}$$

where β is the discount factor, and the superscripts I and C indicate choices of the incumbent and the challenger, respectively. Ideologically, the incumbent is located to the left of $\overline{\sigma}^2$ and the challenger to the right. They are further located symmetrically around the $\overline{\sigma}^2$ such that this is the location of the ideologically neutral voter.[13]

Voting Behavior and Beliefs

Voters make their decision according to their policy and ideological preferences. They are forward-looking and wish to maximize their second period expected utility. So, in choosing the best candidate, they compute their expected utility in $t + 1$ under each of them, and vote for the one that gives them the highest, conditional on the ideological bias not offsetting this. Voter j in group i will, therefore, vote for the incumbent if:

$$E \left[U_{i,t+1}(q^I_{t+1})\right] > E \left[U_{i,t+1}(q^C_{t+1})\right] + \left(\delta + \sigma^j\right) \tag{2.5}$$

Since policy is multi-dimensional, the notion of probabilistic voting will be used to find an equilibrium. The vote share of the incumbent in group i, $S^{I,i}$, is thus given by:

$$S^{I,i} = d^i \left[E \left[U_{i,t+1}(q^I)\right] - E \left[U_{i,t+1}(q^C)\right] - \delta - \overline{\sigma}^i\right] + \frac{1}{2} \tag{2.6}$$

[12] Throughout the analysis k will be used to indicate the politician's type and i the citizens' type, where $k, i = 1, 2, 3$.

[13] The same assumption is made in Persson and Tabellini (1999).

The probability of winning the election differs depending on the electoral rule in place. Since the empirical analysis is performed for US gubernatorial elections, I focus on a majoritarian system with a single electoral district.[14] Under a single-district system, a politician in each state wins the election if she obtains more than $\frac{1}{2}$ of the total votes of the population in that state. Thus the incumbent's probability of winning in given by:

$$\pi^I_{q^I} = \Pr\left[\frac{\sum_{i=1}^{3} S^{I,i}}{3} \geq \frac{1}{2}\right] \tag{2.7}$$

By equation (2.7), the assumption on the distribution of δ, and the assumptions on the distribution of voters' preferences,[15] this probability is given by:

$$\pi^I_{q^I} = \frac{z}{\sum_{i=1}^{3} d^i}\left[\sum_{i=1}^{3} d^i \varepsilon^i\right] + \frac{1}{2} \tag{2.8}$$

where $\varepsilon^i = E\left[U_{i,t+1}(q^I)\right] - E\left[U_{i,t+1}(q^C)\right]$

Voters have prior probability λ^P_i that a politician $P = I, C$ is of type i, for each $i = 1, 2, 3$. After observing first period policies, voters in each group update their beliefs on the incumbent's type through Bayesian updating, while keeping their prior on the challenger. Hence, the incumbent has a scope to use current policy to change voter's beliefs regarding her preferences, that is, to *signal* a type, which might not be the true one. If the politician's signaling changes the voters' prior beliefs, we say it was *effective*.

2.3.2 Full Information Benchmark

The model is solved by backwards induction. Since there are no more elections after the last period, in $t + 1$ the politician of type $k = 1, 2, 3$ in power simply chooses the policy

[14] The analysis is easily extendable to a multiple district framework, which national level elections would fit. The results of this case are available upon request, and show that pork barrel with signaling purposes occurs even more frequently under a multiple district electoral rule.

[15] In particular, that $\overline{\sigma}^2 = 0$ and $\overline{\sigma}^1 d^1 + \overline{\sigma}^3 d^3 = 0$

that maximizes her utility:

$$\begin{aligned} \max_{g_{i,t+1}} \quad & \mu_k g_{k,t+1} + v(G_{t+1}) + \gamma \\ s.t. \quad & \sum_i^3 g_{i,t+1} + G_{t+1} = T \end{aligned} \tag{2.9}$$

for $i = 1, 2, 3$. Thus the politician will never decide to spend on other issues apart from her preferred one. Assuming $v(T) - v(T - g_{k,t+1}) < \mu_k g_{k,t+1}), \forall k$, the politician will spend on $g_{k,t+1}$, instead of using all the budget for the national level good. Hence, $q^P_{t+1} = \{G^*_{t+1}, g_{k,t+1}\}$, where $G^*_{t+1} = T - g_{k,t+1}$.

With full information on the voters' side the preferences of the politician are known, so there is no scope for signaling. Thus also in the first period the incumbent chooses the fiscal policy that maximizes her period utility, $q^I_t = \{G^*_t, g_{k,t}\}$, where again $G^*_t = T - g_{k,t}$ and $k = \{1, 2, 3\}$ is the incumbent's preferred issue. The only uncertainty is on the incumbent's side, regarding the realization of the popularity shock δ.
In this setting there are two categories of equilibria, depending on whether the politicians are of the same type or of different types. If the incumbent and the challenger have a preference for the same issue, then the probability of winning is equal to $\frac{1}{2}$, independent of group densities or the politicians' popularity. To see this note that $U_{i,t+1}(q^I_{t+1}) = U_{i,t+1}(q^C_{t+1}), \forall i = \{1, 2, 3\}$, that is, $\varepsilon_i = 0$, so the incumbent's vote share in each of the three groups simplifies to $S^{I,i} = d^i \left[-\delta - \overline{\sigma}^i\right] + \frac{1}{2}$.
This means that $\pi^I_{q^I} = \frac{z}{\sum_{i=1}^{3} d^i} \left[\sum_{i=1}^{3} d^i \varepsilon^i\right] + \frac{1}{2} = \frac{1}{2}$.
If the politicians are of different types, with the incumbent of type k and the challenger j, the utility differential of having the incumbent in power for voters in group k is positive and given by $\varepsilon^k = U_{k,t+1}(q^I_{t+1}) = U_{k,t+1}(q^C_{t+1}) > 0$. Similarly, $\varepsilon^j < 0$ and for the third group it is once again zero. The incumbent's winning probability is thus given by $\pi^I_{q^I} = \frac{z}{\sum_{i=1}^{3} d^i} \left[d^k \varepsilon^k + d^j \varepsilon^j\right] + \frac{1}{2} = \frac{1}{2}$. Whether the expression in brackets is positive or negative depends on the densities of the two groups. Since $d^2 > d^1 > d^3$ a politician of type two will win over the other two types, and type one will win over type three. With full information the policy performed is always $q^P_t = \{G^*_t, g_{k,t}\}$, where k stands for the

politician's preference.

2.3.3 Asymmetric Information

Equilibrium Definition

In the asymmetric information case, the equilibrium concert used will be that of a *Perfect Bayesian Equilibrium* (PBE).

Definition 1 ***Equilibrium***
A Perfect Bayesian Equilibrium in this setting satisfies the following conditions:
(a) In the first period, the incumbent decides on the fiscal policy q_t^I *that maximizes her two period utility given by (2.4), subject to the belief system given by the priors and bayesian updating, her expected popularity, and the optimal strategies of voters;*
(b)At the voting stage, voters in each group i maximize their expected utility, subject to the belief system and the incumbent's first period decisions, and therefore vote for the incumbent if $E\left[U_i(q_{t+1}^I)\right] > E\left[U_i(q_{t+1}^C)\right] + \left(\delta + \sigma^j\right)$*;*
(c) Beliefs are consistent on the equilibrium path.

For simplicity, I restrict the analysis to PBE in pure strategies. With the distributional assumptions made, three particular cases arise, depending on which issue the incumbent has a preference for:

1. The incumbent has a preference for the issue favored by the most ideologically dispersed group (group 3)

2. The incumbent has a preference for the issue favored by the group with the most swing voters (group 2), that it, with higher density around the ideological mean

3. The incumbent has a preference for the group with intermediate ideological density (group 1)

The incentives for the incumbent to choose different policies vary between the cases. Due to the discrete nature of the expenditures targeted at each of the three issues, the incumbent's actions are also of a discrete nature: she can spend on all, three, one, or none of the issues. At this point it is convenient to define the *pork barrel* strategy.

Definition 2 ***Pork Barrel***
Performing Pork Barrel in the current setting consists of spending, for re-election purposes, on more issues than what maximizes the politician's period utility.

More specifically, as set out in Section 2.3.2, the politician's period utility is maximized by $q_t^P = \{G_t^*, g_{k,t}\}$. So the incumbent's non pork barrel ($\overline{PB}$) strategy in period t is defined as $q_t^{\overline{PB}} = \{G_t^*, g_{k,t}\}$, where $G_t^* = T - g_{k,t}$ and the superscript I was suppressed since only the incumbent chooses policy in period t. The incumbent's pork barrel (PB) strategy is in turn given by $q_t^{PB} = \{G_t^{PB}, g_{k,t}, g_{i,t}\}, \forall i \neq k$, where $G_t^{PB} = T - g_{i,t} - g_{k,t}, i \neq k, i, k = \{1, 2, 3\}$. Thus, we say that an incumbent is performing pork barrel if she spends on her favorite issue k and one of the other two, instead of maximizing her period utility. When spending on two issues instead of one, the politician is signaling that she might have a preference for any of these two issues.
It is straightforward to see that a politician never chooses to spend on two issues that she does not have a preference for. I further assume she never spends on all three issues, thus choosing $G_t = 0$, nor on none of the issues, thus choosing $G_t = T$. Both these strategies would not signal any type, but the former would give a lower utility than the latter as long as $\mu g_{k,t} < v(G_t = T)$. The latter is also always inferior to the PB strategy as long as $v(G_t = T) - v(G_t^*) < \mu g_{k,t}$. So as long as $v(G_t)$ is sufficiently concave the politician's optimal choice is between q_t^{PB} and $q_t^{\overline{PB}}$.

Political Economic Equilibrium

When deciding between the two policies, q_t^{PB} and $q_t^{\overline{PB}}$, the incumbent of type $k = \{1, 2, 3\}$ compares her expected utility under each, that is $E\left[WU^I(q_t^{PB})\right] > E\left[WU^I(q_t^{\overline{PB}})\right]$ which substituting in the previous equations is:

$$v(G_t^{PB}) - v(G_t^*) + \beta\left[\left(\pi^I_{q_t^{PB}} - \pi^I_{q_t^{\overline{PB}}}\right)\left(\left[1 - \lambda^k\right]\mu_k g_{k,t+1} + \gamma\right)\right] > 0 \tag{2.10}$$

Here $v(G_t^{PB}) - v(G_t^*)$ is the loss in utility in period t from performing the pork strategy, and the expression is square brackets is the difference in the expected utility in $t+1$, relative to the non pork strategy. $\pi^I_{q_t^{PB}} - \pi^I_{q_t^{\overline{PB}}}$ is the difference in re-election probability between performing and not performing the pork barrel strategy, and $\left[1 - \lambda^k\right]\mu_k g_{k,t+1} + \gamma$

the gain in utility from being in office in $t+1$ relative to not being in office. By assumption $v(G_t^{PB})-v(G_t^*) < 0$. Whether or not there is an equilibrium where the politician performs pork thus depends on whether $\pi^I_{q_t^{PB}} - \pi^I_{q_t^{\overline{PB}}}$ can be positive.

The probability of re-election is affected by the incumbent's actions if they alter the voters' beliefs. The incumbent may target other issues apart from her favorite in order to affect the voters' expected utility differential, ε^i_{t+1}, $i = \{1, 2, 3\}$. In particular, if she signals a type other than her own $(-k)$ and this signaling is *effective*, ε^{-k}_{t+1} increases. This is because then voters attribute a higher probability to the incumbent being of type $-k$ than if she had not signaled.
If she performs $q_t^{\overline{PB}}$ her type is revealed. This is because $Pr(q_t^{\overline{PB}}|I \neq k) = 0$, that is, the incumbent will never spend only on $g_{k,t+1}$ if she is of another type. So voters update their beliefs that the incumbent is of type k according to:

$$\Pr\left(I = k|q_t^{I,\overline{PB}}\right) = 1 \tag{2.11}$$

which means that for voters in group k the expected utility differential becomes positive, that is, $\varepsilon^k = (1 - \lambda_k)\mu_k g_{k,t+1}$, while the opposite is true for the other two groups, where $\varepsilon^{-k} = -\lambda_{-k}\mu_{-k}g_{-k,t+1}$. The incumbent's probability of re-election is therefore given by the following expression.

$$\pi^I_{q_t^{I,\overline{PB}}} = \frac{z}{\sum_{i=1}^{3} d^i} g_{t+1} \left(d^k \mu_k \left[(1 - \lambda_k)\right] + \sum^{2} d^{-k} \mu_{-k} \left[-\lambda_{-k}\right] \right) + \frac{1}{2} \tag{2.12}$$

where $g_{i,t+1} = g_{t+1}, \forall i = \{1, 2, 3\}$.
Alternatively, the incumbent may choose $q_t^{PB} = \{G_t^{PB}, g_{k,t}, g_{i,t}\}, \forall i \neq k$. In this case, she will spend on her favorite issue, k, and in one of the other two $i \neq k$. In choosing which of the other issues to target she compares the gain in the probability of winning in each of the other two groups. This is because when voters see that the incumbent spent on their favorite issue they will update their belief that the politician is of their type. However, relative to the $\overline{PB}$ strategy, the incumbent loses votes in her own group, as voters here no longer update the probability that she is of their type to 1. She will then perform the strategy if the gains in terms of votes in the targeted group outweigh the loses of votes in

her own group plus the utility loss in the period before the election.

