European University Institute

DEPARTMENT OF ECONOMICS

Fiscal and Environmental Policy: Three Essays on the Effect on Firms' Investment and Productivity

Silvia Albrizio

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

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Abstract

This thesis studies how fiscal and environmental policies affect firms' behavior and economic performance. In chapter 1, co-authored with Stefan Lamp, we focus on the effect of tax adjustment on firms' investment decisions. Using a detailed narrative of tax changes in Germany covering 40 years of fiscal adjustments, we define and exploit the exogenous variation of tax bills to quantify the effect of tax changes on future investment plans of firms as well as on realized investment. In chapter 2, co-authored with Hélia Costa, we study how uncertainty over environmental policy affects firms' investment in low-carbon technologies. We model policy uncertainty in the context of an emission trading scheme and we develop a three period sequential model. The set-up of the model combines the industry and electricity sectors and encompasses both irreversible and reversible investment possibilities for firms. Finally, in chapter 3, I investigate whether international and domestic firms' productivity growth may be heterogeneously affected by environmental policy. Using a novel measure of environmental policy stringency and a panel of 11 OECD countries and 22 manufacturing sectors over the period 2000-2009, I estimate the difference in multi-factor productivity growth between multinational and domestic firms associated with a tightening of domestic environmental policy.

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I dedicate this thesis to my parents. To my mother Ettorina, because if I ended up being an economist who believes that economic research is an opportunity to contribute to "leave this world a little better than we found it" (Baden-Pawell), is just her "fault". And to my father Gabriele, for supporting me in every decision I took and for the endless faith in my capabilities.

Preface

In recent years, most of the OECD countries have experience fiscal consolidation and environmental policy tightening. Fiscal and environmental policy tightening is necessary for addressing fiscal and environmental sustainability, respectively. Yet these measures may have relevant implications for productivity and growth. This thesis contributes uncovering these effects by investigating how a policy change as well the design of the policy itself (i.e. the choice of the policy instruments and the predictability of the policy rule) influence firms' propensity to invest and firms' productivity. The micro perspective followed throughout this thesis allows to better understand the dynamics of firms' investment and productivity, which would ultimately affect aggregate growth.

The first chapter is a joint work with Stefan Lamp[1] and investigates the relationship between fiscal consolidation, business plans and firm investment. Based on a detailed narrative of tax changes in Germany covering 40 years of fiscal adjustments, we define and exploit the exogenous variation of tax bills to quantify the effect of tax changes on firms' realized and planned investment, considering the IFO investment survey dataset.[2] We find that recently published laws and laws under current discussion in the media and in the parliament shape future investment plans. Taking into account the forward looking behavior and adjusting the announcement dates according, we find that an increase in tax equal to 1% of the value added of the total manufacturing industry leads to a lagged decrease in planned investment of about 4%. For realized investment growth we estimate an average effect of 8%. Not taking into account this anticipation effect would lead to strongly biased estimates. Furthermore, by using micro-level firm data, we are able to elaborate further on heterogeneity in terms of firm size, industry sub sector as well as by type of tax shock. Differently from previous literature, we find that consumption taxes and income tax adjustments are most harmful for growth as they have the strongest negative and persistent effect on investment growth at firm level. The finding thus support recent hypotheses that highlight the importance of the demand channel in the transmission of fiscal policies, and may act through future demand expectation.

[1]Yale School of Forestry and Environmental Studies, Yale University
[2]EBDC Business Investment Panel

The second chapter, joint with Hélia Costa[3], studies how uncertainty over future policy affects firms' investment in low-carbon technologies. In the context of a carbon dioxide Emission Trading Scheme (ETS), we develop a three period sequential model which includes a welfare-maximizing regulator and the two sectors regulated by the European scheme (EU ETS): manufacturing and utilities. Contrary to previous contribution, we allow firms to have two pollution-abatement possibilities: irreversible and reversible investment. Additionally, we explicitly model policy uncertainty as the relative weight that the regulator assigns to economic activity with respect to environment concerns when maximizing the welfare function. We assume that the realization of this preference parameter in unknown by firms and it follows a mean preserving spread process and we calibrate the model using United Kingdom data. In line with previous research, we find the uncertainty always reduces investment in irreversible technologies. However, uncertainty increases investment in reversible technology because it provides firms with an additional instrument to cope with future policy uncertainty: firms can re-optimize and decide which type of technology to employ in the production process after the uncertainty is realized. Finally, the interplay of the two types of investment possibilities (reversible and irreversible) affects the aggregate level of investment in low carbon 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 aggregate investment decreases.

The third chapter looks at another aspect of environmental policy and investigates whether a tightening in domestic environmental policy stringency (EPS) may affect firms' economic performance heterogeneously according to their degree of internationalization. Multinationals (MNEs) may be better suited to adjust to an increase in EPS through two main channels: off-shoring part of their production to affiliates in countries with lax environmental policy, exploiting intra-group technology transfers and scaling-up investments in energy-efficiency. MNEs may consequently experience higher productivity growth than domestic firms that are, instead, not able to exploit such international channels when facing an EPS tightening. Using a panel of 11 OECD countries and 22 sectors over the period 2000-2009, I estimate a Neo-Schumpeterian model of multi-factor productivity. Productivity growth depends on the firm's ability

[3]Grantham Research Institute on Climate Change and the Environment, LSE

to adopt innovative and efficient technologies available in the market (technological catch-up) and on firms' ability to innovate (technological pass-through) (Acemoglu et al., 2006; Aghion and Howitt, 2006). Environmental policy stringency is proxied using a novel OECD cross-country and cross-time indicator and, in the mode, the EPS is allowed to affect firms depending on their technological advancement, the industry environmental dependence and their degree of internationalization. The estimated effect of a change in EPS for the most productive multinational firms is 60% higher than for domestic firms. This positive effect is confirmed using two alternative measures to approximate the degree of integration in the global market at industry level: participation in global value chains and outsourcing of production of intermediates abroad. Finally, larger changes in EPS are associated with higher boosts in MNEs productivity growth, suggesting possible non-linearity of the effect of EPS on productivity.

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Chapter 1

The investment effect of fiscal consolidation.

With Stefan Lamp (Yale School of Forestry and Environmental Studies, Yale University)

1.1 Introduction

Fiscal consolidation represents one of the main challenges that policy makers are currently facing in most OECD countries. Understanding how different fiscal consolidation measures (i.e. spending cuts and tax increases) affect growth is therefore crucial. In a recent paper, Alesina, Favero, and Giavazzi (2012) show empirically that tax-based fiscal adjustments have a statistically significant different effect on output compared to spending-based adjustments. The former ones are not only more costly in terms of output loss than spending adjustments, but they can be also linked to longer-lived recessions. The macro analysis of Alesina, Favero, and Giavazzi (2012) focuses on a large set of OECD countries and points out that the strong effect of tax-based consolidation on output is driven by shifts in business investment. Understanding further the links between fiscal consolidation, business confidence and firm investment is even more crucial in periods of excessive debt and/or deficit, when the economy needs an effective growth policy agenda. Therefore, our analysis focuses on tax adjustments and tries to shed light in the interconnection between tax adjustments, business confidence and investment. Previous studies have been unable to capture the causal link between these elements either due to the aggregate nature of the data, which does not allow matching firm expectations with their investment behavior, or due to the endogeneity of the fiscal policy, as one of the key issues in estimating the impact of economic policy is the identification of exogenous fiscal shocks.

To deal with the unavailability of firm investment expectations, previous literature focuses mainly on realized investment both at the macro and at firm level. Alesina and

Perotti (1996), using case studies, stress the "credibility effect" that a decisive discrete change in the fiscal policy stance may have on interest rates which would crowd in private investment. Alesina, Ardagna, Perotti, and Schiantarelli (1999) associate one percentage point of GDP increase in labor tax with a decrease of aggregate investment over GDP by 0.17 on impact and a cumulative effect of about 0.7 in five years. Confirming these results, Cloyne (2011), Mertens and Ravn (2009), and Hayo and Uhl (2013) find a negative, sizable and statistically significant effect of tax increase on investments at the aggregate level. At firm level, previous literature builds heavily on neoclassical models of investment based on the user cost of capital and the Q-theory[1]. In the user-cost framework, higher taxes affect investment negatively through the increase in user cost of capital. Cummins, Hassett, and Hubbard (1996) exploit cross-sectional variation in user cost due to major tax reforms. They find significant effects with an implied long-run elasticity of the capital stock with respect to the user cost between -0.5 and -1.0 [2]. Chirinko, Fazzari, and Meyer (1998) analyze UK firm investment behavior using both the underlying Q-theory and user cost of capital, and their estimated effect reduces to -0.25. Finally, micro evidence based on cointegration models (Caballero, Engel, and Haltiwanger (1995) among others) estimates an average long-run relationship between capital-output ratio and the user cost of -0.1, where estimates range between -0.01 and -2.

Regarding the second limitation, the identification of exogenous fiscal shocks, the economic literature distinguishes three main methodologies. The first branch of literature follows the structural vector autoregressive approach (SVAR). In this approach, exogenous fiscal shifts are unobservable and identification is achieved using sign restrictions derived from economic theory (Mountford and Uhlig (2009)) or by taking into account institutional features of tax and transfer systems (Blanchard and Perotti (2002)). The VAR approach has led to a wide range of estimates of the spending multiplier (see Ramey (2011) for a literature survey). The second group of studies consists mainly of case studies (Giavazzi and Pagano (1990), Alesina and Ardagna (2010), and Alesina and Ardagna (2012)) find that spending based adjustments can have a very small

[1] See Bond and Van Reenen (2007) for a comprehensive overview of microeconometric models of investment and employment.

[2] Additional firm-level evidence on the user-cost elasticity of the investment rate is given by Schwellnus and Arnold (2008) and Johansson (2008).

or no output cost at all. Finally, a more recent method that found increasing attention in the economic literature is the narrative approach. Identification is based on observable exogenous shifts in fiscal stance by considering official documents, and hence by definition focusing only on fiscal adjustments that are motivated by deficit reducing purposes. As pointed out in Mertens and Ravn (2013), an attractive feature of this approach is that the narrative record summarizes the relevant features of a potentially very large information set.

This paper aims at filling the above described research gap, investigating further the set of correlations and causality between tax adjustments and private investment, in order to provide clear insights on the impact of fiscal reforms on firm incentives, and therefore on growth. In particular, we contribute to the debate in three ways: Firstly, by considering micro level data we move one step further in establishing a causal link between tax-based fiscal consolidation, business confidence and investment. Taking advantage of the information on firms' planned investment provided by the IFO investment survey[3], we are not only able to compare our micro-based results with the previous findings from the macro literature, but also to take into consideration forward-looking behavior of the firms. Secondly, the detailed structure of the dataset allows us to disentangle the effect in two different dimensions: a heterogeneous effect depending on firm size and on the industry sub-sector. In line with Romer and Romer (2010) and Pescatori, Leigh, Guajardo, and Devries (2011), we employ the narrative approach to identify exogenous tax adjustments. Based on a detailed narrative created by Uhl (2013) for Germany, we revise 40 years of documented tax legislation (1970-2009) in order to create a dataset of tax adjustments that are not cyclically driven nor dictated by long-term growth considerations. We further investigate the timeline of tax adjustment not only considering the publication date, as provided by Uhl (2013), but also looking for the date when the public discussion of the adjustment started. To do so, based on the LexisNexis database, we collect journalistic documents that discuss each of the tax changes we considered.

Finally, focusing on one country only, we are not only able to consider a much more accurate policy dataset, testing the results for different shock reference dates (discus-

[3]EBDC Business Investment Panel, http://www.cesifogroup.de/ifoHome/facts/EBDC.html

sion date, publication and first implementation date) but also to disentangle the effect according to the type of tax change (income tax, business and corporate tax, or consumption tax). In fact, as pointed out in Mertens and Ravn (2013) and Cloyne and Surico (2013), there is little reason to expect that the different types of taxes available to governments all have the same impact on the economy.

The remainder of this paper is structured as follows. Section 1.2 introduces the series of exogenous tax shocks as developed by Uhl (2013), and which have been adopted for the purpose of this paper, as well as the firm level investment data. Section 1.3 describes in detail the identification and the estimation strategy, while the main results are discussed in section 1.4. Section 1.5 further elaborates on heterogeneity and section 1.6 performs a series of robustness and sensitivity checks. Finally, section 1.7 concludes.

1.2 Tax shocks and firm investment data

1.2.1 Narrative of German tax changes

The series of tax changes is based on Uhl (2013), who elaborates an extensive record of tax legislation in Germany[4]. In order to identify all relevant tax law changes Uhl (2013) uses in a first step a size criteria of the budgetary impact of tax changes. Tax shocks are thus considered important and are included in the narrative if their budgetary impact reaches 0.1% of GDP in a given year[5]. This first criterion led to the identification of 95 important tax changes that are revised in a detailed fashion in Uhl (2013) and that are classified according to their main motivation in "endogenous" and "exogenous" tax measures in line with the previous literature (see for example Romer and Romer (2010),

[4]The analysis in Uhl (2013) is based mainly on the Finanzbericht and Bundesfinanzplan of the Federal Republic of Germany. In order to recover all budgetary details of individual tax laws we revised the Finanzbericht for the years 1970-2009 and the four-year budget plans (Bundesfinanzplan) for the time period 1990-2009.

[5]Tax shocks are also included if the measure is (close to but) below the 0.1% GDP threshold but tax law changes consist of individual well defined measures. Other narratives, such as Pescatori, Leigh, Guajardo, and Devries (2011) do not state a precise cutoff rule, however for their full dataset of fiscal adjustments, only 5 out of 173 fall below the 0.1% rule, none for Germany.

Pescatori, Leigh, Guajardo, and Devries (2011) and Cloyne (2013))[6].

Key in the narrative approach is to identify the exact motivation behind each tax change, as this allows excluding tax policy changes dictated by business cycle fluctuations and changes correlated with the dependent variable through other unobserved factors. As pointed out in Romer and Romer (2010), simply regressing output growth on all legislated tax changes will lead to biased estimates, given the fact that some tax changes might be correlated with the error term. Moreover, this bias might be even more emphasized in case the researcher does not account for the fact that the policy makers might adjust their policy measures to the current state of the economy, for example employing countercyclical policies. Even controlling in the regression framework for known macroeconomic shocks and conditions would not solve the issue of identification, as firstly it would be impossible to proxy for all information about future output movement that the policy maker may have had and secondly the response to tax changes is likely to vary from period to period and may be hence correlated with other unobserved factors in the error term. Thus it is crucial to identify the exact motivation behind individual tax changes.

We align our classification of the motivation of tax changes with Uhl (2013), however we revise each of the Uhl tax shocks and regroup them according to "exogenous" and "endogenous" for our analysis of investment. Uhl (2013) classified spending driven tax changes, countercyclical policies and tax changes due to macroeconomic shocks as "endogenous" measures. On the other hand, "exogenous" measures are those dealing with budget consolidation and structural considerations. While consolidation measures are related only to past spending and are exogenous to the current macroeconomic stance, the category of structural tax changes is more controversial as it includes both measures that aim at long-term growth, incentivizing investment, as well as tax changes that have been induced by court-rulings and that are hence unrelated to investment activity. Therefore, building on the previous narrative-literature, in our reclassification we define as "exogenous" only those structural changes that are not cyclically driven nor motivated by long-term growth considerations and hence aimed at investment. The

[6]As the previous literature building on the narrative approach we slightly abuse terminology and consider "exogenous" all changes that are not systematically correlated with current or lagged output and investment.

appendix provides some examples of tax changes and their classifications[7].

Given the fact that we have exact information on the timing of individual tax measures - the date the first draft was introduced to the parliament, the date the tax law was published and information on the public discussion in the newspapers - we test for the impact at different dates. Differently from other studies that use this approach, we consider the budgetary impact at announcement. This choice relieves us from difficult considerations regarding revisions that are potentially correlated with investment and the contingent economic situation[8] as well as from potential measurement errors. Furthermore, to avoid heterogeneous displacement effects, we focus on exogenous tax shocks that are announced and implemented within the same period.[9] Figure 1.1 depicts the full series of important tax changes in Germany announced and implemented within the same period for both "exogenous" and "endogenous" motivations for the period 1970-2009, using half-yearly data frequency. As the graph shows clearly, endogenous tax changes are on average larger and more frequent than the exogenous category. In total, we count with 19 exogenous shocks and 31 endogenous ones. The correlation between the two time series is 0.09, and is not statistically significant (p-value of 0.53).

Given data availability our main analysis focuses on the period 1970-2010[10]. As explained in more detail in the following section, we group tax changes in both yearly and half-yearly periods in line with our firm level investment data. The original tax shock series, expressed in billions of Euros (governmental budgetary impact), has been first deflated using the gross fixed capital formation deflator for the manufacturing industry[11] and divided by total value added (VA) in the manufacturing industry in 2005, in order to have the main regression variables at a similar scale, which allows for easier

[7]For a complete overview of all important tax measures in the Federal Republic of Germany, see Uhl (2013).

[8]Examples of factors correlated with investment which could drive the revisions are: resistance from trade unions, deterioration of the economic situation, etc.

[9]This is in line with the previous literature. See for example Mertens and Ravn (2011) that exclude tax changes with implementation lag exceeding one quarter. In the robustness section we also control for shocks that are announced but that are implemented in subsequent periods.

[10]Our last fiscal shock is observed in 2009, however we include one additional year of firm investment data to capture the lagged investment effect.

[11]The deflator is based on STAN Industry Rev. 3, 2008 (OECD) Database. Investment and financial variables are deflated in the same way.