The following proposition describes the main conclusion.

Proposition 1 *Under certain thresholds describing the ordering of densities and intensity of preferences, given by equation (2.A.4), a political economy equilibrium exists where the incumbent performs the strategy q_t^{PB}. In this equilibrium, the incumbent uses pork barrel to signal effectively, thereby increasing her re-election probability.*

Proof See Appendix 2.A.

Whether this equilibrium exists depends on the ordering of densities and the intensity of preferences given by μ_i. When the politician has a preference for the preferred issue of the group with the highest density, that is, $k = 2$, for pork barrel to be *effective* $\mu_1 - \mu_2$ or $\mu_3 - \mu_2$ has to be large enough to compensate the fact that $d_1, d_3 < d_2$. So, for given preference intensities, an incumbent is more likely to target highly densely concentrated groups. This means in particular that the group with the most dispersed ideology, group 3, is less likely to be targeted, as for it to be targeted μ_3 would need to be very high. If this does not happen when a politician has a preference for a more heterogeneous group signaling is not *effective* and so the incumbent does not perform the pork barrel strategy. In practice, if it is *effective* in terms of altering the voters' beliefs about the preferences of the incumbent, delivering pork corresponds to a shift in the position of a given group in Figure 1 towards the left. This implies that it is always better for the incumbent to target groups with higher densities. An incumbent will only target a group with a lower density than the one she has a preference for if the valuation of the preferred issue by that group is strong enough. Thus, the pork barrel strategy might arise in equilibrium for signaling purposes, but is less likely to occur towards ideologically heterogeneous groups.
From equation (2.10), whenever $\pi^I_{q_t^{PB}} - \pi^I_{q_t^{\overline{PB}}} > 0$, that is, whenever equation (2.A.5) is satisfied, the incumbent has an incentive to perform the pork barrel strategy. Her incentive to do so is larger the larger β is - that is, the more future oriented the politician is - the larger μ_k is - that is, the more the incumbent values her preferred issue - the lower the valuation of G_t and the prior on the challenger's type λ_k are, and the higher the payoff of being in office, γ, is. Intuitively, an incumbent that is future oriented or has a high payoff of being in office is willing to give up more utility in the present in exchange for

re-election.
These results can be summarized in the following proposition.

Proposition 2 *The conditions under which pork barrel arises as an equilibrium strategy for signaling purposes are given by equations (2.10) and (2.A.4). This equilibrium is characterized by a high density and intensity of preferences of the targeted group, a low discount factor, a high valuation of the targeted expenditures relative to the public good, and a high payoff for being in office.*

Empirical Implications

The model derives conditions under which pork barrel may arise as an equilibrium strategy for an incumbent, thus putting forward testable implications. The first is that in majoritarian systems in election years particularistic expenditures should be systematically higher than those made during the rest of a politician's mandate. When politicians behave differently in election years they are deviating from the policy that maximizes their fiscal utility $u^I_{k,t}(q^I_t)$.
The second and third refer to re-election incentives. Particularly, these distortions should not take place when a politician cannot be re-elected - when she is a "lame duck" - and they should be smaller when she is subject to term limits, even when are not binding. The intuition for the former is that, if an incumbent cannot run for re-election, she does not have an incentive to signal her preferences through current policy. The latter is a measure of the time horizon of the politician, and should therefore approximate her discount factor: if an incumbent is not subject to term limits she has a much higher potential future payoff, which in our simplified framework means she has a smaller discount factor. Thus she should have a higher incentive to perform pork. Finally, we should not see election year increases in particularistic expenditures if voters with strong preferences for them are more ideologically dispersed than the average population. If these distortions are in fact generated by the signaling motive then politicians will choose to perform them towards groups that are more densely concentrated ideologically and are therefore easier to sway.

2.4 Empirical Strategy

The model is tested for the case of U.S. state level policy, namely for environmental expenditures. Gubernatorial elections in the U.S. more closely approximate the majoritarian single-district system. This is a particularly suitable laboratory to test the signaling motive for pork barrel hypothesis for several reasons. The first is that U.S. governors have substantial control over several policy areas, including environmental policy (List and Sturm (2006)). This provides state governments with significant discretion over their expenditures. The second is that the environment triggers strong opinions by the electorate, which makes it a natural candidate to represent one of the particular issues in the model that some voters care about. The third is that in the U.S. a large number of surveys are conducted before elections, such that incumbents are likely to be well informed of the preferences of the electorate, particularly regarding salient issues. Finally, the large number of years available and the detail of the data allows for a rich analysis of incentives, while facilitating the identification strategy.

2.4.1 Variable Definition

A first key empirical question is what constitutes pork barrel spending. I define pork barrel as the environmental expenditures occurring in election years in excess of what the politician's choice would be in the absence of electoral incentives. Accordingly, I use two alternative measures. The first are systematic increases in election year environmental spending as compared to all non-election years. This measures if in election years decisions differ from what is optimal in every other year. The second is calculated as the deviation in the environmental spending level in election years with respect to the average expenditure for each incumbent politician. This measures whether election year decisions differ from what is optimal for the same politician in every other year.

In order to measure voters' environmental preferences and ideological dispersion I use responses to surveys representative at the state level.[16] For each respondent I measure the degree of environmental preference and the ideological inclination. For the first I create a scale from responses on questions about the importance of the environment and government's action regarding the environment, env_i, and for the latter I use the answer

[16]The surveys are described in Section 2.4.4. and Appendix 2.B.

to the question of whether the respondent is a conservative, moderate, liberal, or does not think in those terms. I use the latter to create an indicator of ideological dispersion at the state level, $totdisp_i$, by calculating the standard deviation of this measure in each state. Furthermore, using the degree of environmental preference I classify respondents into environmentally biased or not, simply by generating a dummy equal to 1 if env_i is higher than the mean of the population and 0 otherwise, and calculating the ideological dispersion in each state only if the dummy is 1, $envdisp_i$. I then calculate the dispersion of environmental voters' ideology relative to the total dispersion in state i as $disp_i = \frac{envdisp_i}{totdisp_i}$. I experiment with different cutoffs for the dummy variable, but since the results do not vary I use only this indicator.

2.4.2 Econometric Model

The analysis aims at assessing the existence of election-year distortions in environmental spending across states, and the factors contributing to them. The basic empirical model is given by

$$Environment_{it} = \alpha_1 + \delta elyear_{i,t} + \alpha_2 X_{it} + \eta_i + \epsilon_{it} \tag{2.13}$$

where $Environment_{it}$ is the dependent variable, a measure of environmental expenditure in state i and year t. Two sets of equations will be estimated: one where the dependent variable is $envexp_{it}$, real total environmental *per capita* expenditures in state i at time t, and one where it is dev_{it}, deviations from politician mean in environmental expenditures in state i at time t.[17] As in List and Sturm (2006), total environmental expenditures are the sum of expenditures in three categories: *forests and parks*, *fish and games*, and *others*. They argue they can be pulled together as all three record very similar types of spending and are used as substitutes. Expenditures are deflated to 1982-1984 dollars. Because increases in environmental expenditures would take place if the politician was simply increasing all spending in election years, I use total environmental expenditures as a percentage of total expenditures for $envexp_{it}$.[18] $elyear_{it}$ is a dummy variable equal to 1 if year t is the year before an election in state i and 0 otherwise.[19] X_{it} is a vector

[17]Calculated as $envexp_{it} - av_P$ where av_P is the average environmental expenditure for a given politician.

[18]I also present the main estimation using total environmental expenditures, and logged expenditures, in the last two columns with no qualitative change in results.

[19]Distortions may take place in the year before election in order to give the electorate more time to observe changes. Following Veiga and Veiga (2007), I experiment with both election year, the year before

of economic and demographic variables affecting fiscal choices for each state, η_i is a state fixed effect, and ϵ_{it} is the error term. The fixed effect is included to control for unobserved heterogeneity. Alternatively, the variable measuring how environmentally biased a population of a given state is, $envbias_i$, is included. Given that this does not vary with time, fixed effects are not included when the latter is. The main coefficient of interest is therefore δ, that measures systematic changes in the dependent variable occurring in election years. If pork barrel takes place for environmental expenditures this coefficient should be positive and significant.

The control variables included in X_{it} aim at capturing a given state's resources and needs. The variables 17_{it} and 65_{it}, respectively the percentage of people between 5 and 17 and over 65 years old in state i at time t, measure population needs, $taxes_{it}$, the real *per capita* taxes in state i at time t, and $income_{it}$, the real *per capita* state income at time t, provide a measure of the state's resources, and pop_{it}, the state population in millions, is included to account for economies of scale or congestion effects in the provision of public goods. Finally, because public expenditures are likely to be persistent over time, I include a lagged dependent variable, $envexp_{i,t-1}$ in the estimations using total environmental expenditures, as a percentage of total expenditures, as the dependent variable.

The model with this dependent variable is thus given by:

$$envexp_{it} = \alpha_1 + \gamma envexp_{i,t-1} + \delta elyear_{it} + \alpha_2 X_{it} + \eta_i + \epsilon_{it} \tag{2.14}$$

The model having the deviation of environmental expenditures from the politician's average as a dependent variable in turn does not include the de lagged dependent variable. The basic model in that case reduces to:

$$deviation_{it} = \alpha_1 + \delta elyear_{it} + \alpha_2 X_{it} + \eta_i + \epsilon_{it} \tag{2.15}$$

To the basic model I add additional variables, in turn, to test further implications. The predication that pork occurs less towards ideologically dispersed groups is tested by including the interaction of the dispersion index $disp_i$ with the election year dummy, while also including the index separately. For this variable a negative coefficient is expected: environmental expenditures in election years should be lower in states where citizens with

the election, and the year after. Since the dummy for the year before the election was always statistically significant and that for election years was not I use only the former.

environmental preferences are dispersed ideologically when compared to those less dispersed. To test the prediction that a higher discount rate leads to less environmental pork I include a dummy variable equal to 1 if state i has term limit legislation at time t and 0 otherwise, $limit_{it}$, and an interaction of this with the election year dummy. The coefficient of the interaction term is expected to be negative, indicating that if the time horizon of a politician is smaller, incentives to perform pork decrease. Finally, to test whether politicians who cannot be re-elected have different incentives I include $lame_{it}$, a dummy equal to 1 if the incumbent is a "lame duck" (is not up for re-election) and 0 otherwise. The interaction of this dummy with the election year dummy thus measures election year incentives for "lame ducks" as compared to incumbents up for re-election. Thus a negative sign is expected.

2.4.3 Empirical Issues

Due to unobserved heterogeneity for both dependent variables a Fixed Effects (FE) model is estimated instead of Ordinary Least Squares (OLS). However, when estimating equation (2.14), because of the inclusion of the lagged dependent variable, the FE estimation biased as the fixed effect η_i is correlated with it. Thus, following Arellano and Bond (1991), I take the first difference of equation (2.14) including the lag, thus eliminating the fixed effect, and use lags of the dependent variable of two or more periods, which are not correlated with the variable in differences, as instruments. Their Generalized Method of Moments (GMM) estimates the model parameters directly from the moment conditions and combines the instruments efficiently. However, since there is a high level of persistence I use use the system GMM (GMMsys) estimation (Arellano and Bover, 1995 and Blundell and Bond, 1998) which additionally uses the moment conditions for the model in levels, and is more robust to problems like measurement errors and weak instruments. This method has the additional benefit of accounting for the possible endogeneity of the states' environmental bias, $envbias_i$.

2.4.4 Data

The database used includes information for the 48 continental states in the US between 1970 and 2000, making a total of 1488 observations.

Data on environmental expenditures as well as all political and demographic variables used in the analysis come from List and Sturm (2006). The latter are in turn updated versions of the data used in Besley and Case (1995) and the former were collected from the Census of State Governments. Environmental expenditures vary largely across states and time between a minimum of 6119 and 168297 dollars. The dummy for term limits includes states with a one, two or three period term limit, and the legislation in several states changed during the sample period.[20]

Data on state environmental preferences and ideology was collected from five surveys, conducted between 1983 and 2007. These surveys were conducted by CBS with the New York Times, and ABC News with Stanford University and Time Magazine, and are available from the Inter-university Consortium for Political and Social Research (ICPSR). They include questions that measure environmental inclination, such as a classification of the importance of the environment, as well as ideological preferences. According to List and Sturm (2006), environmental inclination is persistent over time in US states (namely between 1987 and 2000). Thus I pull together the information on the five surveys, which allows me to have 4824 individual observations, from which the state ideological dispersion and degree of environmental inclination are calculated. The resulting measure of environmental preference is correlated, although varying considerably less, with that of List and Sturm (2006), consisting of the percentage of state population enroled as a member of the largest environmental organizations.

Table 2.1 presents the summary statistics for the data. The first six rows represent the measures of environmental expenditures used, specifically: total spending and its three disaggregated components, environmental spending as a percentage of total expenditures and the deviation from politician average. The following five rows include the control variables, followed by the four electoral variables. These include in addition to the variables described above, the percentage of democratic vote in a given state and the winning margin of the party in power - calculated as the percentage share of the governor in the share of the top two candidates minus 50 - which are used as part of the identification strategy. Finally the last rows are the variables derived from the survey data. Appendix 2.B describes the surveys in more detail and presents maps with the resulting measures of environmental bias and ideological dispersion index.

[20] A description of the term legislation in each state, as well as detailed sources, can be found in List and Sturm (2006).

Table 2.1: Summary statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
Environmental Expenditures	27.058	16.983	6.119	168.297	1488
Fish & Game	6.836	6.697	0.515	52.086	1488
Forests & Parks	11.522	6.712	0.560	58.666	1488
Other Environmental	8.701	9.026	0.164	118.244	1488
Environmental Percentage	1.823	0.833	0.515	6.81	1488
Deviation	0	5.268	-29.86	44.458	1488
Taxes in State	0.817	0.219	0.316	1.731	1488
Personal Income	12.914	2.537	6.745	24.093	1488
State Population in millions	4.955	5.191	0.333	34.002	1488
Percentage between 5-17	0.209	0.029	0.071	0.304	1488
Percentage over 65	0.118	0.02	0.04	0.188	1488
Lame Duck	0.261	0.439	0	1	1488
Term Limits	0.606	0.489	0	1	1488
Percentage Democrat Vote	0.526	0.089	0.218	0.946	1488
Winning Margin	8.396	7.737	0	50	1448
Environmental Preference	13.044	4.632	3.609	31.888	1488
Dispersion Index	0.92	0.214	0.203	1.415	1488
Dispersion Environmentalists	1.471	0.530	0.794	3.479	1488
State Ideological Dispersion	1.68	0.748	0.773	5.581	1488

Sources: List and Sturm (2006) and ICPSR.

2.5 Results

The results from the dynamic model in equation (2.14) are presented in Table 2.2. Columns (1) to (7) present the results where the dependent variable is real *per capita* environmental expenditures as a percentage of total expenditures. Because this variable is very small, in order to make the coefficients easier to read, it was multiplied by ten. Thus the coefficients have to be interpreted accordingly. In order to verify that the variation is indeed driven by environmental, and not total, spending, column (8) presents the results of the basic estimation using as a dependent variable total real *per capita* environmental expenditures. Column (9) presents the same estimation with logs of all the variables (except for the percentages). The results to not change qualitatively.

All estimations include the lagged dependent variable and the main variable of interest, $elyear_i$. This variable is positive and statistically significant across all estimations. The first two columns show the results for the dynamic model without controls estimated by OLS and FE. Although biased, these estimations are used as a benchmark for the consis-

Table 2.2: Basic Model Results

Estimation	(1) OLS	(2) FE	(3) GMMsys	(4) GMMsys	(5) GMMsys	(6) GMMsys	(7) GMMsys	(8) GMMsys	(9) GMMsys
$envi_{it-1}$	0.905***	0.650***	0.685***	0.575***	0.648***	0.612***	0.598***	0.605***	0.717***
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(9.21e-08)	(0)
$elyear_{it}$	0.363*	0.298*	3.131**	3.637***	7.580**	5.278**	6.786***	4.491**	0.188**
	(0.0566)	(0.0958)	(0.0212)	(0.00169)	(0.0308)	(0.0235)	(0.00514)	(0.0316)	(0.0350)
$taxrevenue_{it}$	0.661	-3.464***	-1.231	-3.205	-6.975	-2.574	-2.840	0.675	0.130
	(0.209)	(0.00195)	(0.677)	(0.340)	(0.249)	(0.427)	(0.367)	(0.947)	(0.379)
$income_{it}$	-0.0362	0.146	0.109	0.101	0.351	0.0909	-0.0522	0.485	0.0730
	(0.581)	(0.324)	(0.727)	(0.738)	(0.327)	(0.757)	(0.844)	(0.533)	(0.758)
65_{it}	-2.235	29.43	-7.561	72.75	58.37	52.68	16.15	179.4	4.23
	(0.708)	(0.179)	(0.637)	(0.127)	(0.453)	(0.213)	(0.759)	(0.108)	(0.218)
17_{it}	2.477	2.871	0.983	23.89	11.43	18.10	5.869	37.32	1.172
	(0.611)	(0.627)	(0.909)	(0.314)	(0.728)	(0.293)	(0.729)	(0.411)	(0.545)
pop_{it}	-5.10e-08***	-7.61e-08	-1.02e-07	8.54e-08	-1.30e-07	-4.37e-08	4.78e-08	1.49e-10	0.0141
	(0.00381)	(0.492)	(0.141)	(0.591)	(0.632)	(0.673)	(0.695)	(1.000)	(0.897)
$envbias_i$				1.286*	0.531	0.986	0.646	3.089*	0.0581
				(0.0714)	(0.628)	(0.137)	(0.409)	(0.0725)	(0.295)
$disp_i$					3.760				
					(0.842)				
$disp_i \times elyear_{it}$					-7.454**				
					(0.0481)				
$lame_{it}$						0.336			
						(0.471)			
$lame_{it} \times elyear_{it}$						-4.982**			
						(0.0396)			
$limit_{it}$							5.552		
							(0.238)		
$limit_{it} \times elyear_{it}$							-7.238*		
							(0.0742)		
Constant	1.575	3.568	5.385	-22.65	-11.19	-15.25	-5.812	-65.19	-0.987
	(0.420)	(0.194)	(0.259)	(0.247)	(0.626)	(0.319)	(0.722)	(0.121)	(0.744)
Observations	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392
R-squared	0.837	0.816							
Number of states	48	48	48	48	48	48	48	48	48
AR1			-4.312	-4.493	-4.384	-3.871	-4.364	-3.520	-4.365
p-value			0.000	0.000	0.000	0.000	0.000	0.000	0.000
AR2			-0.0150	0.243	-0.0922	0.410	0.802	-0.170	0.273
p-value			0.988	0.808	0.927	0.682	0.423	0.865	0.785
Hansen			12.28	7.764	19.52	13.18	9.677	8.471	3.612
p-value			0.198	0.558	0.243	0.434	0.469	0.487	0.607
DF			9	9	16	13	10	9	5

P-values in parentheses. Dependent variable (1)-(7)$envi_{it}$; (8) Total Environmental Expenditures; (9) Log of Total Expenditures. Significance level at which the null hypothesis is rejected: ***1%, **5%, *10%.

tent GMMsys estimations. They show a high persistence of environmental expenditures, corroborated by the GMMsys estimation in column (3). The latter places the coefficient of the lagged dependent variable between the upward biased OLS estimation and the downward biased FE estimation.

All GMMsys estimations use a two-step estimation with a finite sample correction for standard errors (Windmeijer, 2005). They are robust to heteroskedasticity and error term serial correlation. Since the results show there exists first but not second order autocorrelation, I use two or more lags of the dependent variable as instruments, while considering the demographic variables exogenous. The political variables are also considered exogenous, while state taxes and income are considered pre-determined. Accordingly, only lags of the latter of at least one period are used as instruments. Finally, environmental bias and ideological dispersion are also considered endogenous. As having too many instruments may invalidate the estimation, all instruments are collapsed. The Hansen test for each estimation validates the instruments.

In columns (3)and (4) the basic model is estimated. Column (4) includes the time-invariant environmental bias by state, $envbias_i$. This variable is positive and statistically significant at a 10% confidence level.The results show that environmental expenditures present a large degree of persistence, with a coefficient between 0.575 and 0.685 statistically significant at a 1% confidence level. In election years expenditures increase on average between 3.131 and 3.637, which is significant at a 5% and 10% level respectively. The coefficient on the population is negative, suggesting the existence of economies of scale in environmental expenditures.

Finally, columns (5) to (7) present the results of the predictions of the model regarding features that increase incentives for pork barrel with signaling purposes. In column (5) the coefficient for $disp_i \times elyear_{it}$ is negative and statistically significant at a 5% level, corroborating the predictions of the model. It means that in election years, states with higher ideological dispersion than the average receive less environmental expenditures relative to those less dispersed, which indicates that incumbents choose to use their budget for other types of spending. The dispersion index is not statistically significant. Column (6) tests the “lame duck” hypothesis. The results show that although in the last term incumbents tend to spend more, politicians that are “lame duck” spend less in the year before the election as compare to those that can be re-elected: the coefficient for $lame_{it} \times elyear_{it}$ is negative and statistically significant. Finally, column (7) reports results for the effect of term limits. They show that environmental expenditures in years before election are smaller for states with term limit legislation in place by 7.23$, and this difference is statistically significant at a 5% level. This is in accordance with the prediction that politicians with a smaller time horizon in office have less incentives to perform pork.

Finally, the results from the estimations of equation (2.20), using the mandate mean deviations, are presented in Table 2.3. Only the coefficients for the variables of interest are presented, although the estimations include the same control variables as before. Columns (1) and (2) present the results for the basic estimation. Column (1) does not include the state environmental bias as an explanatory variable and so is estimated using FE. Column (2) is estimated with simple OLS. Standard errors are robust to heteroskedasticity and clustered over states. The estimations show that in the year before an election incumbents spend on average over 0.65$ more than their yearly average environmental expenditure, indicating that politicians systematically deviate from their optimal level. If signaling is in fact driving these results we should see deviations in elections that are less likely to be decided by an ideological bias - if the ideological bias is too high then pork barrel is less likely to swing enough voters. Thus I run the regression in column (1) while cutting the sample to include only states where the average democratic vote share is smaller than 0.7 and larger than 0.3. The results are reported in column (3) and show that the coefficient for the election dummy is again statistically significant, and even higher than that of the full sample. This indicates that when elections are less likely to be decided on the basis of ideology, incumbents have an even higher incentive to use environmental expenditures as pork barrel. Additionally, incentives to perform these policies should be seen in close elections if the signaling motive is behind them. Thus I estimate the same equation restricting the sample to elections where the incumbent won with a winning margin of 15% or less. The results are presented in Column (4) and again the coefficient of the year before election is statistically significant. Finally, I restrict the sample to include both only states with small ideological biases and close elections. The results are reported in column (5) and the coefficient is once again statistically significant, and higher than that of the unrestricted sample. I additionally test whether this behavior is particular to incumbents of a given ideology by including a dummy equal to 1 if the incumbent is a democrat and the interaction of this with the election dummy. The coefficients are never significant, indicating that politicians deviate from their mandate means regardless of their ideological inclination.[21]

Table 2.3: Election Year Deviations

Sample	(1) Full	(2) Full	(3) Restricted Ideology	(4) Restricted Margin	(5) Restricted Both
$elyear_{it}$	0.685*	0.656*	0.797*	0.791**	0.959**
	(0.0762)	(0.0720)	(0.0609)	(0.0449)	(0.0287)
$envbias_i$		-0.00610			
		(0.616)			
Observations	1,440	1,440	1,339	1,111	1,050
R-squared	0.049	0.0405	0.044	0.049	0.047
Number of states	48	48	48	48	48
Estimation	FE	OLS	FE	FE	FE

P-values in parentheses. Dependent variable dev_{it}. Robust standard errors. Cluster $envbias_i$; *** p<0.01, ** p<0.05, * p<0.1

2.6 Conclusion

This chapter presents evidence of the existence of pork barrel spending with signaling purposes. A simple model of electoral competition derives conditions under which pork arises in equilibrium for an incumbent to signal preferences for different issues, for which groups in the population care about differently. The resulting conditions are tested for the case of US state environmental expenditures. Environmental issues are likely to be subject to electoral manipulation since they elicit strong preferences from particular subgroups. The empirical analysis shows support for the theoretical model. There are systematic increases in environmental spending in years before election across states, both when compared to every other year and when compared to a politician's average choices. These are smaller when the environmentally biased groups are more ideologically dispersed, when term limits are implemented (which proxy for the incumbent having a high discount rate), and when the politician cannot be re-elected. Additionally, these distortions are visible when restricting our attention to elections that are less likely to be decided on the basis of ideology and close elections.