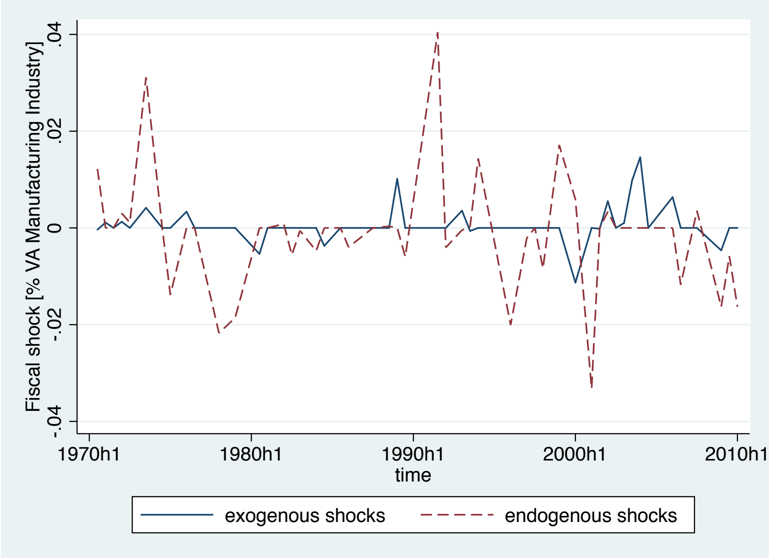

Figure 1.1: Legislated tax changes. Half-yearly frequency

interpretation of the coefficients. The exogenous shock series contains both positive and negative tax measures ranging from -0.011 to 0.014 with a mean absolute impact of 0.002 and a standard deviation of 0.004.[12]

In terms of timing, focusing on the subset of exogenous shocks, the average length from the date the draft of the law is introduced to the parliament and the date of publication of the same is around five months [13]. On the other hand the average time between publication and first implementation of the tax measure is two months. However a detailed revision of the shocks brings the fact to light that most of the shocks are induced by a lengthy public discussion prior to the initiation of the legal process of tax change. The media and newspapers report these discussions and we refer to the date of the first article mentioning as "discussion date". In order to check for this possibility we look at the timing of news coverage of tax measures prior to the draft date using the online database LexisNexis. We find that the average time lag between initial discussion of the tax measure and its publication is one year. The appendix provides an overview (Table

[12]We use the mean absolute impact rather than the simple mean, given both positive and negative shocks. Alternatively the mean impact of the 12 positive shocks has been 0.005 (0.004) shocks, and for the seven negative shocks -0.004 (0.004).

[13]The exact draft date can only be reconstructed for shocks posterior to 1977.

1.2) containing discussion, draft and publication date of selected tax shocks[14].

1.2.2 Firm investment data

Data on firm investment is obtained from the IFO investment survey (IVS). As pointed out in Seiler (2012) the IVS was originally introduced in 1955 and considers the manufacturing sector in Germany, however annual investment data is available only from the mid 1960s onwards. While the initial questionnaire has been distributed only once a year, from 1993 onwards the survey has been performed bi-annually, in spring and autumn of the same year, leading to an even richer data structure[15].

The IVS questionnaire focuses mainly on firm investment activity and includes both forward and backward looking statements of realized and planned investment. As the questionnaire includes only a small list of potential control variables, the dataset has been enriched by the Economic and Business Dataset Center (EBDC) with balance sheet data obtained from Amadeus and Hoppenstedt[16]. The merged investment data counts with a total of 202,368 observations that belong to 5,590 firms. In principle the dataset is longitudinal however the number of firm that exit at some point in time the panel is high, so that there are few firms reporting the entire sample period. In terms of representativeness, in 2009 the IVS sample covered 31% of all employment in the German manufacturing sector (7% of companies), with better representation of bigger firms (2% of employment size class < 50 and 66% of employment class size $>$1000).[17]

For the purpose of our analysis, the original dataset has been first converted to Euros, using the fixed Euro-DM exchange rate and then deflated with the OECD deflator for gross fixed capital formation in the manufacturing industry. Furthermore we drop IFO sector 210 from the analysis, manufacture of mining products, as it does not find a

[14] Using LexisNexis, we were able to track back news coverage for tax adjustments for the period 1992 to 2010.

[15] Data previous to 1991 corresponds to West Germany, while data posterior to 1991 includes also firm from former Eastern Germany.

[16] The exact merging procedure is described in Seiler (2012).

[17] The authors would like to thank Heike Mittelmeier and Christian Seiler from the EBDC for providing this information regarding the IVS.

clear correspondence in the ISIC manufacturing classification. Converting the dataset to an annual data structure, and constructing the change in realized investment as log difference of investment at time t and investment at time $t-1$, we are left with 64,310 observations belonging to 5,186 distinct firms[18] [19]

Most of the literature dealing with firm level investment considers as dependent variable the ratio of investment (defined as the change in capital stock) over capital. Even though the IFO data provides a direct measure of investment, it does not provide us with an initial capital stock[20]. Therefore, as alternative measure we normalize investment by firm specific average asset stock over the sample period, which is available for the subset of firms that have been merged with the Amadeus and Hoppenstedt databases. Nevertheless also this procedure reduces the sample coverage considerably. Therefore we use this specification only as robustness check for our findings, estimating a dynamic firm-level investment model as derived in Bond, Harhoff, and van Reenen (2005) (see section 1.6).

Our empirical analysis focuses both on realized investment growth and on updates of planned investment. However updates of planned investment are only available for the subsample period 1993-2010, in which the IVS has been conducted at a bi-annual frequency. In each round firms are asked to provide an estimate for their planned investment for the same year. In addition, in spring firms are asked how much they have been investing in the previous year (realized investment in $t-1$) and, in autumn, how much they are planning to invest next year ($t+1$). Therefore the richness of the IFO investment dataset allows us considering both realized investment changes and updates

[18]Conditioning our sample on firms that report in two consecutive periods does not change significantly the size composition: For the full sample (sample in differences) there are 17.6% (15.6%) in size group up to 49 employees, 31.9% (31.2%) in size group up to 199 employees, 34.7% (35.8%) in the size group up to 999 employees and 15.8% (17.3%) in the category >1000.

[19]We allow for zero growth in case a firm reports zero investment in two consecutive years. As robustness check we further experiment with a second specification, imputing a small, but positive number for investment in years t or t-1 in case a firm reports in either of the two periods zero investment. Given that this procedure leads to additional variability, for the analysis we cut the variable at the first and 99th percentile to make the measure outlier proof. We find that our results are not affected by the specification of the dependent variable.

[20]Backtracking the capital stock using inventory methods would be only meaningful for balanced data or data with few gaps.

in planned investment. Formally, realized investment growth in year t is defined as:

$$\Delta ln(I_t) = ln(I_{t,A}) - ln(I_{t-1,A}) \tag{1.1}$$

while the change in planned investment is defined for reference year t, respectively in each period p=1 between 1 October (t-1) and 31 March (t) and p=2 between 1 April (t) and 30 September (t), as:

$$\Delta ln(PI_{t,1}) = ln(PI^t_{t,S}) - ln(PI^t_{t-1,A}) \tag{1.2}$$

$$\Delta ln(PI_{t,2}) = ln(PI^t_{t,A}) - ln(PI^t_{t,S}) \tag{1.3}$$

where the subscript indicate the year and the survey round (S=spring, A=autumn) when the plan is revealed, while the superscript refers to the forecast horizon, i.e. the year the investment is supposed to take place. The exact timing of the half-yearly investment structure is depicted in Figure 6 in the appendix.

1.2.3 Summary statistics and representativeness

Table 1.1 shows the main variables of interest for our analysis at annual frequency for the full sample period and two subsample periods 1970-1990 (West Germany only) and 1991-2010. The main dependent variable, realized investment growth is small in absolute terms, however as the standard error suggests there exists considerable variation across firms. The alternative measure (investment over average capital stock) has a mean of 0.25 (median of 0.18), which however includes more bigger firms. The exogenous fiscal shock measured in terms of total value added in the manufacturing industry is very similar for the two time periods in terms of the average, however the standard error in the later period (1991-2010) is almost the double. For comparative purposes Table 1.1 also reports the aggregate control variables for the interest rate as well as sales growth and firm size (number of employees), as these variables are reported for all firms in the questionnaire [21]. While the interest rate has been around 1% higher in the early subsample (1970-1991), average sales growth was nearly double compared to the second sample period. These tendencies are related to general structural changes in the German economy.

[21] As mentioned, other financial covariates, such as assets and liabilities, are only available for a subset of firms (those listed in either Amadeus or Hoppenstedt and that could be merged).

	Total sample: 1970-2010		Subsample: 1970-1990		Subsample: 1991-2010	
	Mean	std	Mean	std	Mean	std
Realized investment change	-0.0110	(-1.046)	0.0297	(0.965)	-0.0424	(1.104)
Investment / Average total assets	0.2520	(0.229)	0.2580	(0.234)	0.2487	(0.226)
Exogeneous fiscal shock	0.0011	(-0.006)	0.0013	(0.004)	0.0010	(0.007)
3 month interbank rate	2.4670	(-1.616)	3.0911	(1.904)	2.0205	(1.186)
Sales growth	0.0231	(-0.261)	0.0312	(0.225)	0.0164	(0.288)
Total employment last year	837	(5195)	948	(5247)	753	(5154)
Observations	64310		27936		36374	

Note: Investment / Average total assets counts with a total of 39751 observations.

Table 1.1: Summary statistics: main variables

In order to provide further evidence on the representativeness of our data, Figure 1.7 in the appendix compares realized changes in aggregate investment in the manufacturing sector in Germany obtained from STAN (OECD, Rev.3 2008) with aggregation based on our sample data. The figure indicates that the series co-move closely over the entire sample period but that our aggregation based on firm data shows slightly more variability than the official statistics. Furthermore the appendix provides some first evidence for the negative correlation of our fiscal shock measure and aggregate investment growth. The two series show a correlation coefficient of -0.15 (Figure 1.8). We present the same evidence by ISIC 3 industry sub-sector and by size group (Figure 1.9 and Figure 1.10 in the appendix).

1.3 Identification and empirical specification

As pointed out above, the key assumption behind the narrative approach is that both the tax changes itself and their composition are "exogenous" i.e. tax changes are not dictated by business cycle fluctuations nor long-term growth concerns. In line with the previous literature (see for example Cloyne and Surico (2013)), we test for exogeneity using a four-variable VAR at annual frequency including the tax shock series (for both the endogenous and exogenous category), GDP growth, the three month interbank rate and the average investment change as main dependent variable [22]. We construct the aggregate change in investment as log difference of average investment in period t and

[22] In an alternative specification, we also account for the structural break due to the German reunification (1990) and the recent financial and economic crisis (post 2007); our results are robust to the inclusion of these exogenous dummies.

t-1 weighted by employment shares [23]. The selection-order criterion suggests in most specifications unanimously a lag structure of order one for the VAR. Table 1.3 in the appendix provides evidence from the granger causality tests, showing that the exogenous tax shock series implemented in the same period of the publication date cannot be predicted neither by macroeconomic conditions in the last year, nor by past investment activity. On the other hand, the "endogenous" tax adjustments can be predicted by economic growth (p-value 0.063). The three excluded series jointly (investment growth, GDP growth and interest rate) moreover carry information to forecast the endogenous fiscal shock series at 10%. These results strongly support our key identification assumptions [24].

As second test for exogeneity of our fiscal shock series we run an ordered probit regression to see if the government's decision to adjust taxes can be predicted by past macroeconomic data. The same approach has been taken by Cloyne and Surico (2013) and Mertens and Ravn (2009). We hence construct an indicator variable ω_t equal to 1 if the government implements a positive fiscal shock, zero if no action has taken place and -1 if there has been a negative fiscal adjustment. Results are presented in Table 1.4 in the appendix and indicate that while movements in the exogenous shock cannot be predicted neither by lagged changes in aggregate investment nor by lagged levels of GDP, the endogenous shocks are correlated to lagged investment growth. As additional test, we run the ordered probit model on official data from the manufacturing sector (Table 1.5) using both changes in gross fixed capital formation (GFCF) and levels of GFCF from the OECD (STAN) database. While the results for GFCF growth are fully comparable with our in-sample findings (only lag 2 of GFCF growth) is significantly correlated with the endogenous shock, for the levels equation we find strong evidence that movements in the endogenous series are highly correlated with both lagged levels of investment and GDP. The shocks that have been classified "exogenous" on the other hand are not

[23]We also test for other measures of aggregation, using changes in total investment from period t to period $t + 1$, and hence conditioning on firm presence in two consecutive years, or using simple unweighted average investment change. The main results hold for all definitions of aggregate investment. We furthermore test that the investment series are stationary, using an augmented Dickey-Fuller test.

[24]Given the fact that our tax shock series includes both structural and consolidation motivated shocks, as sensitivity check, we furthermore exclude all shocks with structural motivation. The presented findings are robust to the selection of shocks.

predictable.

Using the exogenous tax adjustment series, our analysis first focuses on the revision of investment plans, and secondly, we study how realized investment is affected. Both analysis are based on the following main regression specification:

$$\Delta I_{i,j,t} = \alpha + \beta_m(L_m)\tau_t + \psi m_{t-1} + \rho g_{t-1} + \nu \Delta z_{i,t-1} + D_{90} + D_{07} + \theta_j + \epsilon_{i,j,t} \tag{1.4}$$

where $\Delta I_{i,j,t}$ is the growth rate of realized investment for firm i, in sector j, in period t. The investment changes are defined separately for realized and planned investment as introduced in section 1.2. The fiscal shock τ_t is the exogenous tax adjustment published at time t, and is uncorrelated with other shocks to investment by construction. Macro-level controls consist of the monetary policy stance m_{t-1} (previous period three-month interbank rate) and economic condition g_{t-1} (lagged levels of GDP). Dummies to account for the crisis period 2007-2010 (D_{07}) and for the structural change 1990 (D_{90}) are included in the regression equation[25]. Finally, lagged sales growth at firm level ($\Delta z_{i,t-1}$) is part of the regression controls to proxy for current and future demand conditions at firm level. In all specifications we include furthermore sectorial fixed effects θ_j and standard errors are clustered at firm level [26]

1.4 Main regression results

The following section presents the main regression results for both planned and realized investment growth at firm level. Table 1.13 in the appendix also provides some evidence for the effect of fiscal shocks on realized investment changes aggregated at sub-sector level.

[25]To account for the structural break in the statistical data more than the actual historical date of the German reunification.

[26]Given the fact that our main explanatory variable is aggregated at annual level, we potentially could cluster on years, however clustering on year assumes that firm level errors are uncorrelated from one year to another, an assumption that is unlikely to hold. Alternatively we test for clustering at industry sub-sector (branch). The main findings are unaffected by the choice of the clustering variable.

1.4.1 Planned investment

As previous contributions have suggested (see for example Alesina, Favero, and Giavazzi (2012)), business confidence and private investment are found to be the main drivers of the output effect of fiscal consolidation. Studying the change in future investment plans at micro level helps to understand and pin down the business expectation and confidence channel. As mentioned in section 1.2, in the IVS firms are asked about their investment plans for next period. Given the opportunity cost of investments, these plans, and in particular their revisions, incorporate business expectations and anticipation about future economic and policy conditions.

Insert Table 1.6 here

We observe updates on planned investment for the period 1993 to 2010 at a bi-annual frequency. For this period, we count with a total of 10 exogenous fiscal shocks with a mean impact of 0.001 and a standard deviation of 0.0048. Moreover given the fact that our analysis focuses on the announcement effect of fiscal policy, we use the shock publication date. Table 1.6 presents the estimates of the effect of a tax change equal to 1% of total manufacturing value added on the revision of planned investment. Block 1 (column (1) - (3)) includes only lags of the fiscal shock, while block 2 (column (4) - (6)) includes also leads. For the rest, the two blocks include the same set of covariates: the first column of each block includes a set of aggregate controls (lagged GDP, lagged three month interbank rate, and a dummy accounting for the recent financial crisis) in addition to industry fixed-effects, the second column includes additionally lagged firm level sales growth, and finally the third column includes firm level fixed effects. In all specifications we furthermore include a separate dummy for the second half-year (autumn), in order to account for potential differences in volatility of the two revisions[27], which results to be highly significant in all specifications.

Block 1 shows that there is a significant and negative effect of tax shocks on planned investment. A shock equal to one standard deviation of the exogenous fiscal shock[28]

[27]Due to a lower degree of uncertainty, the autumn investment update might be more accurate and hence less volatile than the spring update. The authors would like to thank Antonello d'Agostino for pointing this out in his discussion at the Banca d'Italia Fiscal Policy Workshop 2014.

[28]As the shock can take on both positive and negative values, we standardize using a standard deviation

hence translates to a decrease in planned investment of around 1.2% in the next investment plan. Once we additionally include leads, in order to test for a potential anticipation effect in block 2, the lagged effect on planned investment becomes quantitatively larger. We furthermore confirm that agents anticipate the fiscal adjustment as both lead 1 and 2 show up to be significant in all three specifications. Note additionally that all control variables (but lagged GDP in some specifications) show up to be statistically significant with the expected sign. The R^2 is low even when including firm level fixed effects, which indicates that investment changes are indeed very lumpy and volatile [29].

The forward looking behavior of the firms can be explained by the average length of the legislative process for tax changes in Germany. To test this hypothesis we investigate in a more detailed fashion the legislative timing, starting from the moment when the draft of the law is discussed in the public (media coverage in major German newspapers and news magazines). Therefore we search for news contents related to the discussion of fiscal shock measures employing the database LexisNexis [30]. In fact we find clear evidence that between the time of public discussion and publication of the law, on average, there passes one year. Compared to the draft date, the date when the law is officially introduced in the parliamentary discussion, the public discussion happens around half a year earlier. Table 1.2 in the appendix provides an overview of mayor exogenous tax shocks since 1992 including their official publication dates, draft dates and periods of public discussion in the media (discussion dates). Given these findings, we re-estimate our main regression model focusing on the discussion date as "true" announcement date of the shock.

The results are reported in Table 1.7. We find that once we consider the media discussion date, controlling for firm-level sales growth or using firm-level fixed effects, no forward lag shows up to be significant. In fact compared to the publication date, the fiscal shock is only significantly (and negatively) correlated with changes in planned

measure. Alternatively we could use the mean of the absolute shock impact in order to quantify the shock impact on investment growth, which is very similar in magnitude.

[29] Note furthermore that the R^2 from the firm level fixed effect regressions, column (3) and (6) are adjusted and hence lower than the other columns, that report an unadjusted regression fit.

[30] LexiNexis contains all major German newspaper and covers news contents from the beginning of the 1990s.

investment at impact, i.e. when the news is announced. [31] Generally, using the discussion date, we find quantitatively similar, but more stable effects of downward revision of -3.5% to -4% for a shock equal to 1% value added in the manufacturing industry. A shock equal to one standard deviation hence led to a downward revision of investment plans by 1.9% for the sample period 1993-2010.

Insert Table 1.7 here

To sum up, when firms make their plans for next period investment, they are influenced by laws currently under discussion and laws published in the previous half year. Given the fact that we are interested in identifying the announcement effect of fiscal consolidation measures on planned and realized investment, we hence use the discussion date as main specification in the remaining sections of this paper.

1.4.2 Realized investment

After analyzing firm behavior in terms of investment expectation, it is interesting to apply a similar analysis to realized investment in order to be able to compare our findings with the previous macro-level results. We consider firms' annual investment growth from 1970 to 2010 as defined in section 1.2. Table 1.8 presents the point estimates of the effect of a tax change equal to 1% of total manufacturing value added on investment growth. Column (1) does not include any controls while column(2) includes aggregate controls and column (3) furthermore lagged sales growth at firm level. Column (4) presents the results for realized investment for the period 1991-2010, while column (5) for the earlier period and Western Germany alone (1970-1990).

Insert Table 1.8 here

Interestingly, we find that the fiscal shock has a negative and significant impact on realized investment that is strongest in the year of public discussion[32] but has also a

[31] We also tried alternative specifications including additional lags up to lag 4, but the only significant impact remains at lag zero.

[32] Using as true announcement date the date of public discussion as introduced in the previous section.

lagged effect. The initial impact is stable to the inclusion of additional aggregate and firm level controls (column 2 and 3), however once we include the set of controls, we find a more persistent effect. Adding up the significant lags in column 3, the total impact of a one percent tax shock on investment growth is around -15.6%, which however is smaller when evaluated at the mean absolute impact or the standard deviation measure: -5.7%. In fact, for the annual shock series, there are a total of 19 fiscal shocks with a mean value of 0.0007 and a standard deviation of 0.0037. All aggregate control variables show up to be significant and show the expected sign. The sample split in column 4 and 5 suggests two clearly different patterns: while in the more recent period 1991-2010, the fiscal shock shows quantitatively the same impact as for the entire sample period (-8.8%), the earlier subsample shows a significant lagged effect that is biggest at lag 1. As for the half yearly analysis there are 10 shocks for the subsample post 1991, with a mean impact of 0.00096 (0.0047) and 9 shocks for the first subsample referring to column 5 with a mean impact of 0.0004 (0.0027). Hence the different fiscal policy over the period considered translates into bigger and more volatile shocks in more recent years. In addition to differences in the fiscal shock series, firms might have changed their behavior over the last 20 years, using more technology and respond faster to changes in the companies legal and fiscal environment.

Generally, the results are in line with the macro level findings even though the magnitudes are not directly comparable. Alesina, Favero, and Giavazzi (2012) for instance find that a one percent GDP tax shock has a negative and significant lagged effect on fixed capital formation growth in Germany that increases from -4% in the first quarter after the adjustment to around -6% one year after the adjustment. In fact, while in the macro literature the shock is standardized by GDP, in our micro set-up it makes more sense to re-scale the expected budgetary impact using the value added of the total manufacturing sector. Moreover, another difference between our framework and the macro analysis is the difference in timing.

In order to verify that fiscal shocks, defined as exogenous, are not correlated with the shocks that were announced in the past but implemented at time t, we reestimate our regression model including both the previously announced shocks and in a second step also the shocks that we classified as endogenous. Running our main specification (column (3), containing both aggregate and firm level controls), and including the shocks previously identified as endogenous, we get results very much in line with those presented in Table 1.7. While the leads do not show up to be significant, at impact we estimate an effect of -7.65, at lag1 of -5.87 and at lag 2 of -2.95, all significant at 1%[33]. On the other hand, including the anticipated tax shocks, we confirm these findings: while the leads are not statistically significant, at impact we estimate an effect of -8.29, at lag1 of -6.39 and at lag2 of -4.89. These findings can be seen as a first robustness check for our main regression results.[34]

While section 1.5 reports the results for heterogeneity of realized investment changes depending on type of tax adjustment, firm size and the sub-sector of the manufacturing industry, section 1.6 performs further robustness checks, providing also evidence for the negative and significant effect of tax adjustments using a rigorous difference-in-difference strategy that allows us controlling for other unobserved factors potentially correlated with the fiscal shock series and investment growth.

1.5 Heterogeneous effects

The long time span of available data for realized investment growth allows us studying the effect of tax changes by looking at three main dimensions: type of tax adjustment, heterogeneous effects by firm size and by manufacturing sub-sector as well as their interactions.

Looking at GDP per capita, Johansson (2008) find that corporate taxes are most harmful for growth, followed by personal income taxes and consumption taxes. To test for the effect of exogenous tax changes on realized investment we group the shocks in different categories. As depicted in Figure 1.2, we distinguish three main tax categories:

- personal income tax, pension & savings tax
- corporate & business tax, energy tax, property tax

[33]This results hold independent of the inclusion of control variables.

[34]Table 1.13 presents the effects of fiscal consolidation at industry level, provides similar evidence. Including previously announced shocks or shocks considered endogenous does not alter our main findings.

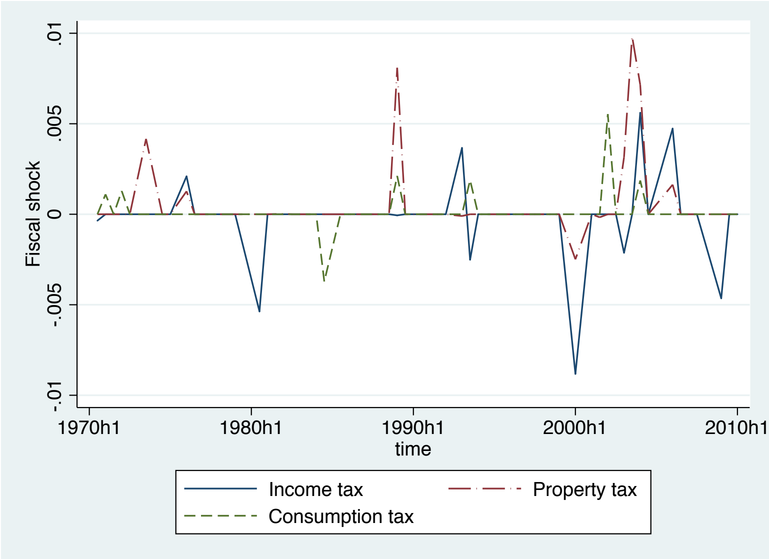

Figure 1.2: Exogenous tax adjustments; by tax type

- consumption tax

Breaking down the tax shock into these subcategories, we are able to distinguish 11 tax measures for the first category, 11 for category two and 7 for the third category. In order to identify these categories we revised a total of 42 tax law changes that consist of 184 individual tax measures.

Insert Table 1.9 here

Including the three fiscal shock series in our reduced form estimation, both in the same regression (Table 1.9, column 1) and in separate regressions, we find important differences with respect to the previous estimates found in Johansson (2008): consumption tax shocks have a strong negative and lagged impact, while tax adjustments affecting income tax seem to have the biggest impact within the same year. Property and corporate taxes, on the other hand, have a smaller effect at impact. These findings support a recent hypothesis[35] which highlights the importance of the demand channel for the transmission of fiscal shocks. Consumption taxes affect demand and consequently

[35]See for example the discussion of Aghion and Kharroubi (2013) at the annual BIS conference (June 2013) by Reichlin.

firms' investment in the successive periods through future demand expectations.

In order to compare our results with the aggregate findings on realized investment (section 1.4), we look at the standard deviation measure of the distinct categories of fiscal shocks and find that while income (0.0021) and property (0.0022) adjustments nearly have the same variability, consumption shocks are smaller, almost half (0.0011). Using the estimated coefficients from column (1) this leads to an effect of a standard deviation fiscal adjustment on investment growth of -4.1% for income tax, -1.76% for property tax and -1.9% for consumption tax. In order to contrast these results, we aggregate fiscal shocks in an alternative way, considering income and property tax as direct taxes and the consumption tax as indirect taxes. Results are presented in Table 1.10 and show the same pattern that is stable to the inclusion of additional controls, fixed effects and also to the inclusion of previously excluded tax shocks. While direct taxes show a negative effect at impact, indirect taxes only lead to a downward revision of realized investment in the subsequent period, and hence providing further evidence for the demand channel hypothesis.

Recent firm-level literature has furthermore stressed the importance of considering heterogeneous and distributional effects of fiscal and other policies in general. To test for different impact in terms of firm size we use the IFO firm class sizes of employees (1-49, 50-199, 200-999, $>$1000) and run the regression for each subgroup separately. Given the potential residual correlation across size classes, we adopted a seemingly unrelated regression (SUR) framework. The results highlighted in Figure 1.3 show that at impact all size classes are negatively and significantly affected by the tax adjustment. Furthermore the effects are larger for firms that belong to size group 1 to 3. The largest firms show the smallest coefficient. Moreover we confirm that the lagged effect is present for all size classes but for the smallest firms (size group 1), where lag1 does not show up to be significant. This finding might be due to the fact that the smallest group is highly heterogeneous, as it is also suggested by the wide confidence band. The magnitude of the effect is in line with the aggregate findings for the impact and slightly larger for lag1.

In a next step, we investigate if distinct tax shocks have different effects by firm size. The tax effects might differ as firm size can be also seen as a proxy for legal status. Figure 1.4 shows the results for direct and indirect tax shocks at impact and for lag1 for the distinct size groups. As pointed out above, given the strong heterogeneity in the smallest size group, we cannot confirm any significant effect for either tax category. On the other hand we do confirm the main pattern that we found when looking at type of tax shocks. Direct tax adjustments have a negative impact at lag 0 that is quantitatively smaller than the impact for indirect (consumption) taxes at lag 1. Furthermore the impact is larger for smaller firms (coefficient for size group 2 > size 3 > size 4, for both direct and indirect taxes), which might indicate that smaller firms are on average more credit constraint and hence a fiscal shock translates to a stronger effect (see Zwick and Mahon (Working Paper) for recent evidence from the US).

A final dimension of heterogeneity that we test is the response by sub-sectors of the manufacturing industry. For that purpose, we divide the firms in our sample into 12 sub-sectors based on the two-digit ISIC 3 classification with some aggregations[36]. We apply the same SUR methodology as used for firm size, and regress investment growth on contemporaneous and lagged fiscal shocks, including furthermore our set of control variables. The results for lag 0 are displayed in Figure 1.5 [37]. We find that almost all sub-sectors show a negative and significant impact at lag 0, but the sub-sectors "food, beverages & tobacco", "leather", "non-metallic mineral products", and "transport equipment"[38]. The significant coefficients range from -5 to -11 and are hence in line with our previous findings.

Using the narrative identification for fiscal shocks allows us considering and aggregating a wide range of shocks, and thus identifying a robust average effect of tax adjustments; however, at the same time, and given the shock heterogeneity, the narrative

[36]The manufacturing industries covered are food, beverages and tobacco (1516), textiles and wearing apparel (1718), Leather industry (1900), wood (2000), pulp, paper and printing (2122), chemical, rubber, plastics and fuel products (2325), other non-metallic mineral products (2600), basic metals and fabricated metal products (2728), machinery and equipment n.e.c. (2900), machinery and equipment (3033), transport equipment (3435) and manufacturing n.e.c. and recycling (3637).

[37]For lag one we only find a significant (and negative) effect for sub-sectors 1718, 2122, 2900, and 3033.

[38]While "food, beverages & tobacco" are a very heterogeneous group of firms, "leather" and "non-metallic mineral products" are very small and specialized sub-sectors within the German manufacturing industry. The fact that we do not find a significant effect for the transport equipment sector might be related to the strong export orientation of this sub sector, which includes the entire German car industry.

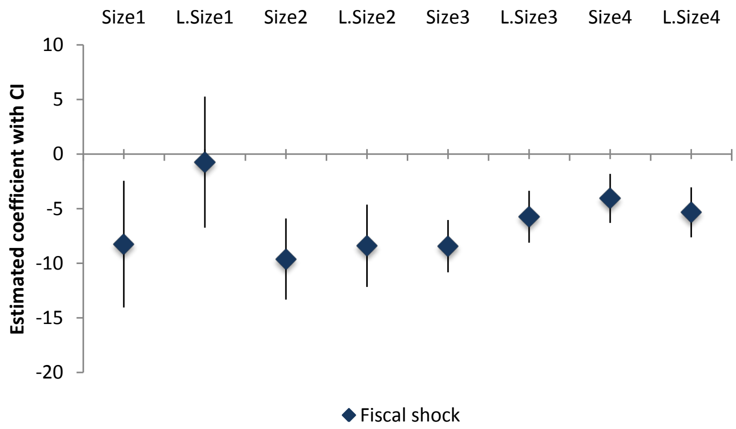

Figure 1.3: Heterogeneous effect by firm class size

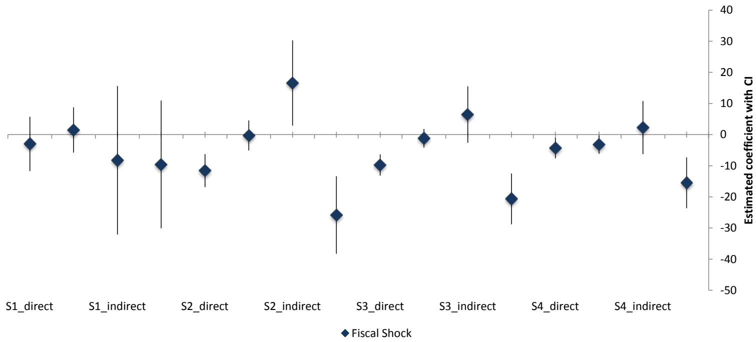

Figure 1.4: Heterogeneous effect by size and tax type

approach makes it difficult to pin down a single channel.

1.6 Robustness

1.6.1 Sensitivity analysis

In addition to the first model checks presented in the main section, we further elaborate on robustness in the present section. First, given the strong impact that the recent financial and economic crisis had on the economic activity in Germany (negative changes in realized investment of around 30 % in 2009 alone), a first sensitivity check consists of excluding the period 2007-2010 from our analysis. As pointed out in the methodological

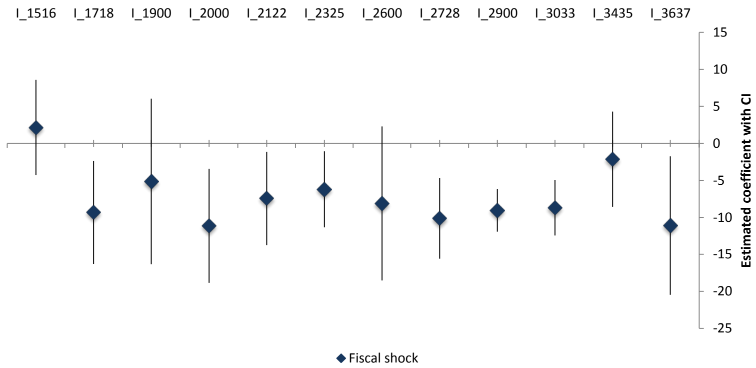

Figure 1.5: Heterogeneous effect by ISIC sector classification: at impact

section, in the original regression specification we already control with a dummy for the recent crisis period, however excluding the period completely represents a good robustness check for our findings. Dropping the period post 2007, we are left with 38,950 observations. For our preferred regression specification, including both aggregate and firm-level controls we find that the leads are not predictable and that the estimated coefficients for the fiscal shocks show the same sign and magnitude as before: -8.76, -5.54, and -3.05 for lag 0 to lag 2.

Another important robustness check is to exclude the biggest single sub-sector within manufacturing (manufacture of machinery and equipment) and to see if our results are stable. Dropping 17,710 observations from the annual dataset does not affect our results to an important degree and the estimated coefficients are directly aligned with our analysis of annual realized investment changes: -7.99, -4.21, and -2.96 for lag 0 to lag 2. Moreover, given the potential concern that structural shocks differ from consolidation shocks in their nature, i.e. they are based on "structural" considerations, these shocks might be correlated to past output and investment levels. We hence exclude them from our regression analysis and re-estimate the model using only shocks that are labeled unambiguously consolidation shocks in both Uhl (2013) and our classification. Again, our results are strongly aligned with the ones presented previously.

Finally, and in order to follow the literature on firm level investment, we model firm investment as in Bond, Harhoff, and van Reenen (2005). We hence estimate a dynamic model of firm investment focusing on the investment rate rather than on investment growth [39]. Due to data availably, we normalize investment by average assets of the company rather than by the capital stock at time $t-1$. The investment model specifies that current investment, the dependent variable, is explained by lagged investment, current and lagged sales growth, levels of sales, current and lagged cash flow to capital ratio and the second lag of the difference between capital stock and sales $(k-y)$. As explained in Bond, Harhoff, and van Reenen (2005), for consistency with the error correction specification, we require the coefficient of $(k-y)$ to be negative. For stability we furthermore require that the coefficient of lagged investment is lower than one in absolute terms.