[21] These results, as well as results using different cutoffs, are available upon request.

These results have important implications for the theoretical literature on politically driven policy distortions, as well as for governance discussions. First, I present empirical evidence of the signaling motive for pork barrel across issues and not geographic groups. To the best of my knowledge no study has shown this before. This allows to corroborate the assumptions made in several theoretical studies. Second, the fact that more homogeneous groups are targeted more often has implications for the literature on the formation and influence of special interest groups. It suggests that groups that are organized around ideology will be more able to attract benefits from politicians seeking re-election. Finally, the results show that issues that elicit strong preferences from the electorate are prone to distortions to get electoral advantage, through the signaling mechanism. This makes them particularly subject to electoral cycle variations. In particular for environmental policy, which requires continued action across time in order to be efficient, this has important implications. Namely, mechanisms restraining the discretionary power of politicians that limit the size of electorally driven cycles could increase the efficiency of environmental policy, by protecting it from electoral incentives.

Appendix

2.A Political Economic Equilibrium

Proof of Proposition 1

Denoting the targeted group j, voters in all groups update their beliefs that the politician is of types k, and symmetrically j, according to:

$$\Pr\left(I = k | q_t^{PB}\right) = \frac{\Pr(q_t^{PB}|I = i).\lambda^i}{\Pr(q_t^{PB}|I = k).\lambda^k + \Pr(q_t^{PB}|I = -k)(1 - \lambda^k)} \tag{2.16}$$

with $i = \{k, j\}$.

To solve for the equilibrium, I first assume that the incumbent has an incentive to perform the pork barrel policy, and then check whether this is true. So $Pr(q_t^{PB}|I = k) = 1$ and $Pr(q_t^{PB}|I = -k) = \frac{\lambda^j}{\lambda^j + \lambda^{-j-k}}$. Substituting in the previous expression, we have that for voters in group k, and symmetrically for those of group j:

$$\varepsilon^k = \varphi^k \mu_k g_{k,t+1} \tag{2.17}$$

where

$$\varphi^k = \frac{\lambda^k \left[1 - \lambda^k - \left(1 - \lambda^k\right) \frac{\lambda^j}{\lambda^j + \lambda^{-k-j}}\right]}{\lambda^k + (1 - \lambda^k) \frac{\lambda^j}{\lambda^j + \lambda^{-k-j}}} > 0 \tag{2.18}$$

Once again, for the group whose preferred issue is not spent on, $\varepsilon^{-k-j} = -\lambda_{-k-j} \mu g_{-k-j,t+1}$. Substituting in the re-election probabilities we have that the difference in re-election probabilities for an incumbent of type k of performing or not pork barrel by targeting group j is given by:

$$\pi^I_{q_t^{PB}} - \pi^I_{q_t^{\overline{PB}}} = \tag{2.19}$$

$$\frac{z}{\sum_{i=1}^{3} d^i} \left[d^k \mu_k g_{k,t+1} \underbrace{\frac{\left(\lambda^k - 1\right) \frac{\lambda^j}{\lambda^j + \lambda^{-k-j}}}{\lambda^k + (1 - \lambda^k) \frac{\lambda^j}{\lambda^j + \lambda^{-k-j}}}}_{A} + d^j \mu_j g_{j,t+1} \underbrace{\frac{\lambda^j}{\lambda^j + (1 - \lambda^j) \frac{\lambda^k}{\lambda^k + \lambda^{-k-j}}}}_{B} \right]$$

Since A is negative and B is positive, and $g_{k,t+1} = g_{j,t+1}$, whether (2.A.4) is positive or negative depends solely on the ordering of densities and the intensity of preferences given by μ_i. When the politician has a preference for the group with the highest density's preferred issue, that is, $k = 2$, for (A.4) to be positive and so pork barrel to be *effective* $\mu_1 - \mu_2$ or $\mu_3 - \mu_2$ has to be large enough to compensate the fact that $d_1, d_3 < d_2$.

Substituting equation (2.A.4) into equation (2.10), the condition under which the strategy q_t^{PB} constitutes an equilibrium is given by:

$$v(G_t^{PB}) - v(G_t^*) < \tag{2.20}$$

$$\beta \left[\left(\frac{z}{\sum_{i=1}^{3} d^i} \left[d^k \mu_k g_{k,t+1} A + d^j \mu_j g_{j,t+1} B \right] \right) \left(\left[1 - \lambda^k \right] \mu_k g_{k,t+1} + \gamma \right) \right]$$

2.B Survey Description

The data used to create the variables measuring ideological dispersion and environmental bias at the state level were collected from four surveys. All the surveys were accessed through the Inter-university Consortium for Political and Social Research (ICPSR) and I used only surveys that included both questions measuring preferences towards the environment and ideology. The first two were conducted by CBS News and New York Times, respectively in April and June of 1983. They were a part of a larger set of surveys performed throughout the year to collect the electorate's views on several subjects (CBS News et al., 1984). To create the environmental preference index I used the response to whether the environment was the most important (or second most important) problem at the time. To create the ideological dispersion I used the respondents' self classification into Liberal, Moderate, Conservative, or Does Not Think in Those Terms. I re-classified the latter as "Moderate" voters, and calculated the standard deviation. The third was conducted by ABC News, Stanford University, and Time Magazine in March 2006 (ABC News et al., 2006) and the fourth by ABC News, The Washington Post, and Stanford University in April 2007 (ABC News et al., 2007). To create the environmental index I used the response to the question of how important the respondent considers respectively the environment and global warming, on a scale of 1 to 5, as well as other similar questions. The same ideological classification was used. The total number of observations in the four surveys put together is 4824.

The figures below map the resulting measures. Fig.2.A.1 maps the environmental bias by state and fig.2.A.2 the ideological dispersion of environmentally biased voters as the share of total state environmental dispersion.

Figure 2.2: Environmental Bias

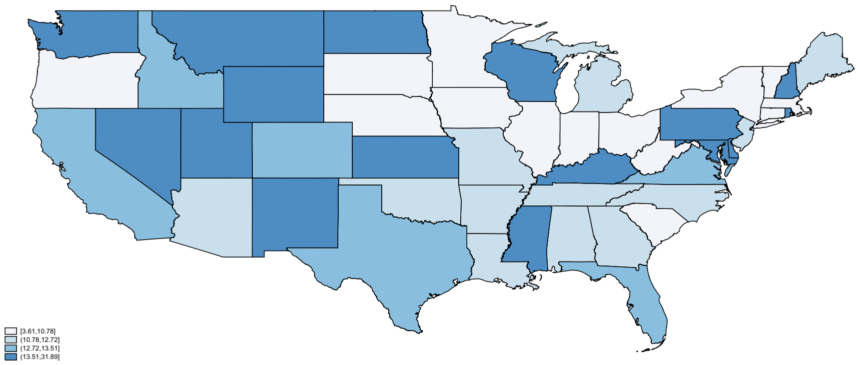
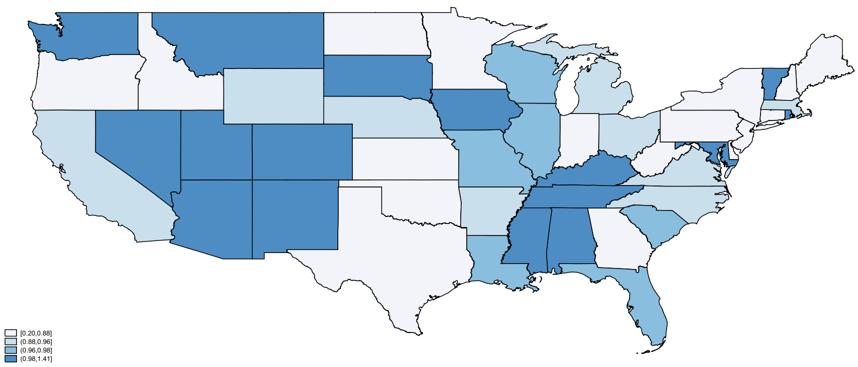


Figure 2.3: Ideological Dispersion Index



Chapter 3

Interactions in local governments' spending decisions: Evidence from Portugal

With Linda Veiga and Miguel Portela

3.1 Introduction

Strategic interaction among governments has been a significant matter in public finance and regional science for quite a long time. This chapter builds on this literature by investigating if Portuguese local governments' spending decisions influence each other. This is a major issue to understand the distribution of expenditures across municipalities, and the impact of budget decentralization policies. The institutional reforms that Portugal is implementing under the financial assistance program agreed with the IMF and the EU, in May 2011, renders additional relevance to the topic. In order to promote fiscal consolidation, it is important to gain new insights into public policy decisions at the local level.

To our knowledge, interactions between Portuguese local governments have never been investigated. Veiga and Veiga (2007), found strong evidence of strategic manipulation of expenditures' levels and composition by mayors, as more is spent in election years on items that are highly visible to the electorate. They control for transfers received from the central government and for the demographic and political characteristics of the municipalities. However, they did not take into account that the actions of a local government may affect the policy decisions of its neighbors. An important finding of the present chapter is that an increase in a municipality's neighbors' expenditures increases its own expenditures due to spillover effects and mimicking behavior. This is particularly relevant for investment decisions.

Portugal is also an interesting case study because municipalities are all subject to the same rules and legislation, have the same policy instruments and resources at their disposal, and local politicians have some discretionary power over them. Additionally, a large and detailed data set is available (all mainland municipalities from 1986 to 2006), allowing the analysis of spending in specific categories. Furthermore, in mainland Portugal there is only one level of local government and, therefore, the estimated magnitude of municipalities' fiscal interaction cannot be attributed to vertical externalities among different levels of authorities, as may occur in many countries that have a multi-tier structure of government. The chapter is organized as follows. The next section presents a brief review of the literature, and section 3.3 describes the Portuguese institutional framework. In section 3.4, the empirical methodology is laid out, and in section 3.5 the empirical results for the geographical matrices are presented. Finally, section 3.6 presents the results for alternative weighting matrices and section 3.7 concludes the chapter.

3.2 Literature Review

Interjurisdictional interaction is largely acknowledged in the fiscal federalism literature[1] and its consequences in terms of policy choices and efficiency have been broadly studied. The empirical literature on strategic interaction between decentralized levels of government is typically divided into three categories: tax and welfare competition, benefit spillovers, and yardstick competition.[2] The first includes models where a jurisdiction is affected by the choices of other jurisdictions as a result of the existence of a particular resource that they share: the tax-competition literature studies how taxes are chosen strategically when they are levied by governments on a mobile tax base, and that on welfare competition analyzes the strategic choices of governments regarding welfare benefit levels, as a result of the mobility of the poor.[3] Research on spillovers investigates if public expenditure of a jurisdiction generates beneficial or negative effects that spread across its boundaries, affecting the welfare of residents in neighboring jurisdictions. It tries to assess whether

[1]See Oates (1999) for a survey. Brueckner (2003) and Revelli (2006b) survey the empirical research on strategic interaction among local governments.

[2]An exception is Allers and Elhorst (2011) that studies fiscal policy interactions in Dutch municipalities, in an integrated way. They estimate a system of simultaneous equations for expenditures and taxes, taking into account differences in spending needs between jurisdictions. They argue that in single equation models the degree of interaction is estimated inefficiently.

[3]Examples of the latter include Brueckner (1998), Saavedra (2000), Allers and Elhorst (2005), Fiva and Rattsø (2006), Revelli (2006b), and Redoano (2007).

decisions of a local government depend on policies chosen elsewhere. If expenditures refer to local public goods that are complementary, such as environmental services or infrastructure and road building, expenditures in neighboring jurisdictions are likely to boost local governments' own expenditures. However, if local public goods are substitutable (i.e. sports, recreational and schooling facilities) the reverse may occur. Finally, yardstick competition models, often considered to fit the benefit spillover framework, assess how voters, in an asymmetric information setting, use neighboring jurisdictions' public services and taxes to judge their own government's performance. Not having complete information on the cost of public goods and services, they compare the expenditures and tax levels they face with those most easily observable - those of nearby jurisdictions (Salmon, 1987).[4]

Since the main purpose of this chapter is to analyze the extent to which municipalities' spending is influenced by the spending of neighboring municipalities, and the possible sources of this interdependence, we focus our attention on empirical studies of spillovers. The pioneering work of Case et al. (1993) formalizes a model for the United States, in which a jurisdiction's welfare is assumed to depend, among others, on the public spending in neighborhood jurisdictions. Neighbor is defined not only in terms of geographic proximity, but also in terms of economic and demographic similarities. Their results provide strong evidence that states' expenditures are significantly influenced by those of their neighbors, in line with theoretical models of benefit spillovers among jurisdictions.