As the investment rate depends on investment in the previous period, the model has to be estimated by general method of moments (GMM) [40]. Given the fact that the GMM estimator is a large N, small T estimator, we focus on the sample period 1991 to 2004 in order to maximize the numbers of tax shocks and firm observations, but repeat the exercise for the full sample with very similar findings. In a first step, we estimate the model as in Bond, Harhoff, and van Reenen (2005), including time fixed effects, in order to account for the economic cycle and other unobserved factors (Table 1.11, column 1). In order to estimate the effect of our annualized fiscal shocks, we replace the time fixed effects by aggregate controls (column 2) and confirm that the main results do not change. Finally, the fiscal shock is included in column (3). Similar to our previous findings on investment growth, we find a negative and significant effect for fiscal shocks on the investment rate at impact and lag1. The coefficients can be interpreted as a 1% tax adjustment in terms of VA in the manufacturing industry leads to a decrease in investment by -1.4% at impact and -1.1% at lag one, and hence a total aggregate effect of -2.5%. The test statistics for column 3 indicate that the Hansen-statistic of non-valid instruments can be rejected, while the model shows clear evidence of autocorrelation only at lag1.[41].

[39] The interested reader is referred to Bond, Harhoff, and van Reenen (2005), where the error correction model of firm investment is derived in detail.

[40] For efficiency considerations, we adopt the system GMM approach as in Bond, Harhoff, and van Reenen (2005)

[41] As additional model check we ignore the potential correlation between lagged investment and the error term and estimate the investment equation by both OLS and fixed effect regression. Given the induced bias the true value for lagged investment should be in-between the two naive approaches. We find that his is the case with an OLS estimate of 0.45 and FE estimate of 0.09 for the lagged investment

1.6.2 Towards a causal interpretation

Using a narrative identification strategy for fiscal shocks should overcome any type of endogeneity by construction. Nevertheless, taking advantage of the micro-level dataset and the detailed shock breakdown, we can provide further evidence that the investment response is indeed driven by the fiscal shock and that there are no unobserved factors driving the investment response, using a difference-in-difference approach. In order to do so, we focus on one specific type of shock that is likely to affect only some sub-sectors of the manufacturing industry. This identification strategy can help us to get closer to a causal interpretation of investment impact of fiscal consolidation.

For this purpose, we focus on tax changes that affect the cost of energy. Our assumption is that controlling for a set of aggregate and firm level factors, some energy intensive sectors will be highly affected by this type of tax adjustment, while other sectors will not respond to this tax change. Key is that both sectors, belonging to the manufacturing industry, share the same unobserved trends and hence any difference in outcome can be assigned to the effect of the tax shock. The pulp and paper industry seems a good candidate to test this hypothesis, given its high energy dependence[42]. As control groups we consider the food and tobacco industry (ISIC 1516) and the group of non-classified manufacturing (ISIC 3637). Even though some firms in the food and tobacco industry might be dependent on energy in their production process, both control sectors are highly heterogeneous in terms of products and production processes and hence it is likely for energy tax changes not to show any aggregate effect.

Our "treatment" group "paper" consists of 10,357 observations and the combined group of "controls" has a total of 10,946 observations for the sample period 1970-2010. For this period we count a total of 4 energy shocks[43]. Investment change for the en-

coefficient.

[42]On a worldwide scale the pulp and paper industry is considered the fifth largest consumer of energy. One additional advantage of the pulp and paper industry is that the products and manufacturing processes are highly standardized and hence a shock on energy prices (tax increase) is likely to affect all companies in the industry in a very similar fashion.

[43]Shocks in 1972, 1980, 1987 and 2001. Given the small number of shocks, we focus on realized invest-

tire sample period for the control group has a mean value of -0.012 (1.01) and for the treatment group 0.001 (1.36). The regression results are reported in Table 1.12, where the first column (1) refers to a pooled regression, column (2) includes fixed effects for the individual sub-branches summarized in the two categories, and column (3) includes firm level fixed effects. The results show that there exists a strong negative lagged effect for pulp and paper, while the control sector does not show any significant response to energy tax increases. Adding firm level fixed effects in column (3) alters the estimated coefficients only slightly, but leads to a higher level of significance for lag 1. In order to compare the magnitude of the coefficients with our previous findings, we evaluate them at the mean impact of energy shocks. Given a standard deviation of energy shocks of 0.002, firms in the pulp and paper industry respond to an average shock by reducing their investment growth by -4.8%. The results are hence highly aligned with our previous findings.

1.7 Conclusion

Private investment has been shown to be one of the main drivers of aggregate output during periods of fiscal consolidation. Nevertheless, previous literature has failed to provide a causal link between fiscal adjustment, business confidence and firm investment. The urge for understanding this channel is even more relevant in periods of excessive debt and/or deficit when the economy needs an effective growth policy agenda.

Based on a detailed narrative record for tax changes in Germany (Uhl (2013)), we reclassify 40 years of fiscal shocks into "exogenous" and "endogenous" changes with respect to investment and to the contingent state of the economy. Exploiting this exogenous variation, we study the effect of a tax change on firms' realized and planned investment, considering the IFO investment survey dataset. We find that recently published laws and laws under current discussion in the media and in the parliament shape future investment plans. Taking into account the forward looking behavior and adjusting the announcement dates according, we find that an increase in tax equal to 1% of the value added of the total manufacturing industry leads to a lagged decrease in planned

ment changes rather than updates in planned investment.

investment of about 4%. For realized investment growth we estimate an average effect of 8%

Finally, the use of micro-level firm data allows us to elaborate further on heterogeneity in terms of firm size, industry sub sector as well as by type of tax shock. Differently from the previous literature, we find that consumption taxes and income tax adjustments are most harmful for growth as they have the strongest negative and persistent effect on investment growth at firm level. The finding thus support recent hypotheses that highlight the importance of the demand channel in the transmission of fiscal policies, and may act through future demand expectation.

1.8 Appendix

1.8.1 Narrative & firm investment data

This section shows some examples of tax changes as discussed and classified in Uhl (2013). For our purpose of analyzing the effect of exogenous fiscal tax changes on investment we revise all structural and consolidation tax measures in Uhl and reclassify them accordingly in "endogenous" and "exogenous" measures.

An example for an exogenous structural tax measure is given by shock number 20 in Uhl (2013) ,"Gesetz zur Fortentwicklung der oekologischen Steuerreform". It corresponds to the continuation of the ecological tax reform, published on 22 December 1999, with a total budgetary impact of 10,635 billion Euros it represents a tax measure with structural motivation that is included in our analysis. Even though the revenues from the original ecological tax reform were aimed at reforming the retirement scheme in Germany from a pure pay-as-you go system to a more capital oriented system (the so-called "Riester Rente"), and hence might have indirect impact on investment, the continuation law discussed here did not directly contribute to the structural reform of the pension scheme, and revenues were not used to reduce the contribution rates to the social security system. The main argument that dominated the parliamentary debate was that that additional block grants were used to avoid future increases. We label the tax measure structural and include it in our analysis.

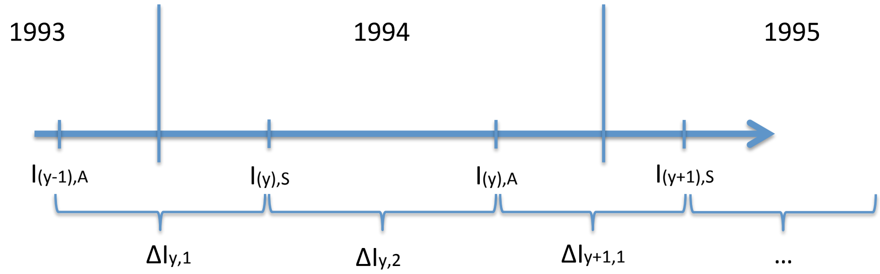

Figure 1.6: Timing of the half-yearly investment survey

On the contrary, shock number 28 in Uhl (2013) " Gesetz zur Senkung der Steuersaetze und zur Reform der Unternehmensbesteuerung", represents a good example of structural shock that we consider endogenous, differently from Uhl (2013) . It refers to a law that has the objective to decrease taxes and reform company taxation (published in October 2000). This law implemented one of the most extensive tax reforms in Germany and substantially reduced income - and corporate tax burden. Furthermore the corporate tax imputation system was replaced by a 50 percent income taxation rule. The introduction of the bill clearly postulated that the motivation behind the law is to promote growth and employment by reducing the tax burden. Tax reductions were supposed to stimulate consumption, employment and investment. Therefore we do not included it in our analysis as it is directly aimed at increasing firm investment activity.

Finally, a good example for a consolidation shock is given by shock number 62 in Uhl (2013), a law published in March 1981, with the objective to increase petroleum tax and taxes on spirits (Mineraloel und Branntweinsteuer-Aenderungsgesetz 1981). As pointed out in Uhl (2013), the main motivation behind the law was budgetary consolidation. Although structural effects cannot be excluded completely (in order to improve the structure of tax revenues), consolidation considerations dominated the discussion.

Tax shocks: Number in Uhl (2013)	Parliament Publication date	Parliament Draft date	Newspaper coverage Discussion date	Comments
No 5. Law for the continuation of the legal situation 2006 for commuter's tax allowances	Dec-08	Mar-2009, Constitutional court ruling(Dec-2008)	Oct-07	Case rulings in 2007 made clear that the constitutional court likely declares the previously introduced measure for the "Pendlerpauschale" unconstitutional.
No 10. Tax reform act 2007	Jul-06	May-06	Nov-05	Negotiation of the coalition agreement in November 2005 defined list of important changes, amongst others the commuter's allowance.
No 12 .Law for limitation of the loss incorporation in the context of tax deferral	Dec-05	Nov-05	Apr-04 to Jun-05	Already in April 2004 changes in the classification of certain type of life insurances. End of 2004, same applies to closed real estate investment funds. Law as extension of these measures.
No 13. Law to increase tax compliance	Dec-03	Jul-03	Feb-03	Presentation of a white paper by the Financial Ministry in February 2003 to increase the declaration of unreported earnings from abroad.
No 15. Reform of the retirement income (AltEinkG)	Jul-04	Dec-03	Mar-03	Commission established in 2002. Report on the reformation of the pension scheme published in 2003.
No 16. Act for the change of the tobacco tax and other consumption taxes	Dec-03	Jul-03	May-03	First press news in May 2003, however possibility to increase consumption taxes due to financial situation has been already discussed in coalition negotiations after the federal elections in autumn 2002.
No 20 Law for the continuation of the ecological tax reform	Dec-02	Nov-02	Jun-01	Discussion of the further development of the ecological tax.
No 24. Law for the reform of the pension insurance and the promotion of capital pension schemes (AVmG)	Jun-01	Nov-00	Early 2000	Discussion of aging society and unsustainability of the Pay-as-you-go pension scheme in early 2000. Presentation of the pension scheme reform in May 2000.
No 42. Law for the new regulation of the interest taxation	Nov-92	Apr-92	Jan-92	Press notes on the discussion of the consistency with the constitution of the revised interest taxation in early January 1992.
No 44. Law for the implementation of the federal consolidation package (FKPG)	Jun-93	Mar-93	Feb-91	Coalition agrees on substantial tax increases in order to finance the burden of the German reunification. Biggest impact has the solidary surcharge on income and wages.

Table 1.2: Previous news coverage of fiscal shocks

1.8.2 Summary statistics

This section presents evidence for the representativeness of our sample data for the overall manufacturing sector in Germany. We compare aggregate firm level data, obtained as log difference of total change at time t and time t-1 (d_inv_t) and a size-weighted average measure of investment changes (d_inv_a_w), with the benchmark for realized investment changes (gross fixed capital formation data obtained from STAN Industry Rev.3 2008 (OECD).

Table 1.3 and Table 1.4 present results from the aggregate VAR analysis and provide evidence that the shock series cannot be predicted by macroeconomic variables or lagged investment changes. On the other hand, all announced shocks at time t seem to have an impact on changes in investment (Table 1.4); the null hypothesis of no granger causality can be rejected at the 10% significance level.

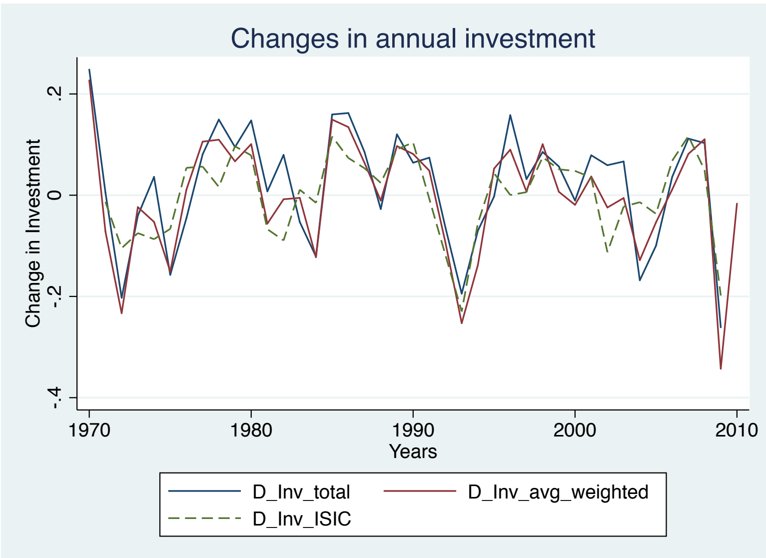

Figure 1.7: Change in aggregate investment: STAN vs. sample aggregation

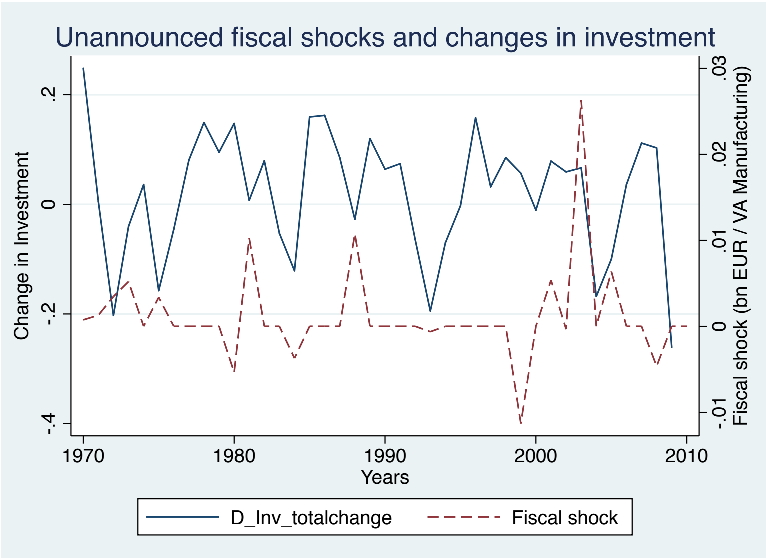

Figure 1.8: Change in aggregate investment vs. exogenous fiscal shock series

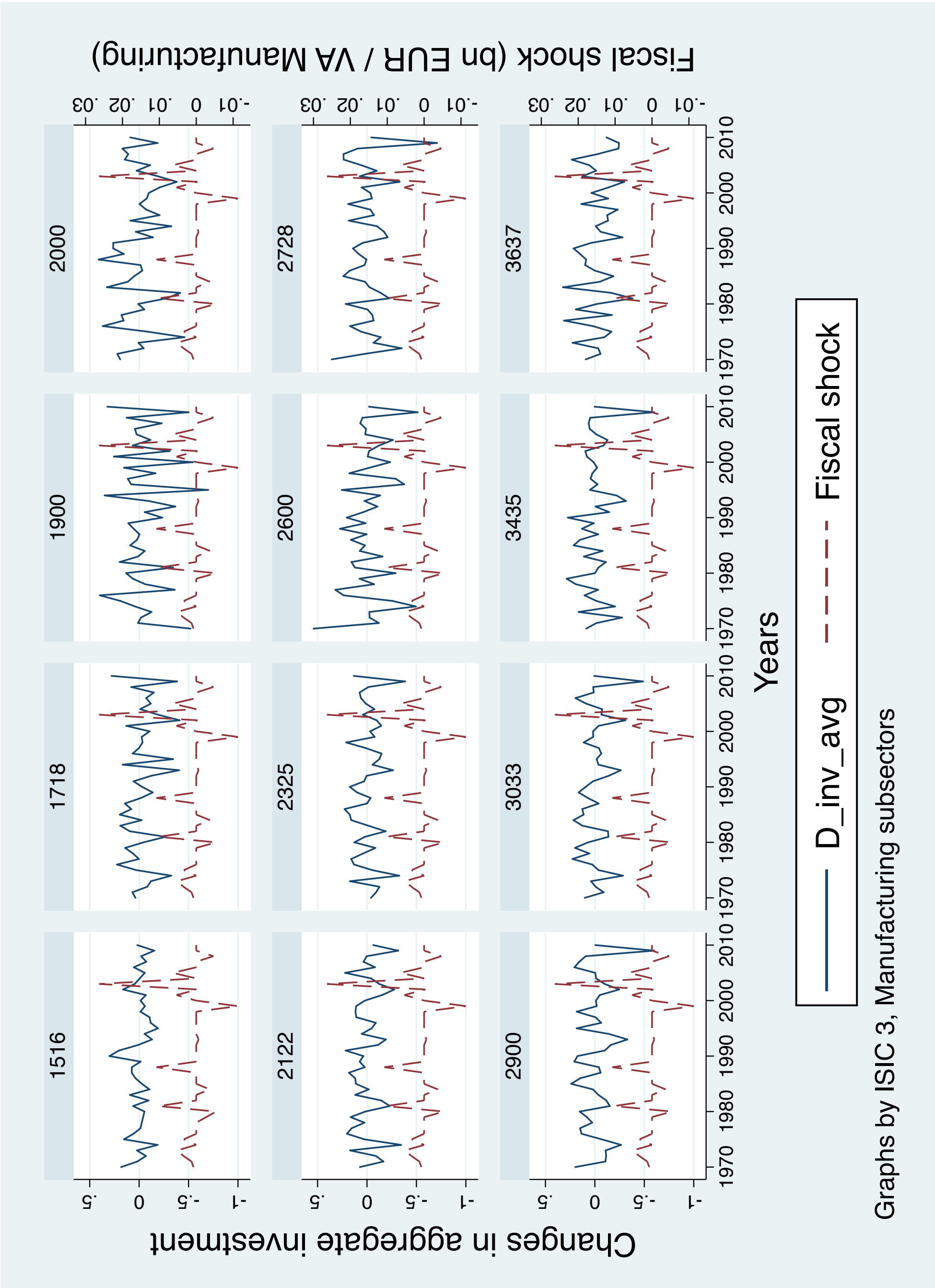

Figure 1.9: Change in aggregate investment in ISIC3 sub sectors vs. exogenous fiscal shock series

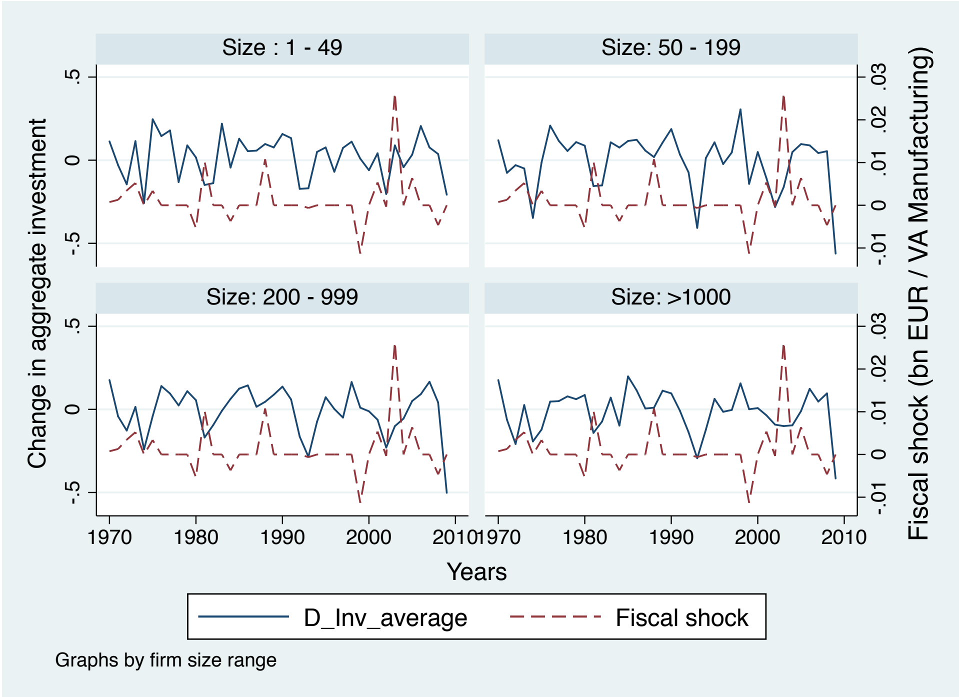

Figure 1.10: Change in aggregate investment by size class vs. exogenous fiscal shock series

Equation	Excluded	chi2	df	Prob > chi2	Equation	Excluded	chi2	df	Prob > chi2
Exog. fiscal shock	Interest rate (3month)	0.003	1	0.959	Endog. fiscal shock	Interest rate (3month)	2.572	1	0.109
Exog. fiscal shock	GDP growth	0.689	1	0.407	Endog. fiscal shock	GDP growth	3.447	1	0.063
Exog. fiscal shock	Change in investment	0.172	1	0.678	Endog. fiscal shock	Change in investment	2.141	1	0.143
Exog. fiscal shock	ALL	1.461	3	0.691	Endog. fiscal shock	ALL	6.283	3	0.099
D.investment	Exog. fiscal shock	0.020	1	0.887	D.investment	Endog. fiscal shock	0.297	1	0.586
D.investment	Interest rate (3month)	1.426	1	0.232	D.investment	Interest rate (3month)	1.040	1	0.308
D.investment	GDP growth	1.620	1	0.203	D.investment	GDP growth	1.964	1	0.161
D.investment	ALL	2.732	3	0.435	D.investment	ALL	3.028	3	0.387

Exogenous fiscal shock and investment change (39 obs.) | Endogenous fiscal shock and investment change (39 obs.)

Table 1.3: Granger causality test based on 4 variable VAR

Dependent variable: Exogenous fiscal shock			Dependent variable: Endogenous fiscal shock		
	beta	se		beta	se
L.1 Change in investment	-2.626	(2.108)	L.1 Change in investment	-0.335	(-2.005)
L.2 Change in investment	1.670	(1.942)	L.2 Change in investment	4.766**	(-2.099)
L.1 GDP	0.000	(0.000)	L.1 GDP	0.000	(0.000)
L.2 GDP	0.000	(0.000)	L.2 GDP	0.000	(0.000)
Observations	39		Observations	39	
Pseudo R2	0.06		Pseudo R2	0.09	
For the sample period 1970-2010 there are 6 negative adjustment, 25 periods of no action and 10 years with positive shocks.			For the sample period 1970-2010 there are 14 negative adjustment, 15 periods of no action and 12 years with positive shocks.		

Table 1.4: Ordered Probit: Insample

Dependent variable: Exogenous fiscal shock			Dependent variable: Endogenous fiscal shock		
	beta	se		beta	se
L.1 GFCF	-2.93E-11	(7.81e-11)	L.1 GFCF	1.82E-10**	(8.15E-11)
L.2 GFCF	5.03E-11	(6.73e-11)	L.2 GFCF	-7.13E-11	(6.71E-11)
L.1 GDP	-.000	(0.000)	L.1 GDP	-0.002**	(0.001)
L.2 GDP	0.000	(0.000)	L.2 GDP	0.001**	(0.001)
Observations	38		Observations	38	
Pseudo R2	0.05		Pseudo R2	0.12	
For the sample period 1970-2010 there are 6 negative adjustment, 25 periods of no action and 10 years with positive shocks.			For the sample period 1970-2010 there are 14 negative adjustment, 15 periods of no action and 12 years with positive shocks.		

Table 1.5: Ordered Probit: Official Statistics (OECD STAN)

Table 1.6: Revision in planned investment

Dependent variable: Revision in planned investment	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)	(5) β / (SE)	(6) β / (SE)
F2.fiscal shock				−5.520***	−4.021*	−5.012**
				(2.076)	(2.148)	(2.175)
F.fiscal shock				−2.945*	−4.141**	−4.033**
				(1.769)	(1.830)	(1.928)
Fiscal shock	−1.601	0.103	−0.398	0.050	2.504	1.838
	(2.170)	(2.264)	(2.370)	(2.071)	(2.184)	(2.201)
L.fiscal shock	−2.573*	−3.750**	−2.149	−5.293***	−6.575***	−5.816***
	(1.544)	(1.755)	(1.892)	(1.631)	(1.691)	(1.901)
L2.fiscal shock	−1.587	−2.018	−0.794	−0.187	−0.325	0.289
	(1.681)	(1.815)	(1.833)	(1.679)	(1.790)	(1.839)
Dummy_autumn	0.095***	0.099***	0.102***	0.083***	0.084***	0.086***
	(0.014)	(0.015)	(0.015)	(0.014)	(0.015)	(0.015)
Dummy_crisis	−0.089***	−0.061***	−0.050**	−0.130***	−0.116***	−0.113***
	(0.018)	(0.020)	(0.021)	(0.020)	(0.021)	(0.023)
L.GDP	0.000	−0.000	−0.000*	0.000***	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L.3 month interbank rate	−0.030***	−0.042***	−0.031**	−0.025***	−0.026***	−0.027**
	(0.009)	(0.011)	(0.013)	(0.009)	(0.010)	(0.012)
L.Sales growth		0.090***	0.046		0.100***	0.061*
		(0.029)	(0.032)		(0.028)	(0.032)
Observations	25189	19525	19525	23151	19525	19525
R^2	0.006	0.009	0.007	0.007	0.009	0.006
Industry FE	Y	Y	N	Y	Y	N
Firm FE	N	N	Y	N	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at firm level in parentheses.

Table 1.7: Halfyearly: discussion date of the fiscal shock

Dependent variable: Revision in planned investment	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)
F2.fiscal shock	−4.831**	−3.149	−3.268
	(2.452)	(2.551)	(2.645)
F.fiscal shock	1.566	1.632	0.933
	(2.265)	(2.287)	(2.406)
Fiscal shock	−4.132***	−3.418**	−3.941**
	(1.498)	(1.565)	(1.590)
L.fiscal shock	−1.548	−1.736	−1.810
	(1.510)	(1.564)	(1.651)
L2.fiscal shock	−1.910	−0.813	−1.012
	(1.816)	(1.888)	(1.892)
Dummy_autumn	0.081***	0.081***	0.085***
	(0.014)	(0.015)	(0.015)
Dummy_crisis	−0.116***	−0.100***	−0.097***
	(0.020)	(0.021)	(0.022)
L.GDP	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)
L.3 month interbank rate	−0.017**	−0.018**	−0.020*
	(0.008)	(0.008)	(0.010)
L.Sales growth		0.095***	0.056*
		(0.028)	(0.032)
Observations	23151	19525	19525
R^2	0.007	0.008	0.006
Industry FE	Y	Y	N
Firm FE	N	N	Y

* p < 0.1, ** p < 0.05, *** p < 0.01. Clustered standard errors at firm level in parentheses.

Table 1.8: Annual: realized investment change

Dependent variable: Investment growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)	(5) β / (SE)
F2.fiscal shock	2.659***	1.239	0.584	2.126*	3.085
	(0.922)	(0.940)	(0.945)	(1.150)	(2.022)
F.fiscal shock	0.895	0.056	−0.020	0.642	4.563**
	(0.896)	(0.904)	(0.910)	(1.208)	(1.923)
Fiscal shock	−8.949***	−8.502***	−8.724***	−8.789***	−2.359
	(0.952)	(0.960)	(0.960)	(1.245)	(1.811)
L.fiscal shock	−2.901***	−4.682***	−4.853***	−1.704	−7.072***
	(0.849)	(0.876)	(0.883)	(1.056)	(1.824)
L2.fiscal shock	0.858	−1.757*	−2.164**	0.529	−3.275*
	(0.941)	(0.986)	(0.993)	(1.248)	(1.895)
Dummy_90		−0.270***	−0.276***		
		(0.018)	(0.018)		
Dummy_crisis		−0.098***	−0.097***	0.065	8.88
		(0.032)	(0.036)	(0.051)	8.88
L.GDP		0.000***	0.000***	−0.000	0.000***
		(0.000)	(0.000)	(0.000)	(0.000)
L.3 month interbank rate		−0.028***	−0.028***	−0.047***	−0.047***
		(0.002)	(0.003)	(0.009)	(0.005)
L.Sales growth			0.032	0.053	0.000
			(0.031)	(0.034)	(0.056)
Observations	43738	43738	42046	23024	19022
R^2	0.003	0.007	0.008	0.007	0.013
Industry FE	Y	Y	Y	Y	Y

* p < 0.1, ** p < 0.05, *** p < 0.01. Clustered standard errors at firm level in parentheses.

Table 1.9: Heterogeneous effects: Tax type

Dependent variable: Investment growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Income tax	−13.956***	−18.096***		
	(2.298)	(1.925)		
L.Income tax	−5.670**	−5.808***		
	(2.403)	(1.963)		
Property and Corp tax	−7.958***		−12.959***	
	(2.052)		(1.575)	
L.Property and Corp tax	0.947		−6.606***	
	(2.037)		(1.474)	
Consumption tax	0.176			−6.754***
	(2.998)			(2.533)
L.Consumption tax	−17.392***			−17.800***
	(3.044)			(2.550)
Dummy_90	−0.225***	−0.213***	−0.239***	−0.191***
	(0.016)	(0.015)	(0.016)	(0.015)
Dummy_crisis	−0.227***	−0.207***	−0.240***	−0.216***
	(0.017)	(0.016)	(0.016)	(0.016)
L.GDP	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
L.3 month interbank rate	−0.023***	−0.026***	−0.027***	−0.024***
	(0.002)	(0.002)	(0.002)	(0.002)
L.Sales growth	−0.002	−0.002	0.002	0.006
	(0.022)	(0.022)	(0.022)	(0.022)
Observations	54261	54261	54261	54261
R^2	0.008	0.007	0.007	0.006
Industry FE	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at firm level in parentheses.

Table 1.10: Heterogeneous effects: direct vs. indirect taxes

Dependent variable: Investment growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)
Direct taxes	−9.720***	−10.228***	−9.869***
	(1.086)	(1.114)	(1.102)
L.Direct taxes	−0.906	−1.641	−0.959
	(1.081)	(1.106)	(1.087)
Indirect taxes	3.054	2.449	3.298
	(3.053)	(3.097)	(3.160)
L.Indirect taxes	−16.265***	−15.903***	−16.055***
	(2.778)	(2.822)	(2.844)
Observations	53164	53164	53164
R^2	0.01	0.01	0.01
Controls	Y	Y	Y
Anticipated shocks	N	N	Y
Industry FE	Y	N	Y
Firm FE	N	Y	N

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at firm level in parentheses.

Table 1.11: Results from GMM Model (Bond et. al (2003))

Dependent variable: Investment / Assets	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)
L. Investment / Assets	0.222***	0.218***	0.236***
	(0.020)	(0.020)	(0.021)
Sales growth	0.294***	0.256***	0.254***
	(0.088)	(0.081)	(0.111)
L.Sales growth	0.145***	0.137***	0.153***
	(0.026)	(0.023)	(0.030)
L2.(Assets - Sales)	−0.103***	−0.100***	−0.124***
	(0.022)	(0.020)	(0.030)
F.fiscal shock			−0.094
			(1.001)
Fiscal shock			−1.461**
			(0.681)
L.fiscal shock			−1.101*
			(0.665)
Hansen (p-value)	0.01	0.05	0.13
Arellano-Bond (AR1)	-17.34	-17.72	-15.91
Arellano-Bond (AR2)	1.67	1.75	1.76
Observations	10761	10761	9524
Firms	1875	1875	1798
Year FE	Y	N	N
Aggregate controls	N	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Estimation by SYS-GMM using the one-step estimator. Hansen test (p-value) for over identification restrictions reported. We follow the same selection of instruments as in Bond et. al (2003)

Table 1.12: Results from Diff-in-Diff: Energy tax

Dependent variable: Investment growth	(1) (β / (SE)	(2) (β / (SE)	(3) (β / (SE)
Energy tax X paper industry	3.608	3.410	6.921
	(13.553)	(13.554)	(14.011)
L.Energy tax X paper industry	−23.134*	−23.532*	−24.323**
	(12.269)	(12.272)	(12.289)
L2.Energy tax X paper industry	−20.403	−20.356	−20.427
	(12.683)	(12.697)	(13.105)
Energy tax	−1.535	−1.517	−3.133
	(8.436)	(8.435)	(8.806)
L.Energy tax	4.927	5.158	4.569
	(7.952)	(7.958)	(7.972)
L2.Energy tax	−10.747	−10.927	−12.773
	(9.005)	(9.020)	(9.230)
Pulp & Paper		0.039***	
		(0.013)	
Observations	12960	12960	12960
R^2	0.004	0.004	0.004
Controls	Y	Y	Y
Industry FE	N	Y	N
Firm FE	N	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at firm level in parentheses.

Table 1.13: Aggretated results: by ISIC 3 subsector

Dependent variable: Investment growth	(1)	(2)	(3)	(4)
	β / (SE)	β / (SE)	β / (SE)	β / (SE)
Fiscal shock	−3.689***	−3.689***	−2.301*	−2.278**
	(1.120)	(0.816)	(1.054)	(0.864)
L.fiscal shock	−2.674**	−2.682***	−2.279**	−2.958***
	(1.182)	(0.760)	(0.772)	(0.740)
L2.fiscal shock	−.635	−0.640	−1.091	−1.493
	(1.557)	(2.124)	(2.065)	(2.021)
Fiscal shock anticipated			−0.018	
			(0.689)	
L.fiscal shock anticipated			0.181	
			(0.421)	
L2.fiscal shock anticipated			2.011*	
			(0.989)	
Fiscal shock endog.				1.209*
				(0.649)
L.fiscal shock endog.				−1.129
				(0.679)
L2.fiscal shock endog.				−3.316***
				(0.589)
Dummy_90	−0.248***	−0.249***	−0.253***	−0.202***
	(0.0402)	(0.027)	(0.029)	(0.038)
Dummy_crisis	−0.151***	−0.151***	−0.176***	−0.1678***
	(0.043)	(0.037)	(0.046)	(0.034)
L.GDP_index	0.696***	0.697***	0.689***	0.589***
	(0.135)	(0.101)	(0.097)	(0.122)
L.3 month interbank rate	−.0171***	−0.171***	−0.0183***	−0.011*
	(0.006)	(0.004)	(0.004)	(0.005)
Observations	465	465	465	465
R^2	0.11	0.11	0.12	0.16
Industry FE	N	Y	Y	Y

* p < 0.1, ** p < 0.05, *** p < 0.01. Clustered standard errors at firm level in parentheses.

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Chapter 2

Policy Uncertainty and Investment in Low-Carbon Technology.

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2.1 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

[1] See, for example, Zhao (2003) and Jung, Krutilla, and Boyd (1996).

and the future market price of the allowances for the firms. As a consequence, given the long-term nature of investments 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, Bradley, Bunn, Clarke, Wilson, and Yang (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

[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.

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, Bradley, Bunn, Clarke, Wilson, and Yang (2007) can be directed at this contribution.
Finally, Colla, Germain, and Van Steenberghe (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

[4]Appendix 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, Convery, Perthuis, and Alberola (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.