Since Case et al. (1993), several studies have improved our understanding of how and to what extent spillovers result from local expenditure policies. Hanes (2002) studies Swedish local rescue services and concludes that municipalities respond negatively to benefit spillovers from neighboring municipalities. Using data for Swiss cantons, Schaltegger and Küttel (2002) argue that fiscal autonomy and direct democracy reduces policy mimicking. Revelli (2003) builds up a theoretical framework with horizontal and vertical fiscal externalities in a multi-tier structure of government, in order to assess the source of spatial dependence between English local governments' expenditures. He concludes that, when vertical interaction is accounted for, the magnitude of the horizontal interactions significantly decreases. Baicker (2005) uses exogenous shocks to state medical spending in the US to examine the effect of that spending on neighboring states. She finds substantial

[4]Besley and Case (1995) present empirical evidence of yardstick competition using US state data. For European countries refer to Bordignon et al. (2003), Solé Ollé (2003), Allers and Elhorst (2005), Revelli (2006a), and Redoano (2007). Caldeira (2012) analyzes the Chinese case.

spillover effects, and concludes that states are most influenced by neighboring states from or to which their citizens are most likely to move. Solé-Ollé (2006) presents a framework to analyze and test for two types of expenditure spillovers: benefit spillovers and crowding spillovers, which arise from the crowding of facilities by residents in neighboring jurisdictions. Estimations of expenditure reaction functions for Spanish local governments reveal that spillovers are stronger in urban areas than in the rest of the country, and that both kinds of spillovers occur in the suburbs, while for the city centers only crowding spillovers are relevant. Focusing on cultural spending of Flemish municipalities, Werck et al. (2008) find that large municipalities affect their neighbors' behavior differently from small municipalities. And, finally, Ermini and Santolini (2010) confirm the existence of interdependence among local councils' expenditure decisions in Italy, and suggest it may be driven by spill-over.

All the above mentioned studies used maximum-likelihood or instrumental variables to address the problem of endogeneity of the expenditure interaction variable, since expenditure in one jurisdiction depends on expenditure in another jurisdiction, but the reverse is also true. Recently, a growing body of research has started to implement the Generalized Method of Moments (GMM) in the context of spatial interaction. Using a dynamic panel of European Union countries, Redoano (2007) finds evidence of strategic behavior by central governments on taxes and expenditures. She concludes that: (1) for corporate taxes, European countries follow large countries, while for income and public expenditures, fiscal interactions are driven by yardstick competition; (2) interdependency decreases when countries join the EU. Foucault et al. (2008) test the existence of public spending interactions between French municipalities in a dynamic panel data model. Their results suggest the existence of spending interactions in investment and primary expenditures between neighboring municipalities and between cities whose mayors have the same partisan affiliation. They find evidence of opportunistic behavior in pre-electoral periods (Rogoff and Sibert, 1988), but not of yardstick competition.

To the best of our knowledge, the Portuguese case has never been investigated. The topic assumes additional relevance because of the sovereign debt crisis that the country is facing. One of the structural reforms agreed by the national authorities with the IMF and the EU in 2011, under the financial assistance program, is to reduce the number of local jurisdictions. Better knowledge on expenditure policy decision-making by local governments is therefore necessary.

3.3 Portuguese Institutional Framework

According to the Portuguese Constitution, there are three types of local governments: parishes (*freguesias*), municipalities, and administrative regions. However, administrative regions have not yet been implemented in mainland Portugal, due to the rejection of the proposal to institute them in a national referendum, in 1998; there are only two autonomous regions: Azores and Madeira. In the mainland there are currently 278 municipalities, and in the autonomous regions 30. Our data set does not include these 30 overseas municipalities, given the differences in the territorial organization, the fact that inhabitants of the islands may have different needs from those living in continental Europe, and that the status of ultra-peripheral regions allows them to receive additional European Union's funds. We focus our attention on municipalities because *freguesias*, which are the lowest administrative unit in Portugal, have a very limited scope of functions.
Local governments in Portugal have their own property and finances, and are all subject to the same laws and regulations. Since the reestablishment of democracy in Portugal, in April 1974, there has been a progressive decentralization of competencies from the Central Government to local authorities. Nevertheless, the weight of local governments in general government finances is modest compared to other European Union (EU) countries. The Local Power Law of 1977 (Law 79/77) defined the competencies of municipalities and the division of power among their organs of sovereignty, [5] emphasizing infrastructural interventions, such as the improvement of accessibilities, sewage, and the distribution of water and electricity. In 1984, new legislation (Decree-Law 77/84) was approved enlarging municipalities' competencies to areas such as rural and urban equipment, culture, leisure and sports, transportation and communication, education, and health care. When Portugal joined the European Economic Community, in 1986, the financial situation of municipalities improved considerably, as they started receiving European structural and cohesion funds. Increased resources allowed municipalities to implement several measures that had been delayed due to lack of funds, and to devote greater care to other activities, such as the promotion of culture. Furthermore, more attention was paid to territorial organization and to the establishment of networks with foreign municipalities, namely Spanish jurisdictions near the border. A new law was enacted in 1999 (Law 159/99), which extended

[5] Legislative power in municipalities belongs to the Municipal Assembly, while the executive power rests with the Town Council, where the mayor has a prominent role.

municipalities' attributions regarding the provision of social and cultural services, urban rehabilitation, protection of the environment, consumer protection, promotion of tourist activities, territorial planning and urbanism, external cooperation, and the attraction of corporate activities. Finally, the current Local Finance Law (Law 2/2007) assigned new responsibilities to municipalities in the areas of education and health care, among others. Municipalities account for the bulk of consolidated expenditures of the local administrations. Municipal public expenditures are divided into capital and current expenditures. The former include investment, their main component, capital transfers to parishes, financial assets and liabilities, and other capital expenditures. Until 2001, investment expenditures included miscellaneous constructions (and subcomponents), acquisition of land, housing, transportation material, machinery and equipment, other buildings (and subcomponents), and other investments.[6] As for current expenditures, their sub-components are expenditures on goods and services, financial expenditures, human resources, current transfers to parishes, and other current expenditures.
The main sources of municipal revenue are:

- Transfers from the central government. These address both vertical and horizontal imbalances, and include formula based transfers, matching grants (national and EU funds), and others.

- Local taxes: property, property transfer, vehicle and corporate income taxes are the most important. The property tax is the largest own-revenue source of municipalities, who have autonomy to set the tax rates, within a band. Local governments can levy an optional corporate income tax surcharge on taxpayers that operate businesses or have a permanent establishment in the municipal jurisdiction. The rate can vary from zero to a maximum defined nationally. Municipalities have little discretionary power over the property transfer and vehicle taxes.

- Other revenues: fees and fines, property income, and financial liabilities, among others.

The decentralization process in Portugal also had a reflection on the importance of each source of revenue. Transfers represented 63% of local governments' revenues in 1986, but

[6] In 2002, investment accounts were reorganized into the following categories: acquisition of land, buildings and other constructions (and subcomponents), transportation material, machinery and equipment and, finally, others.

they only account for 43% in 2006. On the other hand, the weight of items where the local government has more discretionary power increased. Taxes increased their share on total revenues from 18% to 33%, and other revenues from 19% to 24%. The fiscal situation of municipalities has deteriorated markedly in past years, generating fiscal imbalances and the accumulation of debt.
Given that transfers from the central government still represent the main source of municipal revenues; local governments have greater autonomy to establish their expenditure levels and composition than revenues. Therefore, this chapter focuses on expenditures to test for interactions between neighboring municipalities. It is important to note that mayors have greater control over investment expenditures than over current expenditures, since items such as salaries are quite rigid. Furthermore, investment expenditures can be used by local decision makers to attract corporate activity and households, and to gain votes in municipal elections.

3.4 Empirical Framework and Econometric Procedure

The purpose of this chapter is to test for strategic interaction in per capita expenditure levels in Portuguese municipalities, and to understand the reasons for its occurrence. If there is interaction, jurisdiction i's spending levels depend not only on their own economic and demographic characteristics, but also on the spending levels chosen by nearby municipalities. There can be either positive or negative correlation in local public expenditure levels, depending on the effect that the neighbor jurisdictions' expenditures have on the marginal utility of a given municipality's public spending. They will have a positive effect if public goods or services supplied by these neighbors are complements of the municipality's own goods, and a negative effect if they are substitutes. Municipality i's reaction function can be described as:

$$G_{it} = \beta_1 + \alpha WG_{it} + \beta_2 mun_{it} + \epsilon_{it} \tag{3.1}$$

where G_{it} is real per capita expenditure in jurisdiction i at time t; WG_{it} is a weighted average of neighboring municipality's real per capita expenditures (W is a geographical weighted matrix), that is, $WG_{it} = \sum_{j \neq i} w_{ijt} G_{jt}$; mun_{it} is a vector of economic and demographic variables for each jurisdiction, affecting their fiscal choices, and it is an error

term.
The rationale behind this is that citizens may derive benefits from public goods and services provided by their own municipality and by neighboring municipalities. Thus, a welfare maximizing government will maximize the following objective function:

$$F\left(G_{it}, WG_{it}; mun_{it}\right) \tag{3.2}$$

Solving the first order condition, a given municipality i will choose G_{it} according to the reaction function $G_{it} = R\left(WG_{it}; mun_{it}\right)$, which consists of its best response to the decisions of other municipalities, taking into account its own characteristics. If there are no spillovers regarding public expenditures, then WG_{it} does not enter the reaction function - the coefficient α in equation (3.1) will be zero.
Since municipalities have a broad range of responsibilities and produce several goods and services, expenditure decisions also involve choosing on which goods and services resources should be allocated. Therefore, we test for interactions on the expenditure level as well as on the composition of expenditures. In a regression framework the dependent variable is the logarithm of real per capita expenditures. Several items of expenditure are considered alternatively: total expenditures, capital expenditures, current expenditures, and investment expenditures and its main components.

3.4.1 Specification of the weight matrix

It is highly important to properly select a criterion to define neighbors, given that a misspecification of the weight matrix may lead to inconsistent estimates and affect the coefficients' interpretation.(Anselin, 1988) The choice of adequate weight matrices is an open discussion within the spatial econometrics literature. Several approaches have been followed to specify the elements of the weight matrix, and no consensus has been achieved on which is better suited for spatial econometric analysis. The matrix has to be specified according to a criterion that reflects previous expectations about the spatial pattern of interaction and, to some extent, reflect economic mechanisms at the base of such interaction. Cheshire and Magrini (2009) argue that exhaustive experimentation with the spatial weight matrix is needed. In the discussion that follows we will discuss different weight matrices within our data. Following the trend in the literature, we assume that a municipality is not considered its own neighbor, so the matrix has zero diagonal values.

A commonly used method is to assign weights based on contiguity.[7] One way to apply this scheme is to assign values of 0 and 1 to the structure of neighbors - binary contiguity. This would imply $w_{ij} = \frac{1}{m_i}$ for municipalities j that share a border with municipality i, and $w_{ij} = 0$ otherwise; where m_i is the number of municipalities contiguous to i. Such matrix (W^0), was created for our sample and later used in the estimation for total expenditures, as a robustness test. However, as discussed by Anselin (1988) this method does not supply a full representation of the degree of spatial interaction present in the data. It is frequent, after Cliff and Ord (1981) to assign different weights to the neighbors, according to the degree to which they affect municipality i, so that $\sum_j W_{ij} = 1$. Different weights may be assigned according to geographical distance, or other variables affecting interactions, namely demographic, economic or political variables.

Following several papers in the literature, we also defined neighbors according to the Euclidean distance between the centers of the municipalities, and constructed the weights as the inverse of this measure. Firstly, and given that Portugal is a relatively small country, all municipalities were considered neighbors (W^T). Secondly, and in order to investigate the robustness of the results, we limited the municipalities that are considered neighbors to those that distance x or less kilometers (W^x), with $x = 50$ and $100km$. This is because benefits are more likely to be internalized by municipalities that are closer. In all the specifications the effect of neighbors is smaller the further away they are. The choice of $100km$ was based on the fact that the maximum frequency of distances between Portuguese municipalities is for $100km$, and that of $50km$ was based on the limits generally used in empirical literature on spillovers between local governments. Additionally, $50km$ is the distance from which a journey is considered medium or long distance.