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 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 paper is organized as follows. Section 2 introduces the model while section 3 presents the methodology and the results. In Section 4 the welfare analysis is presented and, finally, Section 5 concludes.

2.2 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.

2.2.1 The regulator

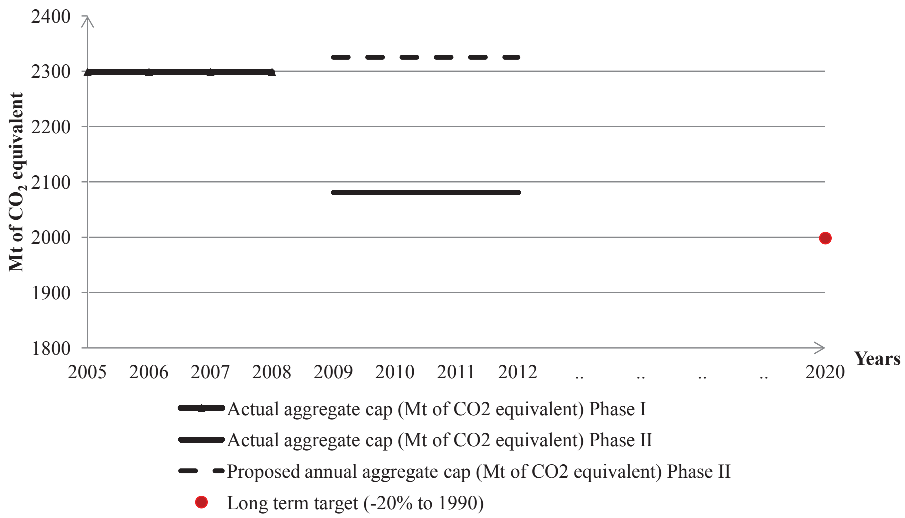
As laid out in the introduction, we focus on the effect of having uncertainty over the policy maker's preferences. Although a long term target for the cap is set out in advance, the policy maker decides period by period on the actual limit in effect for that given trading period (phase), which might 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

[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.

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 tighter, and vice-versa.
An example of policy uncertainty in the context of the *EU ETS* is presented in Fig.2.1. It depicts the information available to the firms in 2003 and the realized cap for the

Figure 2.1: Annual aggregate cap as known in 2003. Source: European Commission.



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.
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:

$$R(\bar{e}; \tilde{\gamma}) = \tilde{\gamma} \left[\sum_{i=1}^{2} \pi_{i,s} \right] - (1 - \tilde{\gamma})\, \phi \bar{e} \qquad (2.1)$$

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

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, Steenberghe, and Magnus (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.

2.2.2 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

[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, Scott1994325 and ECCA:ECCA866).

[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.

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 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 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:

$$\pi_1(a_1, e_1, G_1; \bar{e}) = \max\{\pi_{1,e}(a_1, e_1; \bar{e}), \pi_{1,G}(a_1, G_1; \bar{e})\} \tag{2.2}$$

[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.

$$\pi_{1,e}(a_1, e_1; \bar{e}) = \alpha_{1,e}(a_1 + \bar{a})e_1 - ce_1^2 - p_s\left(e_1 - \frac{\bar{e}}{2}\right) - k_1 a_1^2 \tag{2.3}$$

$$\pi_{1,G}(a_1, G_1; \bar{e}) = \alpha_{1,G}(a_1 + \bar{a})G_1 - gG_1^2 - p_s\left(\lambda G_1 - \frac{\bar{e}}{2}\right) - k_1 a_1^2 - F \tag{2.4}$$

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

$$\pi_{2,e}(a_2, e_2; \bar{e}) = \alpha_{2,e}(a_2 + \bar{a})e_2 - ce_2^2 - p_s\left(e_2 - \frac{\bar{e}}{2}\right) - k_2 a_2^2 \tag{2.5}$$

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 2.3.1). 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

[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.

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 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.

2.2.3 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.2.2.

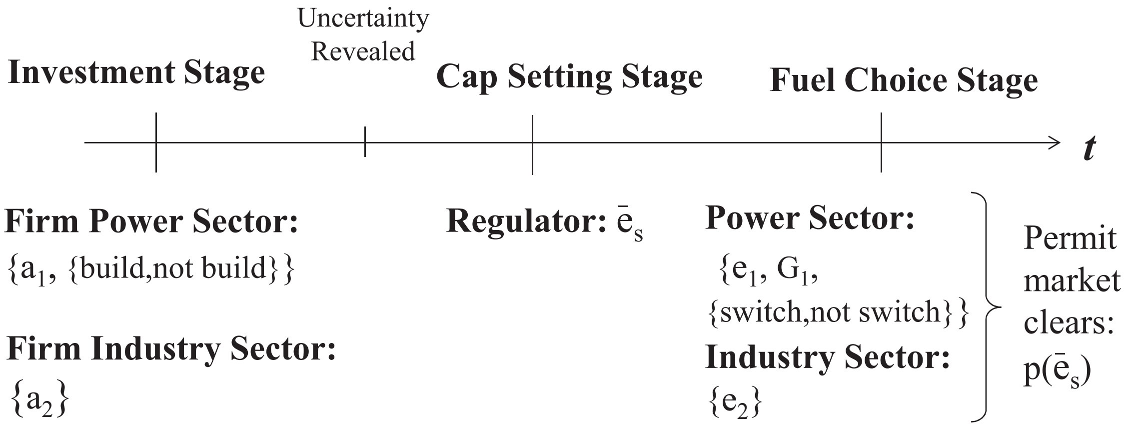
2.3 Methodology and Results

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 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.

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

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

Figure 2.2: Timeline



2.3.1 Irreversible Investment in Isolation

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

$$\pi_{i,e,s}(e, a; \bar{e_s}) = \alpha_{i,e}(a_i + \bar{a})e_{i,s} - ce_{i,s}^2 - p_s\left(e_i - \frac{\bar{e}_s}{2}\right) - k_i a_i^2 \tag{2.6}$$
$$i = 1, 2; s = h, l$$

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:

$$e_{i,s}^*(p_s) = \frac{-p_s + \alpha_i(a_i + \bar{a})}{2c} \tag{2.7}$$

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

[18] As firms do not act strategically, the model could also be solved by forward induction.

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

$$e^*_{1,s}(p_s) + e^*_{2,s}(p_s) = \bar{e}_s \tag{2.8}$$

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

$$p^*_s = \frac{1}{2}\left[\alpha_1(a_1 + \bar{a}) + \alpha_2(a_2 + \bar{a}) - 2c\bar{e}_s\right] \tag{2.9}$$

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:

$$R_s(\bar{e_s}) = \tilde{\gamma}_s \left[\sum_{i=1}^{2} \pi_{i,s}(a_i, e^*_i; \bar{e}_s)\right] - (1 - \tilde{\gamma}_s)\,\phi\bar{e}_s \qquad s = h, l \tag{2.10}$$

where firms' profits are given by (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:

$$\bar{e}^*_s = \frac{(a_1 + \bar{a})\alpha_1\tilde{\gamma}_s + (a_2 + \bar{a})\alpha_2\tilde{\gamma}_s + 2\phi(\tilde{\gamma}_s - 1)}{2c\tilde{\gamma}_s}, s = h, l \tag{2.11}$$

[19]This is true for any other choice of production function which embodies any (even very small) degree of complementarity between inputs.

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 $\tilde{\gamma}_s - 1 > 0$. Rearranging the expression, it can be seen that the existence of a positive cap is guaranteed by the following maximum for the marginal damage parameter:

$$\phi < \frac{\gamma}{(1-\gamma)} \frac{1}{2} [\alpha_1(a_1 + \bar{a}) + \alpha_2(a_2 + \bar{a})] \tag{2.12}$$

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, Germain, and Van Steenberghe (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:

$$E(\pi_{i,e}(a_i;\bar{e})|\gamma,\tau,q) = q[\alpha_{i,e}(a_i+\bar{a})e^*_{i,h} - ce^{*2}_{i,h} - p(\bar{e_h})(e^*_{i,h} - \frac{\bar{e}_h}{2}) - k_i a_i^2 t] \tag{2.13}$$

$$+(1-q)[\alpha_{i,e}(a_i+\bar{a})e^*_{i,l} - ce^{*2}_{i,l} - p(\bar{e}_l)((e^*_{i,l} - \frac{\bar{e}_l}{2}) - k_i a_i^2]$$

$$i = 1,2$$

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:

$$a_i^* = \frac{(\alpha_{i,e}(-\alpha_{j,e}^2\hat{\hat{e}} + 2k_j[\bar{a}(\alpha_{i,e} - \alpha_{j,e}) + 2c\hat{\hat{e}}]))}{16ck_ik_j - 2\left(k_j\alpha_{i,e}^2 + k_i\alpha_{j,e}^2\right)} \tag{2.14}$$

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:

$$4ck_i - \alpha_{i,e}^2 > 0, i = 1, 2 \tag{2.15}$$

$$[q\bar{e}_h + (1 - q)\bar{e}_l] \geqslant \frac{-2k_j\bar{a}(\alpha_i - \alpha_j)}{(4ck_2 - \alpha_j^2)} \tag{2.16}$$

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 (12) and (16) shows (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

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

Condition 2

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

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

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* $\tau > \hat{\tau}$.

2.3.2 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 (2.2) to (2.5) setting a_i to zero.[22] The profits when using coal and gas for production are, respectively, given by:

$$\pi_{i,e}(e_i;\bar{e}) = \alpha_{i,e}e_i - ce_i^2 - p(\bar{e})\left(e_i - \frac{\bar{e}}{2}\right), i = 1,2 \tag{2.17}$$

$$\pi_{1,G}(G_1;\bar{e}) = \alpha_{1,G}G_1 - gG_1^2 - p(\bar{e})\left(\lambda G_1 - \frac{\bar{e}}{2}\right) - F \tag{2.18}$$

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

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

$$E[\pi_{1,NI}(e^*_s;\bar{e}^*_{s,NI})] = q[\alpha_{1,e}e^*_h - ce^{*2}_h - p^*_{h,NI}(e^*_h - \frac{\bar{e}^*_{h,NI}}{2})] + (1-q)[\alpha_{1,e}e^*_l - ce^{*2}_l - p^*_{l,NI}(e^*_l - \frac{\bar{e}^*_{l,NI}}{2})] \quad (2.19)$$

[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.

$$E[\pi_{1,IS}(e_h^*, G_l^*; \bar{e}_{s,IS}^*)] = q[\alpha_{1,e}e_h^* - ce_h^{*2} - p_{h,SI}^*(e_h^* - \frac{\bar{e}_{h,SI}^*}{2})] + (1-q)[\alpha_{1,G}G_l^* - gG_l^{*2} - p_{l,SI}^*(\lambda G_l^* - \frac{\bar{e}_{l,SI}^*}{2})] \quad (2.20)$$

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:

$$E[\pi_{1,IS}(e_h^*, G_l^*; \bar{e}_{s,IS}^*, p_{s,IS}^*)] - E[\pi_{1,NI}(e_h^*, e_l^*; \bar{e}_{s,IS}^*, p_{s,IS}^*)] > 0, s = h, l \quad (2.21)$$

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

$$E[\pi_{1,NI}(e_h^*, e_l^*; \bar{e}_{s,NI}^*, p_{s,NI}^*)] - E[\pi_{1,IS}(e_h^*, G_l^*; \bar{e}_{s,NI}^*, p_{s,NI}^*)] > 0, s = h, l \quad (2.22)$$

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 are $p_{s,IS}^*$ and $p_{s,NI}^*$. The opposite is true when $F > F^{th}$.[26]

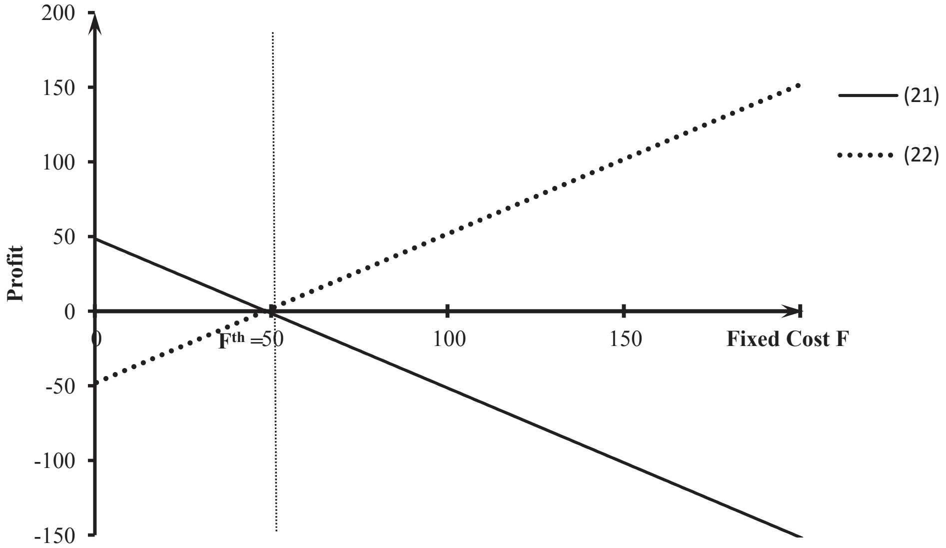
We therefore find a unique equilibrium, given the fundamentals of the economy, consisting of the equilibrium quantities above, the system of beliefs of firms, given by q, the threshold for investment and the condition for switching, determined further below.

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 C. With these values, we plot equations (2.21) and (2.22). In Fig.2.3 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

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

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

Figure 2.3: Investment decision for firm 1



that, for $F < F^{th}$, 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 (21)) and when the cap is set optimally for *NI* (negative part of curve (22)). For $F > F^{th}$ the firm no longer has an incentive to invest: equation (2.21) becomes negative, and (2.22) 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 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.2.3, 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:

$$\varphi = \frac{(1-\gamma)}{\gamma}\phi \qquad (2.23)$$

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.2.3 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]
- 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.*

[27] This result is in line with the analysis of Blyth, Bradley, Bunn, Clarke, Wilson, and Yang (2007).

[28] In the analogous graph to the one in Fig.2.3, 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.

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.

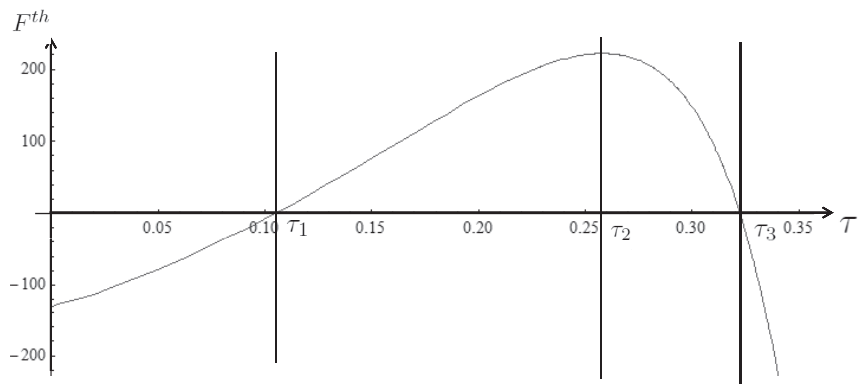
2.3.3 Complete Environment

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 *2.3.2*, but incorporating the first period choices of a_i, as determined in subsection *2.3.1*.
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 *2.3.1*, 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 when-

[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.

ever $\tau > \tau^{th}$, 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.2.4 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 four regions of interest and, consequently, three

Figure 2.4: Investment in Reversible Technology



additional thresholds for τ. For low levels of uncertainty, $\tau < \tau_1$, reversible investment increases with uncertainty as in subsection 2.3.2 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

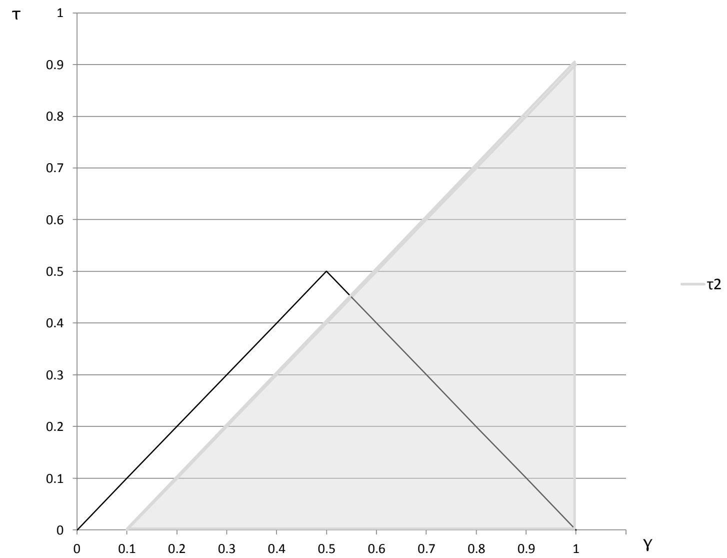
[31]We again use the calibration described in Appendix C. We set again $\gamma = 0.5$ and now $\phi = 150$, such that the constraint on φ is satisfied.

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 2.3.2 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.2.5 plots this threshold for different levels of γ and for a given marginal damage $\phi = 50$. If τ is below the threshold, namely within 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

Figure 2.5: Threshold for positive effect



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.

Table 2.1: Final effect of uncertainty on investment

Parameters	**Preferences**	**Uncertainty Reversible**	**Uncertainty Irreversible**
$\varphi > \varphi^{th'}$	Environment	Negative	Negative
$\varphi < \varphi^{th'}$	2*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

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

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.

2.4 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.

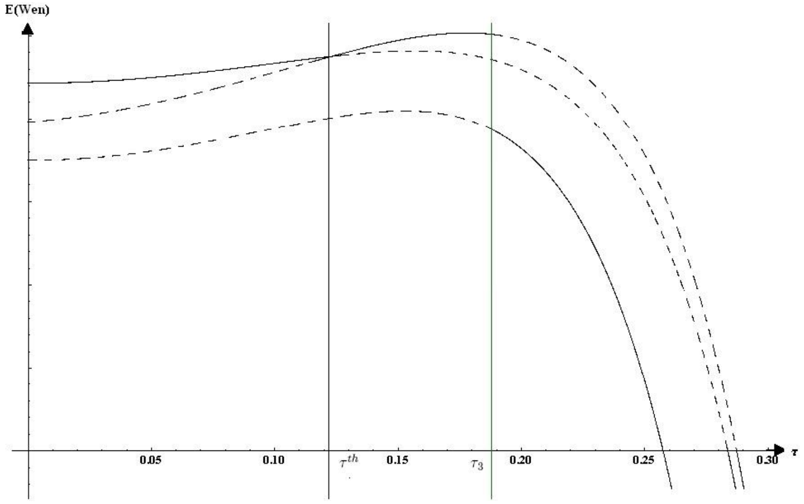
Following Colla, Germain, and Van Steenberghe (2012) and Germain, Steenberghe, and Magnus (2004) in similar analysis, we use the regulator's objective function as a measure of aggregate welfare. This means that ex-ante welfare is a weighted average of the profits in the economy and the disutility of 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.2.6 using the calibration described in Appendix C and $\varphi > \varphi^{th'}$.

Figure 2.6: Welfare function: environmentally biased authority.



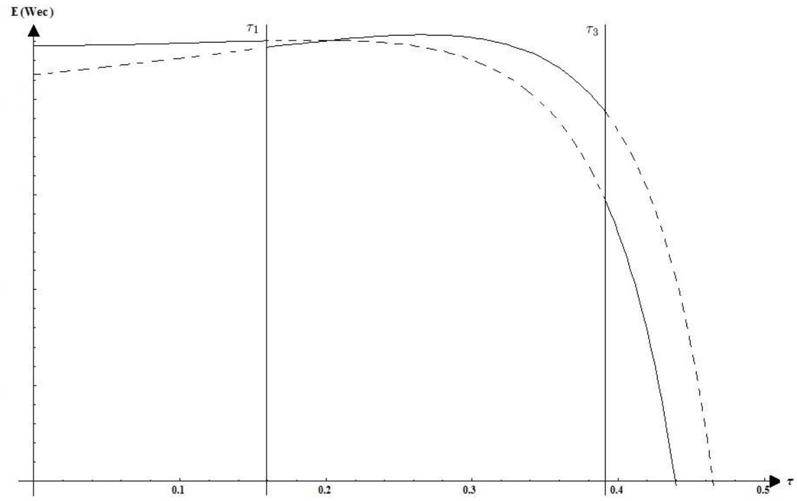
The welfare function is represented by the solid lines, and the two vertical lines correspond to the τ thresholds for switching and investing. When $\tau < \tau^{th}$ the electricity firm chooses to invest in a gas plant and never switches back to coal. Even though the higher the uncertainty (τ) the smaller the investment (see Section 2.3.3), 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.2.7, 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 2.7: 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.

2.5 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 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 (*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.

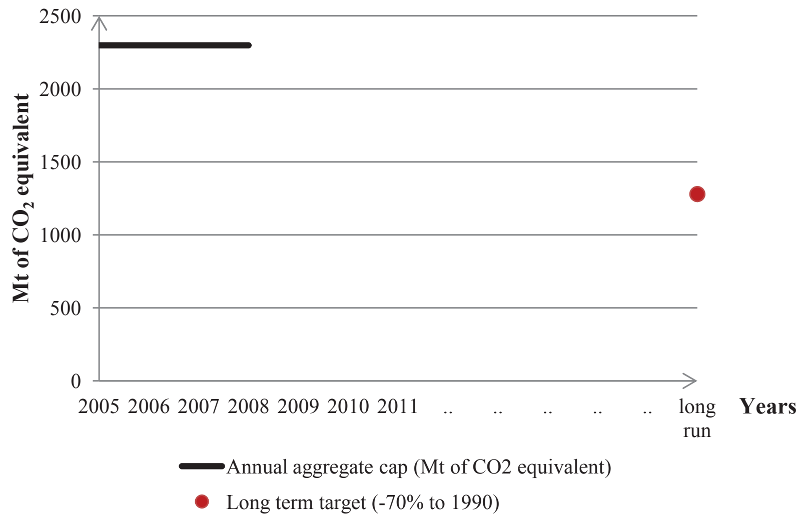
Until 2008 the authority opted for a grandfathering type of allocation, namely based on historical emissions levels, but from 2013 the scheme will move towards an allocation rule based on benchmarking and auctioning.[35] The total amount of the allocated permits constitutes the cap. Both the cap and 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.2.8-2.10 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

[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.

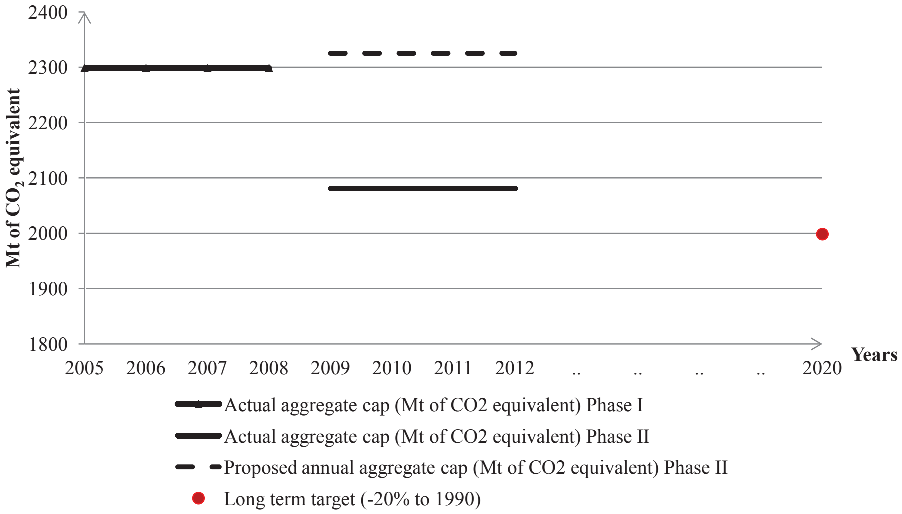
[35]This additional feature should not change our results. In fact, assuming that the auction revenues are redistributed by the authority as lump sum to the same firms, the regulator's objective function is not affected.

Figure 2.8: Annual aggregate cap as known in 2003. Source: European Commission.



in emissions of 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. The only cap set precisely was that of the first phase, 2005-2007 (Fig.2.8). 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 period 2008-2012 was set to 2177MtCO_2, thereby correcting the previously announced one (dashed line in Fig.2.9). 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.2.10, 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 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 con-

Figure 2.9: Annual aggregate cap as known in 2007. Source: European Commission.

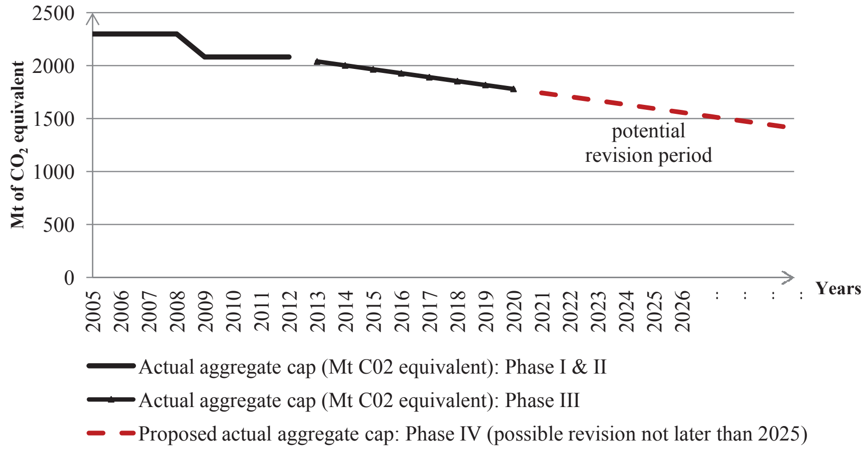


tinue beyond 2020 but may be subject to revision not later than 2025". As underlined above, given the long term nature of low-carbon investments (around 15 years), this uncertainty over the policy instrument, the cap, may affect aggregate investment.

2.6 Appendix 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.

Figure 2.10: Annual aggregate cap as known in 2010. Source: European Commission.



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%

Table 2.2: Coal and gas in the energy mix. Source: Enerdata and IEA.

2.7 Appendix 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 index. Therefore (α_2)is the defined as $\sum_{j=1}^{4} p_j v_j$, where j is the industry index, p_j is the output price of industry j, and v_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: $v = 0.78$, $p = 70$ Euro/t; Steel UK industry: $v = 1$, $p = 400$ Euro/t; Aluminium UK industry: $v = 0.7$, $p = 1800$ Euro/t; Pulp EU industry:[37] $v = 0.83$, $p = 480$ 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.

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

[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.

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.

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Chapter 3

Does Internationalization Pay Off When Environmental Policy Tightens?

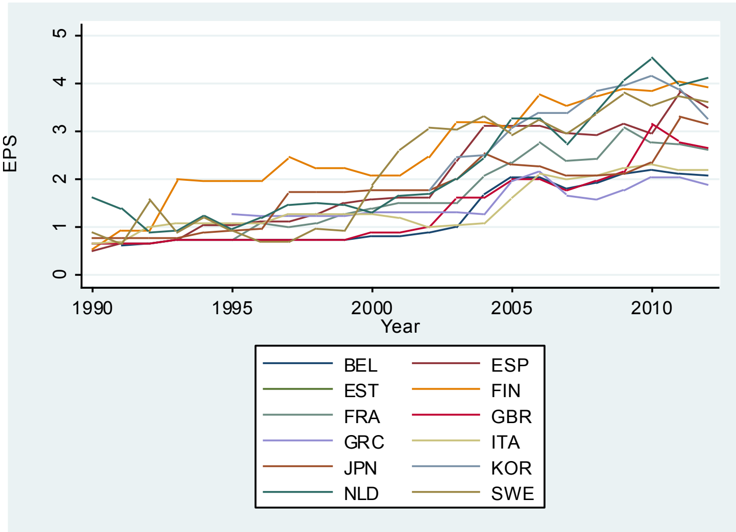
3.1 Introduction

During the last decades governments have increasingly tightened environmental policy, using a diversified portfolio of instruments. Figure 3.1 reports the evolution of environmental policy stringency (EPS) over time for a sample of 11 OECD countries.[1] The upward trend in EPS comes as a response to the increasing awareness of the environmental and economic damages associated with the current production processes and increasing demand to tackle these problems.

By affecting firms' investment choices, production and resource allocation, an EPS tightening is likely to affect firms' economic performance, namely multi-factor productivity growth (Albrizio, Koźluk, and Zipperer. (2014)). On the one hand, environmental policies imply an additional burden for firms. As firms devote resources to comply with the regulation their productivity growth may decrease. Affected firms might react by moving part of their polluting activities to countries with lax environmental regulation (Pollution Haven Hypothesis (PHH)). On the other hand, environmental policies provide incentives for efficiency improvements in energy or waste, which in turn could lead to productivity gains (Porter Hypothesis - Porter (1991); Porter and van der Linde (1995)). These effects might be amplified by firms' international linkages such as international ownership: multinational firms may have additional instruments than domestic ones to cope with the costs and incentives associated with a tightening in EPS. Similar to profit shifting behaviors associated with tax evasion (Maffini and Mokkas (2010), Johansson, Sorbe, and Skeie (2014)) multinationals may elude domestic environmental

[1] The EPS index, developed by Botta and Koźluk (2014), is based on the aggregation of quantitative and qualitative information on environmental policy instruments into one comparable, country-specific measure of environmental policy stringency. See the data section for detailed description.

Figure 3.1: EPS index, country-specific measure of environmental policy stringency, Botta and Koźluk (2014)



regulation. International ownership may facilitate cross-country reallocation processes allowing multinationals to offshore part of their production to foreign affiliates. Additionally, multinationals can exploit intra-group R&D and know-how in efficient and clean technologies, which lowers costs and speeds up technological implementation.[2]

This paper assesses whether there exists a statistically-significant difference in multifactor productivity growth between multinational and domestic firms when they face a tightening of environmental policy. This question is of particular relevance for the design of environmental polices. In fact such heterogeneous effect on productivity may pose concerns on the effectiveness of environmental regulation if multinationals offshore the most polluting parts of the production process and elude domestic regulation. Moreover, by affecting the country's productivity growth distribution, environmental policy stringency may eventually affect the country's competitiveness. This paper finds that MNEs experience higher productivity growth than domestic firms when environmental policies tighten. This result is corroborated by using two alternative industry-level proxies for internationalization: a measure of participation in global value chains and the foreign intermediates outsourcing index. Production processes are increasingly

[2]Costs include: information effort, patents, cost of pilot tests for implementability, etc.

re-organised within the so-called global value chains (GVCs), where different production stages are located across different countries sometimes regardless of firms' ownership structure. "In a global value chain, production is subdivided into fine slices of specialization along the chain, that leads to trade across international boundaries in order to take advantage of efficiencies in different jurisdictions" (Baldwin and Yan (2014)). Similarly to international ownership, firms participating in GVCs may outsource relatively more polluting activities to countries with less stringent environmental regulation (OECD (2013)). In terms of R&D spillovers and efficiency gains, GVC participation may also help firms to capitalize on technology spillovers from other suppliers and custumers in the chain and to scale up investments in abatement. The foreign intermediates outsourcing index captures the foreign intermediate intensity and it is constructed as the share of imported intermediates in the total intermediates expenditure. As for the other internationalization measures, a high level of the index would imply higher possibilities of offshoring polluting intensive activities, reaching comparative cost advantages. The findings from the analysis using the three different internationalization indexes (MNE, GVC and intermediate outsourcing) point in the same direction. They all confirm the hypothesis that international firms have additional instruments to cope with EPS and pave the way for future research to identify the prevailing mechanism: (i) offshoring parts of production to elude EPS or (ii) investing domestically in energy efficiency in order to capitalize on technological spillovers and economies of scale.

This paper is structured as follows: Section I provides an overview of the related literature. Section II describes the data and provides descriptive statistics across groups (multinationals and domestic firms). Section III explains the empirical specification and section IV reports the main results. Section V reports robustness checks and tests an additional hypothesis. Section VI concludes.

3.2 Literature

Two strands of literature look at issues related to the effect of environmental policies on productivity and firms' choices. However, neither tend to pay much attention to the heterogeneous effects across firms, and none of the papers looks at the effect of EPS on productivity conditional on international links. On the one hand, firm and industry studies examine the effect of EPS on productivity growth, but they do not differentiate firms according to international ownership. On the other hand, literature distinguishing between international and domestic dimensions have mainly focused on testing the Pollution Haven Hypothesis (PHH).

Early studies on firm or plant level MFP growth show a negative but not robust effect of environmental regulation on productivity growth. Most of the studies compare productivity growth between regulated and non-regulated firms or plants, finding negative (Gollop and Roberts (1983), Smith and Sims (1985)) or insignificant (Berman and Bui (2001)) results. One of the shortcomings of these studies is the lack of firm or plant specific controls in the analysis. Becker (2010) and Gray (1987) show that firms' specific characteristics are a relevant factors for the analysis, which would lead to a bias if omitted. Moreover, these studies suffer from a lack of generality, as very specific regulations or industries are analyzed in a single country setting. More recent contributions, that use cross country evidence and time series dimension (Albrizio, Koźluk, and Zipperer. (2014)), have found a positive and robust effect of environmental policy stringency on productivity growth for the most productive industries and firms, and a negative effect for the firms lagging behind the global technological frontier. More technologically-advanced firms are often the largest, therefore they are more likely to have the resources to invest in R&D as well as in abatement technologies and scale up these investments. Given that the distribution of the MNEs is concentrated close to the frontier, the results of Albrizio, Koźluk, and Zipperer. (2014) provide motivation and support for the hypothesis tested in this paper.

Empirical literature testing the PHH is based on gravity models or estimates reduced-form specification (Levinson and Taylor (2004), Cole and Elliott (2003), Ederington, Levinson, and Minier (2003), among others). Due to lack of data on intra-group trade at firm level, most of the contributions consider FDI or imports as dependent variable and use abatement cost as proxy for EPS.[3] Both approaches tend to control for costs that affect firms' relocation choices on top of the environmental regulation's burden: labour and capital costs, transportation costs and tax effort. Additionally, distance and market size are often included. Within this set-up, contributions focusing on MNEs find mixed evidence for the PPH. Looking at outbound U.S. investment between 1982 and 1993, Es-

[3] A common proxy for EPS is the Levinson (2001)'s relative abatement costs measure.

keland and Harrison (2003) do not find robust results supporting the PHH. These results might be affected by the small sample size, the poor proxy for stringency used, or, as the authors point out, the complementarity between capital and abatement: if domestic abatement lead to energy efficiency gains, the final domestic investment cost might be smaller than the cost of moving production abroad (FDI). Differently from Eskeland and Harrison (2003), Millimet and Roy (2011) find strong and negative effects of environmental regulation on FDI, in particular for pollution-intensive industries. The authors look at 48 contiguous U.S. states from 1977-1994, and consider two FDI measures: the value of gross property, plant and equipment of foreign-owned affiliates and the employment at foreign-owned affiliates. As for GVCs there are no contributions relating firms' economic performance and EPS within a GVC framework of analysis.

The contribution of this paper is twofold. Differently from previous literature, it uses a cross-country panel and the focus is not restricted to a specific regulation or channel. This approach allows us to understand whether internationally integrated firms have a comparative advantage in adjusting to tighter environmental regulations. This is a first step in uncovering the trade channel of the productivity effect of EPS and the findings add scope for future research in this direction. Secondly, this is one of the first papers that employs a cross-countries and time varying index of EPS, which reduce measurement and identification concerns with respect to previous contributions.