Hence, municipality i's expenditures are assumed to be affected by the expenditures of all its neighbors, in inverse proportion to their distances to i and are normalized afterwards, so that $\sum_j W_{ij} = 1$. Thus, w_{ij} is defined as:

$$w_{ij} = \frac{\frac{1}{dist_{ij}}}{\sum_j \frac{1}{dist_{ij}}} \tag{3.3}$$

[7] See Besley and Case (1995).

or

$$w_{ij} = \begin{cases} \frac{\frac{1}{dist_{ij}}}{\sum_j \frac{1}{dist_{ij}}} & \text{if } 0 < d_{ij} \leq xkm \\ 0 & \text{otherwise} \end{cases}$$

for the first (W^T) and second (W^x) specifications, respectively. Hence, each observation G_{it} is associated to its spatially lagged counterpart, $WG_{it} = \sum_{j \neq i} w_{ijt} G_{jt}$, which is a linear combination of the observations for all i's neighbors.
As a result, four matrices were created: one based on geographical contiguity and three distance decay matrices. Each W is, therefore, a 275x275 matrix for the period 1986-1998, and a 278x278 matrix, for the period 1999-2006, with zero diagonal elements.[8] We chose the geographical criterion to compute the weight matrix because benefit spillovers depend on the mobility of the population, which, in turn, depends on the distance between municipalities.[9]

3.4.2 Econometric issues

According to the model, municipality i's expenditures in year t depend on municipality j's expenditures, and municipality's j's expenditures also depend on those of i. If municipalities react to each other's spending decisions contemporaneously, then WG_{it} is endogenous in model (3.1) and correlated with the contemporaneous error term:

$$E\{\epsilon_{it} WG_{it} \neq 0\} \tag{3.4}$$

In this situation, the Ordinary Least Squared (OLS) estimator is biased and inconsistent and there are two possible solutions: Maximum Likelihood (ML) and Instrumental Variables (IV). The first solution consists in inverting the system, in order to eliminate the dependent variables from the right-hand side of the estimating equation, and using a non-linear optimization routine to estimate the spatial coefficient. Examples of papers using this approach are Case et al. (1993), Besley and Case (1995), Brueckner (1998), and Foucault et al. (2008). However, this procedure is computationally demanding, especially with a large dataset with panel observations. Another possible solution for this problem

[8] Three municipalities were created in 1998: Trofa, Odivelas and Vizela.

[9] An alternative way to measure municipalities' interaction would be to use economic flows across regions. However, the data is not readily available for our analysis.

would be an instrumental variable two-stage least squares (2SLS) procedure, using as instruments the neighbors' variables (mun_{jt}) that influence their fiscal decisions and are not correlated with the error term. Thus, in line with numerous empirical studies, these would be all considered strictly exogenous and would be weighted by W. Several papers have used this method successfully, such as Kelejian and Robinson (1993), Revelli (2002), and Solé-Ollé (2006). Another empirical problem concerning the estimation of a spatial model is that there may be spatial dependence in the error term, given by:

$$\epsilon_{it} = \lambda W \epsilon_{it} + \mu_{it} \tag{3.5}$$

where μ_{it} it is a white noise error term, uncorrelated between municipalities. If this error correlation is ignored, false evidence of strategic interaction may be provided by the estimation. ML solves this by incorporating this error structure, and IV generates consistent estimates of α even in the presence of spatial error correlation (Kelejian and Prucha (1998). Due to the fact that we are dealing with panel data, we have to consider unobserved heterogeneity. Thus, we augmented equation (3.1) with an individual municipality effect. Additionally, we included time effects, with year specific intercepts, in order to control for macroeconomic variables that affect all municipalities at the same time. As noted by Case et al. (1993), these are particularly important so that spending correlations between jurisdictions caused by common national level shocks are not given spatial significance. Finally, according to Veiga and Veiga (2007), Portuguese municipalities' level of per capita real expenditures exhibits a high level of persistency. Hence, we also included a lag of the dependent variable, G_{t-1}. The model to be tested can, then, be specified as follows:

$$G_{it} = \beta_1 + \gamma G_{it-1} + \alpha W G_{it} + \beta_2 mun_{it} + \eta_i + \rho_t + \epsilon_{it} \tag{3.6}$$

where η_i is the individual effect and ρ_t are time effects.

Because G_{t-1} was included, by construction it will be correlated with the individual effect, η_i. In order to solve this problem, and following Arellano and Bond (1991), we can take first-differences of equation (3.6) to eliminate η_i and use as instruments for $\triangle G_{t-1}$ lagged levels of the dependent variable from two or more periods before - which are not correlated with the residuals in differences, assuming no serial correlation in ϵ_{it}. The neighboring variable, being endogenous, can be instrumented in a similar way. Thus, the estimation may be conducted with instrumental variables, more specifically by the Generalized

Method of Moments (as discussed in Arellano and Bond, 1991 - GMM - which combines the instruments efficiently. It does so by estimating the model parameters directly from the moment conditions. However, since we suspect high persistence in expenditures, the use of the System GMM estimation (Arellano and Bover, 1995 and Blundell and Bond, 1998) might be the appropriate solution. This extended estimator combines the moment conditions for the model in first differences and for the model in levels, and is especially suitable when there is a high level of persistency in the dependent variable - it is less biased and more precise. It also allows correcting for econometric problems such as weak instruments and measurement errors. Given its properties, we will consider this solution throughout our empirical analysis, comparing it, where appropriate, with the OLS, Fixed Effects (FE) and GMM applied to first-differences (GMM-Dif) alternatives. The validity of the instruments later used in our estimations will be checked using the Hansen test for overidentifying restrictions. We will specifically address the presence of heteroskedasticity in our data. Additionally, in each regression, following Arellano and Bond (1991) we will investigate whether the residuals are serially correlated. Several estimation procedures have been proposed for spatial models, but the only method that incorporates spatial dependence, temporal lags and other endogenous variables is the system GMM estimator (GMM-Sys).[10] Recently, Kukenova and Monteiro (2009) by performing a Monte Carlo Investigation, found the extended GMM to be suitable to estimate dynamic spatial lag models, especially when N and/or T are large.

3.4.3 Data and empirical model

The empirical model consists of an equation where municipality i's real per capita expenditure in year t (G_{it}), depends on its lagged value, its own characteristics and on the real per capita expenditures of the neighboring municipalities (G_{jt}) in the same year.[11] The following variables are used to capture municipalities' resources and needs:

- $grant_{it}$ is total real per capita transfers from the central government. Since grants represent the main source of municipalities' revenues, a positive and large coefficient is expected. $Capgrant_{it}$ and $Currgrant_{it}$ are, respectively, capital grants and

[10] For a description of estimators dealing with spatial and time dependence in panel datasets see Kukenova and Monteiro (2009).

[11] In preliminary analysis we tested for strategic interaction over time, but additional lags of weighted expenditures by neighboring municipalities never turned out as statistically significant.

current grants. They are included, instead of total grants, in the regressions having as a dependent variable capital, investment and its components, and current expenditures.

- $popdens_{it}$ represents the population density, in jurisdiction i at time t. It proxies for the level of urbanization and allow us to test for congestion effects or scale economies in the provision of local public goods and services.

- In order to pick up differences in population needs, we consider the dependency ratio ($depend_{it}$), which is the proportion of population in the municipality that is under 15 years old and over 65. These groups of the population demand specific services that are provided by local authorities, such as elementary education and facilities for the elderly.

All variables are expressed in logarithm, except for the population density and the percentage of dependent population, so the results can be interpreted as elasticities.
The data set contains annual data on all Portuguese mainland municipalities, for the years 1986 to 2006. Given that three municipalities[12] were only created in 1998, from 1986 to 1998 there are only data for 275 municipalities. Data on municipalities' local accounts were obtained from the DGAL's annual publication *Municipal Finances* (Direccao Gera das Autarquias Locais, 1986-2000). That on population and consumer price indexes was collected from Marktest's Sales Index (Marktest, 2009) and the proportions of population under 15 and over 65 were collected from the Regional Statistical Yearbook, of the Portuguese Institute of Statistics (Instituto Nacional de Estatistica, 1986-2006). Descriptive statistics are presented in Table 3.1. Portuguese municipalities have an average of 540.28 euros per capita for total expenditures in the period in analysis, with a standard deviation of 317.4. Current expenditures account for around 51% of total expenditures, with capital expenditures representing the other 49%. Of the latter, about 81% are investment expenditures.

[12]Odivelas, Trofa and Vizela

Table 3.1: Descriptive statistics

	No Obs.	Mean	Stand. Dev.	Min	Max
Total Expenditures	5791	540.28	317.40	72.05	2315.13
Current Expenditures	5791	277.76	170.40	41.45	1471.92
Capital Expenditures	5791	262.50	179.20	13.48	1620.73
Investment Expenditures	5791	213.71	156.37	10.08	1359.76
Acquisition of land	3460	7.57	12.62	0.0007	233.23
Housing	3009	15.67	31.29	0.0002	394.90
Transportation material	3998	6.41	7.78	0.008	88.99
Machinery and equipment	4359	11.86	11.48	0.009	146.35
Miscellaneous constructions	4398	127.85	113.04	0.07	1810.72
Overpasses, streets, complementary works	4230	31.11	38.01	0.0004	479.11
Sewage	3761	16.50	23.98	0.002	393.37
Water treatment and distribution	3726	19.63	29.42	0.001	570.88
Rural roads	3783	43.88	57.64	0.003	772.90
Infrastructures and solid waste treatment	1074	5.09	23.44	0.0001	561.10
Other Miscellaneous Constructions	4061	25.70	44.23	0.003	705.72
Other buildings	4393	34.02	38.61	0.02	531.77
Sports, recreational and schooling facilities	3951	14.55	24.64	0.001	361.29
Social equipment Expenditures	1597	6.27	13.28	0.0003	237.66
Other Expenditures in Other Buildings	4319	18.94	28.06	0.001	349.35
Other investments	2063	6.60	13.33	0.0003	191.87
Total Grants	5791	356.42	255.85	46.68	1988.24
Capital Grants	5790	187.91	141.14	18.02	1374.26
Current Grants	5791	168.54	124.34	27.53	979.14
Population (number of inhabitants)	5799	34827	57972	1767	727500
Population Density (inhabitants per km)	5799	2.91	8.68	0.06	86.76
Share of Dependent Population (%)	5799	35.88	4.14	17.10	58.19

Sources: INE, DGAL, SI (several years).

Monetary values are expressed in real and per capita terms. The sample period goes from 1986 to 2006, except for investment expenditures subcomponents, for which the period has been restricted to 2001.

3.5 Results for geographical distance matrices

Empirical results based on geographical proximity are presented in Tables 3.2 to 3.4. Our key estimates are discussed in Section 3.5.1, Table 3.2, where we estimate equation (3.6) for Total, Capital, Current, and Investment Expenditures, using W^T as the weighting matrix. In Section 3.5.2, we test for alternative distance weighting matrices, estimating equation (3.6) for Total expenditures. Finally, under Section 3.5.3, we extend our empirical analysis to investment components. Throughout the analysis we implement a similar GMM-Sys strategy, which facilitates the comparison of results obtained for different dependent variables and weighting matrices.

3.5.1 Total, Capital, Current, and Investment Expenditures

Table 3.2 presents estimation results for total, capital, current and investment real per capita expenditures. For total expenditures, we estimate equation (3.6) by Ordinary Least Squares (OLS), Fixed Effects (FE) and System Generalized Method of Moments (GMM-Sys) in columns (1) to (6). For the remaining dependent variables, we only estimate the model by GMM-Sys. In order to take into account for the specific dynamics of each dependent variable, we include several lags as explanatory variables. The specific number of lags of the dependent variable in each equation is reported in the note to Table 3.2. Only the coefficient of the first lag is reported. In all specifications we estimate equation (3.6) with and without neighboring expenditures. The spatial dependence variable was computed using the matrix W^T, which considers all Portuguese municipalities as neighbors, with weights in inverse proportion to the distances between them. For the GMM-Sys we use the two-step estimation with the finite-sample correction for standard errors suggested by Windmeijer (2005). For all specifications we include time specific dummies. The reported statistics are robust to heteroskedasticity and serial correlation in the errors. Since we suspect the errors are non-spherical, we report the Hansen consistent test instead of the Sargan statistic. For the GMM regressions discussed below, we instrument, for the differenced equations, first-differences of the dependent variable using its levels lagged at least two periods, and its lagged first-differences as instruments for the level equations. Grants and neighboring municipalities expenditures are assumed to be endogenous, and are instrumented similarly to lagged own expenditures. The argument is that transfers from the central government can be, to some extent, influenced by local governments. Finally, the demographic variables, as well as the time dummies, are assumed as exogenous. We based this belief on the fact that municipalities have little or no control over demographic variables (such as population density and the percentage of people under 15 and over 65). Furthermore, any shocks that may affect the entire country, which are controlled for by time dummies, are also exogenous to individual municipalities. Our first result (OLS, columns (1) and (2), Table 3.2) indicates that total expenditures show some degree of persistence. Focusing on our key explanatory variable, neighboring total expenditures, we conclude that there are positive spillover effects across municipalities. When accounting for unobserved municipality specific effects, in columns (3) and (4), we corroborate the results obtained by OLS. Although OLS and FE produce biased estimates, due to the presence of the lagged dependent variable on the right hand-side of equation (3.6), they provide a useful benchmark on what we should expect from the consistent GMM estimates.

The serial correlation pattern in the first-differenced residuals in models (5) and (6), by showing insignificant AR(29 (and AR(3)), indicates that we need to instrument the equations in first-differences with two lags of the dependent variable, and first-differences lagged one period for the equations in levels. Additionally, we restrict the instruments for first-differences equations to five lags. In order to limit the number of instruments, we do not apply each moment condition underlying the system-GMM procedure to each time period and lag available. Instead, we apply a single moment condition for each period and regressor.[13] By estimating our model using the GMM system procedure we confirm that total expenditures exhibit some persistence, revealed by the estimated coefficient of 0.41 for lag total expenditures, which is statistically significant at the 1% level - column (6). This might result from the fact that municipalities' spending decisions are highly dependent on their resources and on their population needs, which are also persistent over time. The exclusion of neighboring total expenditures, column (5), does not significantly alter the level of persistency in the series. Focusing on column (6), we conclude that the elasticity of own expenditures with respect to neighboring total expenditures is significant and about 0.48: a one percent increase in neighbors' expenditures is associated with an increase in own expenditures of about 0.48%, confirming the existence of complementary characteristics of local public goods provided by neighboring municipalities or mimicking effects. This result clearly indicates that total expenditures spill over municipalities; i.e., own expenditures vary positively with neighbors' decisions regarding this variable. There is strong evidence in favor of expenditure interactions among Portuguese municipalities - the variable WG_{it} is statistically significant and positively signed. Grants are statistically significant with a large positive coefficient, derived from the fact that transfers from the central government are municipalities' main source of revenue. The density of the population exerts a positive and statistically significant effect on total expenditures, suggesting

[13]The model has been estimated with Stata's command XTABOND2, and the option 'collapse' has been used to define the instruments for G_{it-1}, $grant_{it}$ and $taxes_{it}$.

Table 3.2: Estimation results for Total, Capital, Current and Investment Expenditures

	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12
D. Variable	TotExp	TotExp	TotExp	TotExp	TotExp	TotExp	CapExp	CapExp	CurExp	CurExp	InvExp	InvExp
Model	OLS	OLS	FE	FE	GMM-Sys	GMM-Sys	GMM-Sys	GMM-Sys	GMM-Sys	GMM-Sys	GMM-Sys	
G_{it-1}	0.69***	0.64***	0.31***	0.30***	0.42***	0.41***	0.31***	0.35***	0.72***	0.60***	0.51***	0.52***
	(0.03)	(0.03)	(0.02)	(0.02)	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.05)	(0.04)	(0.04)
WG_{it}		0.33***		0.48***		0.48**		0.69**		0.57***		0.86*
		(0.05)		(0.10)		(0.24)		(0.28)		(0.13)		(0.50)
$grant_{it}$	0.25***	0.25***	0.40***	0.39***	0.19***	0.18***	0.40***	0.31***	0.03*	0.08***	0.28***	0.21**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.05)	(0.04)	(0.09)	(0.08)	(0.02)	(0.02)	(0.09)	(0.10)
$depend_{it}$	-0.006***	-0.007***	0.002	0.003	0.006	0.004	0.005	0.003	0.003*	0.004*	0.004	0.0003
	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.003)	(0.007)	(0.007)	(0.002)	(0.002)	(0.007)	(0.007)
$denspop_{it}$	0.004***	0.004**	-0.002	-0.002	0.003	0.004*	0.004	0.005	0.0007	0.003	0.003	0.005
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.0005)	(0.002)	(0.002)	(0.003)
Observations	5,508	5,508	5,508	5,508	4,67	4,67	5,225	5,225	4,948	4,948	4,947	4,947
R-squared	0.93	0.93	0.90	0.90								
Municipalities			278	278	278	278	278	278	278	278	278	278
AR1					-10.67	-11.21	-12.46	-12.62	-10.48	-8.31	-10.92	-10.95
p-value					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AR2					0.57	0.47	0.17	-1.13	-0.49	-2.00	-0.28	-0.48
p-value					0.57	0.64	0.87	0.26	0.63	0.05	0.78	0.63
AR3					-0.02	0.10	0.11	0.27	-0.45	1.62	-0.46	-0.50
p-value					0.98	0.92	0.91	0.79	0.65	0.11	0.65	0.62
Hansen					8.33	10.13	5.14	15.15	6.30	105.4	35.26	33.87
p-value					0.14	0.34	0.40	0.18	0.39	0.11	0.11	0.17
DF					5	9	5	11	6	88	26	27

Sources: INE, DGAL, SI (several years).

Robust standard errors in parenthesis. Significance level for which the null hypothesis is rejected: ***1%, **5% and *10%. GMM stands for GMM system estimation; two-step estimation results are presented. AR(1), AR(2) and AR(3) refer to first, second and third order autocorrelation tests. DF stands for degrees of freedom. In each model the dependent variable corresponds to D.Variable. GMM-sys estimations for total, capital, current and investment expenditures include, respectively, fourth, second, third and third order lags of the dependent variable.

the existence of congestion effects in the provision of local public goods and services. Contrary to our priors, the share of dependent population does not seem to influence total expenditures. Given the persistency of the series, and the inclusion of several lags of the dependent variables as explanatory variables,[14] it is not surprising that the demographic variables, which are quite stable over time, do not exert a large impact. The tests for serial correlation in the error term reveal, as expected, negative serial correlation in first-differences, which disappears for second and higher orders. This result follows from the formulation of equation (3.6), and constitutes a first validation of the instruments used. The Hansen test's statistic is 10.13, has 9 degrees of freedom, and an associated p-value of 0.34. This result validates the instrument set used in the estimation of column (6). A similar conclusion is valid for the estimates presented in column (5). Moving to capital expenditures, Table 3.2, columns (7) and (8), the estimated coefficient for the lagged dependent variable is slightly smaller than the one estimated for total expenditures. Previous results extend to capital expenditures; i.e., capital expenditures are positively determined by grants. The information conveyed by the serial correlation tests, AR(1) to AR(3), together with the Hansen test, validate de instruments used in our regressions. For both estimations, columns (7) and (8), the p-value of the Hansen test is bounded between 0.18 and 0.40, and the serial correlation in first-differenced residuals disappears after two lags. The estimated coefficient associated with capital expenditures of neighboring municipalities is statistically significant, and has increased considerably, indicating an elasticity of 0.69. Grants continue to exert a positive and statistically significant influence on capital expenditures. Moving to current expenditures, column (10) reveals a different pattern in terms of residual serial correlation. As we can see in the AR tests, residual's serial correlation only disappears after 3 lags. This implies that in the instrument set we use current expenditures lagged three to five periods for first-differences equations, and first-differences of current expenditures lagged two periods for equations in levels. The remaining variables are instrumented as discussed above. Focusing our attention on column (10), the model with neighboring current expenditures, we now observe that there are spillovers of this item across municipalities: a 10% increase in neighbors' expenditures brings about a 5.7% increase in own current expenditures. Persistence is now much higher, when compared to the previous expenditure variables. This is consistent with the economic theory, since local

[14]The choice of the number of lags to include was based on the specific dynamics of the dependent variable, as well as on their statistical significance.

governments may not be able to make sudden changes in their fiscal choices, either because they have too high adjustment costs or because they are blocked by law, namely regarding the wage policy and firing decisions.[15] This is particularly true for current expenditures, which are usually set in advance for several years and are not easily changeable. Furthermore, grants and the demographic variables, although correctly signed, seem to have a smaller impact when compared to the previous two items. Overall, estimations under columns (9) and (10) are validated by the serial correlation and Hansen tests.[16] Finally, investment expenditures, which represent the bulk of capital expenditures (around 80%), reveal significant and large overall investment spillovers from neighboring expenditures, with an elasticity of 0.86. There is also evidence that investment decisions depend on resources available. As before, the instrument set is validated. Given the relevance of this sort of expenditures we will discuss the spillovers for different investment components in Section 3.5.3.

3.5.2 Alternative weighting matrices

In order to test the robustness of the results regarding the use of the weighting matrix, we will now implement our analysis using three alternative weighting matrices described in section 3.4.1: binary/contiguity (W^0), 50kms (W^{50}), and 100kms (W^{100}). The results are shown in Table 3.3. Columns (1) to (3) present distance decay results considering the contiguity matrix, while columns (4) and (5) consider 50km and 100km, respectively, as the maximum distance after which weights are set to zero. The standardized binary/contiguity matrix (W^0) assigns the value 1 to municipalities that share a border and 0 otherwise. Throughout this section we only consider total expenditures as our dependent variable.

Not accounting for specific effects - Table 3.3, column (1) - the elasticity of own expenditures to neighboring total expenditures is quite small (0.09). However, this result is biased, as we ignore both the fixed unobserved effects and the lagged dependent variable. The inclusion of municipalities' fixed effects (column 2) increases the degree to which local governments react to their neighbors expenditure decisions. However, this result is still biased, as the within transformed lagged dependent variable is correlated with the within transformed error term. In order to solve the bias, and to render our results more

[15]Expenditures with employees represent around 50% of current expenditures

[16]We do not restrict the number of instruments when defining the set of instruments for neighboring Current Expenditures, column (10), which explains the high number of instruments used in this regression.

Table 3.3: Estimation results for different weighting matrices

	-1	-2	-3	-4	-5
Weighting Matrix		Binary: W^0		W^{50}	W^{100}
Model	OLS	FE	GMM-Sys	GMM-Sys	GMM-Sys
G_{it-1}	0.66***	0.30***	0.35***	0.36***	0.35***
	(0.03)	(0.02)	(0.04)	(0.04)	(0.04)
WG_{jt}	0.09***	0.13***	0.22**	0.33***	0.41***
	(0.02)	(0.02)	(0.09)	(0.11)	(0.15)
$grant_{it}$	0.24***	0.39***	0.13**	0.10*	0.13**
	(0.02)	(0.02)	(0.05)	(0.06)	(0.05)
$depend_{it}$	-0.007***	0.002	0.02***	0.02***	0.02***
	(0.001)	(0.002)	(0.004)	(0.004)	(0.004)
$denspop_{it}$	0.004**	-0.002	0.002	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	5,508	5,508	5,508	5,508	5,508
R2	0.93	0.90			
Municipalities		278	278	278	278
AR(1)			-12.04	-12.05	-12.17
p-value			0.00	0.00	0.00
AR(2)			1.09	0.91	0.96
p-value			0.27	0.36	0.34
Hansen test			3.76	3.56	3.09
p-value			0.59	0.61	0.69
DF			5	5	5

Sources: INE, DGAL, SI (several years).

Robust standard errors in parenthesis. Significance level for which the null hypothesis is rejected: ***1%, **5% and *10%. GMM-Sys estimations present two-step results. AR(1) and AR(2) refer to first and second order autocorrelation tests. DF stands for degrees of freedom. In each model the dependent variable is Total Expenditures.

comparable to those presented in the previous section, we implement the system GMM-Sys estimation[17] (column 3) and the results clearly indicate the presence of neighboring spillover effects. Analyzing the results shown in columns (4) and (5), both estimated by GMM-Sys, not only do we reinforce the conclusion that there are spillovers of total expenditures between neighbors, but also that their size is determined by the weighting

[17]Hansen tests indicate that, for our data, the system-GMM is preferable to the GMM that only includes the first-differenced equations.

matrix we use. It is clear from our results that, when allowing for a broader definition of neighborhood, we capture a higher effect of neighbors' expenditures. Under the definition of 100km neighborhood, we estimate an elasticity of 0.41 (Table 3.3, column 5), while considering 50km neighborhood (Table 3.3, column 4), we estimate such elasticity to be of about 0.33. This is understandable, given that the latter definition of neighborhood is more restrictive. The remaining results are similar for all regressions. This set of results corroborates and strengthens the discussion and the options made in Section 3.5.1. As such, we conclude that there is strategic interaction regarding Portuguese municipalities' total expenditure levels.

3.5.3 Components of Investment Expenditures

There is no reason to assume that patterns of expenditure interdependence are the same for all categories of investment. It is possible that some types of spending exert complementarity and others substitutability, canceling each other out and reducing the aggregate effect. An analysis of aggregate spending levels might bias downward the effects of spillovers on spending. To investigate this possibility, the model defined in equation (3.6), and discussed in Section 3.5.1, is now implemented for the sub-components of investment expenditures.

Until 2001, investment expenditures had seven main categories: (1) Acquisition of Land, (2) Housing, (3) Transportation Material, (4) Machinery and Equipment; (5) Miscellaneous Constructions; (6) Other Buildings, and (7) Other Investments. Miscellaneous Constructions and Other Buildings were de-composed in, respectively, six and three subcomponents. When analyzing the data set we realized that some of these items have a significant number of zeros and missing values, which led us to exclude some of them from the analysis.[18] Table 3.4 shows the results for 11 of the 16 components and subcomponents of investment expenditures. In this table, we only report the estimated coefficient for WG_{it} and its standard error. Additionally, for the GMM type regressions we report the statistic for the Hansen test, and its degrees of freedom.[19] We report estimation results obtained when using the matrix WT, that is, the matrix that considers all municipalities

[18] Acquisition of land, Housing, Infrastructures on solid waste treatment, Social equipment, and Other investments were excluded because they all have an average of more than 50 missing values or zeros per year.

[19] Results for the entire regressions are available from the authors upon request.

Table 3.4: Estimation results for some investment components

	OLS	FE	GMM-Sys	
D. Variable			Coeff.	Htest
1. Acquisition of land	n.a	n.a.	n.a	n.a
2. Housing	n.a	n.a.	n.a	n.a
3. Transportation material	0.62 (0.10)***	0.09 (0.23)	0.40 (1.78)	23.09 [17]
4. Machinery and equipment	0.60 (0.08)***	0.09 (0.22)	0.94 (0.15)***	112.68 [97]
5. Miscellaneous constructions	0.13 (0.10)	0.51 (0.17)***	0.94 (0.46)**	26.97* [18]
5.1. Overpasses, streets and complementary works	0.43 (0.13)***	0.26 (0.21)	0.28 (0.77)	37.55 [35]
5.2. Sewage	0.28 (0.11)**	0.26 (0.22)	0.86 (0.29)***	73.61* [58]
5.3. Water treatment and distribution	0.04 (0.12)	0.10 (0.17)	0.71 (0.50)	10.13 [7]
5.4. Rural roads	0.60 (0.60)***	0.51 (0.23)**	0.89 (0.30)***	41.94 [40]
5.5. Infrastructures on solid waste treatment	n.a	n.a.	n.a	n.a
5.6. Other Miscellaneous Constructions	0.25 (0.12)**	0.24 (0.21)	0.60 (0.26)**	18.25* [11]
6. Other buildings	0.02 (0.18)	0.34 (0.23)	0.15 (0.35)	28.67* [19]
6.1. Sports, recreational and schooling facilities	0.47 (0.13)***	0.55 (0.14)***	0.78 (0.29)***	45.86* [33]
6.2. Social equipment	n.a	n.a.	n.a	n.a
6.3. Other Expenditures in Other Buildings	0.59 (0.17)***	0.88 (0.21)***	0.86 (0.32)***	36.04 [28]
7. Other investments	n.a	n.a.	n.a	n.a

Sources: INE, DGAL, SI (several years).

Robust standard errors in parenthesis. Hansen test's (H-test) degrees of freedom in brackets. Significance level for which the null hypothesis is rejected: ***1%, **5% and *10%. GMM-Sys estimations present two-step results. In each model the dependent variable corresponds to D. Variable. The reported coefficient and standard error is for the neighboring variable. Estimations include third order lags of the dependent variable; the exception is the estimation for Sports, recreational and schooling facilities, which includes two lags of the dependent variable.

as neighbors. The instrument set associated within each GMM regression is similar to the one discussed in Section 5.1 for investment expenditures. In order to keep the regressions as comparable as possible, we use the same structure to define the instruments, particularly in what concerns exogeneity/endogeneity, and the lags used for the instruments are the minimum required to validate the estimates. For each investment component we report the OLS, FE, and GMM-Sys estimates.
When using the system-GMM procedure, there is evidence of positive spillovers across the border for Machinery and equipment, Miscellaneous Constructions (particularly for Sewage, Rural Roads, and Other miscellaneous constructions), and for two items of Other Buildings (Sports, recreational and schooling facilities and Other expenditures). As before, the instrument set is validated by the serial correlation and overidentification tests. The significant coefficient for the spatial interaction variable associated with Rural roads may be due to coordination among neighboring municipalities. Roads frequently cross the borders of several jurisdictions, implying that improvements or extensions in one jurisdiction may require complementary investments from neighboring municipalities. The same reasoning applies to sewage networks. Regarding other items, such as investments in sports, recreational and schooling facilities, the positive strategic interaction is likely to be due to mimicking of nearby municipalities, since some expenditures may be used to attract households and firms, in line with the tax and welfare competition literature. Mimicking might also occur for political reasons, if it occurs more in election years or between mayors of similar political orientation, or due to similarities in the population's needs, if it occurs more between jurisdictions that are similar in demographic terms.

3.6 Additional sources of fiscal interactions

In order to disentangle the sources of fiscal interactions among jurisdictions, we perform several additional empirical tests. We start by interacting the variable measuring the weighted average of neighboring municipalities' expenditures with a series of dummy variables for electoral years or which characterize municipalities. Second, we test alternative weighting matrices based on population density and mayors' ideology. According to the yardstick competition hypothesis, local jurisdictions react more to their neighbors' fiscal policies during electoral periods because voters compare the mayors' performances. To test this prediction, a dummy variable was created ($MunElection_{it}$) for municipal election years. The dummy was then interacted with the variable representing the weighted average of neighboring municipalities' expenditures (WG_{it}). We find no evidence of yardstick competition in the main expenditure items. Table 3.5 presents the results for Total, Capital, Current and Investment Expenditure. All regressions include the same set of control variables as those of the previous tables but, in order to economize space, only the estimated coefficients associated with G_{it-1}, WG_{it}, and its interactions with the electoral dummy are presented. We cannot include the dummy for municipal elections in the regression because we control for time effects with year dummies, and the former would be a linear combination of latter dummies. We also run the regressions using investment subcomponents as dependent variables, but results are not consistent with larger interactions during electoral years.

Table 3.5: Estimation results for yardstick competition models: Estimates using W^{all}

	-1	-2	-3	-4
D. Variable	TotExp	CapExp	CurExp	InvExp
Model	GMM-sys	GMM-sys	GMM-sys	GMM-sys
G_{it-1}	0.40***	0.34***	0.65***	0.52***
	(0.04)	(0.03)	(0.04)	(0.03)
WG_{it}	0.60***	0.45*	0.28*	0.85**
	(0.17)	(0.28)	(0.16)	(0.32)
$MunElection_{it}$*WG_{it}	0.02	0.20	-0.07	-0.14
	(0.08)	(0.17)	(0.12)	(0.16)
Hansen	36.09	1.16	6.22	33.21
p-value	0.07*	0.14	0.40	0.16
DF	25	11	6	26

Sources: INE, DGAL, SI (several years).

Robust standard errors in parenthesis. Significance level for which the null hypothesis is rejected: ***1%, **5% and *10%. GMM stands for Generalized Method of Moments system estimation; two-step estimation results are presented. AR(1), AR(2) and AR(3) refer to first, second and third order autocorrelation tests. DF stands for degrees of freedom. In each model the dependent variable corresponds to D.Variable. Estimations for total, capital, current and investment expenditures include respectively fourth, second, third and third order lags of the dependent variable.

In order to investigate other sources of political influences, we also test if interactions depend on whether the mayor belongs or not to the Prime-Minister's party, on her right or left-wing orientation, on whether the mayors' party has a majority or not in the municipal assembly and, finally, whether municipal/legislative elections were a close race or not. To test the latter effect for municipal election results, two dummy variables were created: one takes the value of one when the difference in the vote shares of the mayors' party and that of her main opponent was less than five percentage points in the last election; and another dummy for larger differences in vote shares. Empirical results never indicate statistically significant differences in the degree of strategic interaction among municipalities.[20] Following Schaltegger and Küttel (2002), we investigate if municipalities with larger fiscal autonomy, that is, those that depend less on central government transfers, take their expenditure decisions more independently than the others. Empirical results do not confirm this hypothesis. Because municipalities constituting the capital of a district could play a leading role and have different expenditure needs, we include a dummy to signal them and interact it with WG_{it}. No evidence is found that they react differently to expenditures of nearby municipalities. As put by Cheshire and Magrini (2009), there is no a priori basis for selecting distance weights. So, besides the geographical definitions of neighborhood described in the previous sub-section, we use other concepts based on population density and mayors' ideology. Municipalities with similar population density may have a greater tendency to mimic each other's behavior. To test this hypothesis, weights are defined in the following way:

$$w_{ij}^{PD} = \frac{\frac{1}{|denspop_{it} - desnpop_{jt}|}}{\sum_j \frac{1}{|denspop_{it} - desnpop_{jt}|}} \text{with } j \neq i \tag{3.7}$$

The results presented in Table 3.6 reveal that, of the four expenditure items used as dependent variables, the variable capturing average expenditure by neighboring jurisdictions is only statistically significant for investment expenditures.[21] The estimated coefficient (0.33) is smaller than the one reported in column 12 of Table 3.2, but it still suggests that municipalities react to their neighbors' expenditures. On what concerns investment decisions, municipalities seem to imitate those with similar population density. All regressions include the same set of control variables as those presented in table 3.2 but, in order to economize space, only the estimated coefficients associated with G_{it-1} and

[20] These results are not shown in the chapter but are available from the authors upon request.

[21] This result, however, is not confirmed when using the fixed effects estimation procedure.

$W^{PD}G_{it}$ are presented.

Table 3.6: Estimation results using weights based on population density

	-1	-2	-3	-4
D. Variable	TotExp	CurrentExp	CapExp	InvExp
Model	GMM-sys	GMM-sys	GMM-sys	GMM-sys
Population Density				
G_{it-1}	0.44***	0.69***	0.33***	0.53***
	(0.04)	(0.04)	(0.04)	(0.04)
$W^{PD}G_{it}$	0.08	0.02	0.06	0.33**
	(0.06)	(0.05)	(0.13)	(0.14)
Hansen	11.83	4.18	4.69	24.03
p-value	0.22	0.38	0.46	0.15
DF	9	4	5	18

Sources: INE, DGAL, SI (several years).

Robust standard errors in parenthesis. Significance level for which the null hypothesis is rejected: ***1%, **5% and *10%. GMM stands for Generalized Method of Moments system estimation; two-step estimation results are presented. AR(1), AR(2) and AR(3) refer to first, second and third order autocorrelation tests. DF stands for degrees of freedom. In each model the dependent variable corresponds to D.Variable. Estimations for total, current, capital and investment expenditures include, respectively, fourth, third, second and third order lags of the dependent variable.

We also investigate if political ideology similarity between local governments increases mimicking in policy resolutions, because of similar preferences and larger sharing of ideas among politicians. To test this hypothesis, mayors were classified as right or left-wing oriented. Two political weighting matrices were defined. One matrix (W^{SP}) assigns a weight of $1/s_{it}$ when municipalities i and j are ruled by mayors with the same political affiliation at time t, and zero otherwise. s_{it} is the total number of municipalities that are governed by a mayor belonging to the party in office in municipality i at time t. The other matrix is $1 - W^{SP}$. Both matrices have zero diagonals. We then multiply these matrices by the inverse distance matrix, and normalize the weights to one. We intended to include the two series obtained, for the average expenditure of neighbors of the same political color and for neighbors of different political color in the regression and test for the equality of estimated coefficients. However, the two series turned out to be highly correlated and could not be included simultaneously in the same regression. For total expenditures the correlation is 96.6%. This is not surprising, since Veiga and Veiga (2007) found that mayors' ideology does not play a significant role in per capita local governments' expenditure decisions.

3.7 Conclusion

The chapter aims at understanding the driving forces of interactions in Portuguese municipalities' expenditure levels. A dynamic panel data model is estimated based on jurisdictional reaction functions. The analysis was performed for all 278 Portuguese mainland municipalities from 1986 to 2006. Given the persistence of the expenditure series, estimations were performed by system-GMM using alternative ways to measure geographical neighborhood. The empirical results allow us to conclude that local governments do not make their spending decisions in isolation; they are significantly influenced by the actions of neighboring municipalities. For total expenditures, there is evidence that a 10% increase in nearby municipalities' expenditures increases expenditures in a given municipality by 4.8%, on average. For current and, especially for capital expenditures, the effect is also visible at the aggregate level. Results also support the existence of strong spillovers for investment expenditures, and for the sub-components Machinery and Equipment; Sports, recreational and schooling facilities and expenditures on constructions that require coordination among neighboring municipalities.

In order to disentangle the sources of interaction, we use alternative weighting matrices to geographic proximity that take into account similarity in population density and political party similarity of the mayors. Only for investment expenditures does population density seem to be a driving force of spatial interactions among local governments. Similarity, politicians' ideology does not seem to generate copycat effects. We also test for yardstick competition and for differences in interactions among municipalities resulting from mayors' political characteristics (belonging to the Prime-Minister's party, being right-wing oriented, or having a majority in the municipal assembly), from whether municipalities are a district capital or not, and whether the last municipal election was a close race or not. Results allow us to reject these hypotheses. Portuguese municipalities react to each other's expenditures due to spillovers that require coordination in expenditure items and to mimicking behavior of the others, possibly with the purpose of attracting households and firms.

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