3.3 Data

3.3.1 Firm productivity data

The multi-factor productivity index is constructed using the OECD-ORBIS database[4] and following the approach of Wooldridge (2009). Built on Levinsohn and Petrin (2003),

[4]The OECD-ORBIS dataset has been developed by Gonnard and Ragoussis (2012) on the Bureau Van Dijk (BvD) ORBIS dataset. This paper is part of an OECD broader project on environmental policy stringency and economic outcomes, therefore the paper is based on a byproduct of the OECD-ORBIS dataset generated in July and August 2012. Consolidated national and cross border accounts are dropped in order to to avoid double-counting. Thus the dataset includes unconsolidated firm level data.

Wooldridge's production function estimation is a one-step procedure that attempts to solve the capital measurement issue (Ackerberg, Caves, and Frazer (2006)).[5] The panel includes 11 OECD countries and 22 manufacturing sectors over a ten-year time span (2000-2009). The countries included are: Belgium, Finland, France, Greece, Italy, Japan, Korea, Netherlands, Spain, Sweden and United Kingdom. The sample covers manufacturing industries (2-digit, NACE Rev. 1.1, industries from 15 to 37). As usual praxis, the 1st and 99th percentile of the distribution are dropped as they are considered outliers. Growth rates are log-differences of two consecutive periods.

3.3.2 Ownership structure

Following Menon (2014) "a business group can be defined as a set of at least two legally autonomous firms whose economic activity is coordinated through some form of hierarchical control via equity stakes (Altomonte and Rungi, 2013)". Therefore, international ownership refers to any situation in which a firm is controlled, or controls, at least one foreign firm by more than a certain participation threshold. Menon (2014) identifies three thresholds: a "low" one which corresponds to 10 percent of participation shares or more (MNEs 10), a "medium" one, if the participation is 50 percent or more (MNEs 50) and a "high"one if the participation is 90 percent or more (MNEs 90). The algorithm used to compute the ownership structure is based on data for the year 2009, thus the econometric analysis in this paper uses a time invariant definition of MNEs. This feature may lead to a measurement error when a firm is classified as multinational based on 2009 information, while previously it was actually domestic. This said, it is a fair assumption to consider a time invariant MNEs classification for the sample of OECD countries considered in between 2000 and 2009.

The unbalanced sample consists of 592,778 observations, 394,451 firms with an average spell of 4.3 years. MNEs are 9% of the sample, 15% are domestic groups and the rest are standalone domestic firms. According to the three definition of MNEs, Table 3.1 shows that, in the sample, there are 33,807 MNEs under the low ownership threshold and 18,819 under the high one.

[5]See Gal (2013) for a detailed and comprehensive discussion on the construction of the MFP measures as well as on the dataset.

Table 3.1: Sample composition (MNEs and domestic firms)

	N. of firms			N. of observations		
	MNEs	Domestic	Share(%)	MNEs	Domestic	Share(%)
MNE 10	33807	353591	9.56	180468	1444074	12.50
MNE 50	24522	362876	6.76	132807	1491735	8.90
MNE 90	18819	368579	5.11	102439	1522103	6.73

3.3.3 Environmental policy stringency and industry environmental dependence

This paper is based on a new composite index of environmental policy stringency (EPS) developed by the OECD (Botta and Koźluk (2014)). The indicator aggregates information on national stringency across 15 policy instruments for the energy sector, transport sector and refund schemes (waste). It covers most of the OECD countries over the period 1990-2012 and it ranges between 0 and 6, where the highest stringency corresponds to the maximum value (6). Despite the fact that the EPS index is built on only three sectors, it is highly correlated with other available measures of a country's overall environmental policy stringency (CLIMI and WEF index). [6] Therefore, this index can be seen as a good instrument for overall policy stringency. From an econometric perspective, using an EPS proxy based on sectors that are not included in the analysis (such as energy, transport and waste) helps to decrease endogeneity concerns. To check for reverse causality, an ordered probit on aggregate data is run to test whether MFP growth can help to forecast future EPS changes (Mertens and Ravn (2012) and Albrizio and Lamp (2014)). The indicator variable takes the value one if there is a tightening of EPS, zero if there is no change and minus one if there is a negative change. Assuming that the regulator would base policy stringency decisions on the level of the emissions, on the growth of the economy and on technical change, the additional covariates used are: lagged economic growth (GDP growth rate), green house gases, shifts in technolog-

[6]The CLIMI Index (Climate Laws, Institutions and Measures Index) produced by the EBRD it is a cross-country index for 2012 which builds on UN country reports and UNFCCC submissions reports. The World Economic Forum (WEF) measures perceived environmental policy stringency through a survey of business executives.

ical frontier capturing the availability of new and more efficient technologies (proxied by MFP growth of the leader - top performer country by year), as well as a variable to account specifically for the innovation effort in clean technologies (the ratio of green patents over the total patents application in each country).[7] Country fixed effect are included, and one to two-lags specifications are tested. Results lead to reject the hypothesis that past MFP growth can help to explain future EPS changes. On the contrary, past innovation efforts (green patents), shifts in technological frontier as well as past levels of GHG are good predictors of future environmental policy tightenings. Annex I provides the descriptive statistics of the variables used and the results.

As in Albrizio, Koźluk, and Zipperer. (2014), EPS is allowed to affect MFP growth differently according to the environmental dependence (ED) of the individual industry. The underlying assumption is that higher environmental dependence (proxied by pollution intensity) increases industries' exposure to a country's environmental regulation and hence the potential economic effects of the EPS on that specific sector are stronger. To account for this feature, following Rajan and Zingales (1998), the policy variable (EPS) is interacted with an index of industry pollution intensity. This index is constructed using US manufacturing sector data in 1987. United States is chosen as reference country, for two reasons: first it can be considered a good proxy for the pre-sample status quo of technology in the OECD countries included in the analysis;[8] and secondly it reduces endogeneity concerns with respect to a time-varying and country-specific sectoral pollution intensity.[9]

Annex I provides additional details on the methodology used to construct the EPS

[7]Data Source: OECD Statistics.

[8]Due to data unavailability at country-level the validity of this proxy cannot be fully verified, but at least the estimate can be seen as a lower bound for the EPS effect.

[9]This approach has two shortcomings that have to be kept in mind: the first is that using 1987 US values for all the countries considered could represent a source of measurement error and attenuation bias. Secondly, the US environmental policies prior to 1987 are likely to be reflected in the structure and the technology choices of US manufacturing sector generating a bias compared to the other countries where these policies were not in place. Albrizio, Koźluk, and Zipperer. (2014) test the robustness of their results using energy intensity instead pollution intensity and the results are unchanged. Energy dependence is calculated as the share of energy input in production and can be found in the input-output tables

and the ED index as well as summarizing charts.

Table 3.2 provides descriptive statistics of the main variables of interest across the four groups identified: domestic firms, MNE 10, MNE 50 and MNE 90. Given the skewness that characterizes these distributions, the median is a more meaningful statistic for comparison. MNEs are generally bigger and more likely to be technologically advanced, namely close to the technological frontier. In terms of environmental policy changes, tightenings are on average the same across groups.

DTF is the distance to technological frontier, where the latter is defined as the average MFP of the top 5% of firms' MFP distribution by industry across the countries considered in the sample. EPS change is a three year moving average of the change in the EPS index (see next section for details).

Table 3.2: Descriptive Statistics (MNEs)

	MFP(g)	DTF	Employees	Turnover(g)	EPS change
Domestic firms					
mean	0.00	2.89	25	0.04	0.11
median	0.01	2.53	10	0.02	0.11
sd	0.24	1.40	102	0.26	0.12
min	-1.08	0.01	1	-7.84	-0.14
max	0.96	10.24	25266	8.12	0.50
MNEs (10)					
mean	0.00	2.66	211	0.03	0.11
median	0.00	2.19	65	0.02	0.11
sd	0.26	1.55	961	0.26	0.11
min	-1.08	0.01	1	-7.63	-0.14
max	0.96	9.90	183395	7.57	0.48
MNEs (50)					
mean	0.00	2.67	258	0.03	0.11
median	0.01	2.18	82	0.02	0.11
sd	0.26	1.58	1111	0.26	0.11
min	-1.08	0.01	1	-7.63	-0.14
max	0.96	9.90	183395	7.56	0.48
MNEs (90)					
mean	0.00	2.71	288	0.02	0.11
median	0.01	2.21	91	0.02	0.11
sd	0.26	1.60	1238	0.27	0.11
min	-1.08	0.02	1	-7.63	-0.14
max	0.96	9.90	183395	7.56	0.48

3.4 The Econometric Model

The econometric specification is based on a Neo-Schumpeterian model of multi-factor productivity growth. MFP growth is the results of two forces: the pass-through effect, namely the spillovers from the technological frontier, proxied by the industry's leader MFP growth, and the catch-up effect, which consists of the convergence in growth rates proxied by the distance to the frontier (Acemoglu, Aghion, and Zilibotti (2002); Aghion and Howitt (2006); BourlÃs, Cette, Lopez, Mairesse, and Nicoletti (2013); Nicoletti and Scarpetta (2003)). This literature shows that regulation may have a heterogeneous effect on productivity growth depending on the degree of technological advancement of firms. Following these previous contributions and Albrizio, Koźluk, and Zipperer. (2014), environmental policy stringency is interacted with the distance to the industry global frontier.

International ownership data is used to test whether multinationals experience higher MFP growth than domestic firms when facing an EPS tightening. The hypothesis is tested against the three definitions of MNEs as defined by the participation threshold. The rationale is that frictions in technological spillovers, in production shifting and in intra-group trade decrease when international ownership linkages are stronger, namely when firms' international participation shares are higher. Therefore, this differential effect is captured by interacting the EPS index with dummies that distinguish between domestic (independent and group), if the dummy is zero, and multinationals, if the dummy equals one, according to the three thresholds ($D_m = 1$, where $m = 10, 50, 90$) .

$$\begin{aligned} \Delta lnMFP_{cijt} &= \alpha_1 \Delta lnM\tilde{F}P_{it} + \alpha_2 gap_{cijt-1} + \alpha_3 E\bar{P}S_{cit-1} \\ +\alpha_4 E\bar{P}S_{cit-1} gap_{cijt-1} &+ \alpha_5 E\bar{P}S_{cit-1} D_m + \alpha_6 (Tax_{ct} - AveTax_{jt}) D_m \\ &+ \mathbf{x}_{cijt} + \eta_t + \delta_{ci} + \epsilon_{cijt} \\ m &= 10, 50, 90 \end{aligned}$$

$\Delta lnM\tilde{F}P_{cijt}$ is the multi-factor productivity growth of firm j in country c, industry i at time t. The first term of the above equation is the growth of the leader MFP and represents the technological pass-through.[10] The second term is the distance to the frontier,

[10]The frontier is defined as the top 5% most productive firms in each industry and these observations are

gap= $\ln(\tilde{MFP}_{it}/MFP_{cijt})$, which allows for the technological catch-up effect.[11] The third term, $\bar{EPS}_{cit-1}$, is the three-year moving average of the change of the country's EPS, from $t-1$ to $t-3$ and captures the tightening of "industry weighted" environmental policy stringency.[12] Following Albrizio, Koźluk, and Zipperer. (2014), changes of the EPS index (rather than levels) are used for two reasons. From a conceptual point of view, effects on productivity growth are likely to be driven by changes in the environmental policy stringency, while a static level of environmental regulation *per se* (seen as a difference in relative prices of inputs) will not induce changes in the production process of firms. However, firms will react to new policy implementations by investing into abatement capital or re-thinking their production processes. Statistical tests indicate non-stationarity of the EPS index, leading to the use of first difference.[13] The fourth term allows for nonlinear effects of the policy as a function of the technological gap. The two following interactions capture the additional effect of EPS on multinationals ($D_m = 1$). To enrich the analysis, given recent evidence of profits shifting behaviors due to tax evasion (Maffini and Mokkas (2010), Johansson, Sorbe, and Skeie (2014)), the specification controls for the difference between the domestic statutory tax and the average tax that firm j faces due to its multinational linkages (MNE's average group tax). $\mathbf{x}_{cit}$ is a vector of additional controls (GDP HP filter to control for output gap, R&D expenditures at industry level, demand shocks (past turnover growth, proxied by log assets), firm size (log employment), regulatory impact,[14] employment protection (OECD EPL) and current account openness[15]). Country and industry fixed

not included in the analysis.

[11]Note that observations of firms at the frontier are excluded from the analysis.

[12]As mentioned country's EPS tightening is interacted with pre-sample industry environmental dependence (ED).

[13]Notice however that the index is bounded by definition in between 0 and 6. A specification with EPS level has also been tested but it results not to have a robust and significant effect on industry MFP growth. The three-year moving average structure accounts for potential delays in policy implementation as well as for time gap it can take for firms to react. These may depend on various industry, country and policy characteristics, hence a moving average approach is likely an appropriate option.

[14]OECD Indicators of Regulation Impact measures the potential costs of anti-competitive regulation in selected non-manufacturing sectors on sectors of the economy that use the output of non-manufacturing sectors as intermediate inputs in the production process.

[15]Chinn-Ito index measuring a country's degree of capital account openness. It is based on the binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions reported in the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER).

effects control for countries' institutional differences, sectoral regulations and characteristics, such as industry specific transportation costs. Additional robust checks using country-industry dummies are included and standard errors are clustered at firm level.

3.5 Results

Table 3.6 reports the results of the main specification. Column (1) shows the effect of a tightening of EPS without considering international ownership. Column (2) to (4) include the three definitions of MNEs (10,50,90) respectively. Country and industry dummies are included. Table 3.7 reports the results of the analysis with country-industry fixed effects. All specifications include the full set of controls, however, results are robust including firms and country controls separately.

Insert Table 3.6 and Table 3.7 here

Considering both types of fixed-effect specifications, estimates highlight a stronger effect of a tightening of EPS for multinationals than for domestic firms. As an example, when considering firms at the frontier, an average change in the EPS equal to 0.11[16] is associated with approximately 1% increase in the rate of MFP *growth* for domestic firms while the same effect for multinationals (with more than 50 percent of international participation) is 1.6%. Figure 3.2 reports the marginal effect of 1 point change in EPS as function of the DTF (x-axis):

$$\frac{\partial \Delta \ln MFP_{cijt}}{\partial \bar{EPS}_{cit-1}} = \alpha_3 + \alpha_4 gap_{cijt-1} + \alpha_5 D_m$$
$$m = 10, 50, 90$$

The effect is significantly different from zero only for firms within the 50th percentile to the frontier. Figure 3.3 shows that most of the distribution of the distance to frontier for MNEs 50 lies on the left side of the corresponding limit for the significance of the effect (2.45). Actually 65% of MNEs are within this limit.[17]

As shown in Table 3.6 and 3.7, the effect is higher and more robust for firms with medium and high international ownership (MNEs 50 and 90).[18] This evidence suggests

[16] This is the mean over the previous three years of change in EPS across countries/industries and years.
[17] An alternative specification where the effect of EPS varies with the DTF also for MNEs has been tested but results show that this effect is not significantly different from the one observed for domestic firms.
[18] Additional estimations are run on a two-year moving average MFPg and confirm the results

Figure 3.2: Marginal effect of EPS tightening on MFP growth.

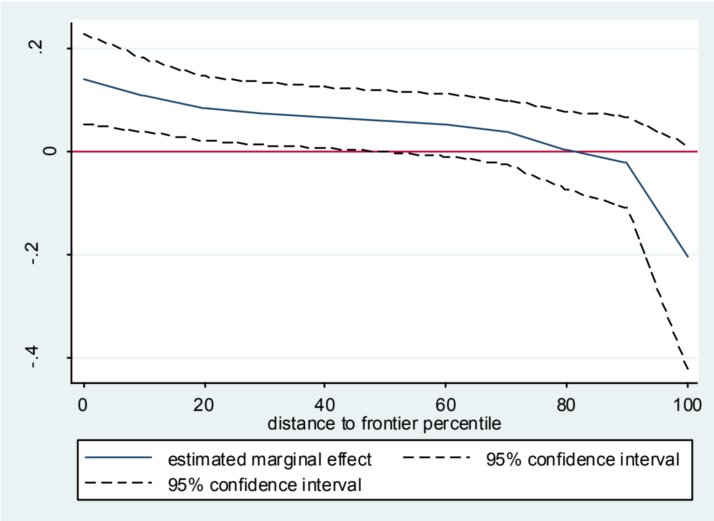
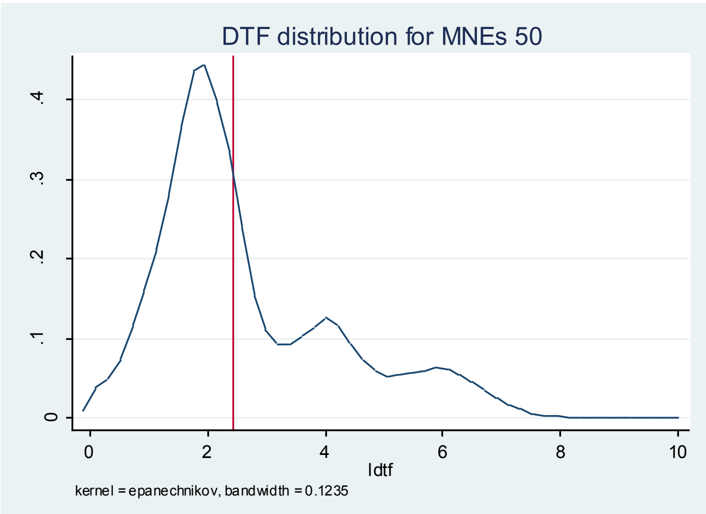


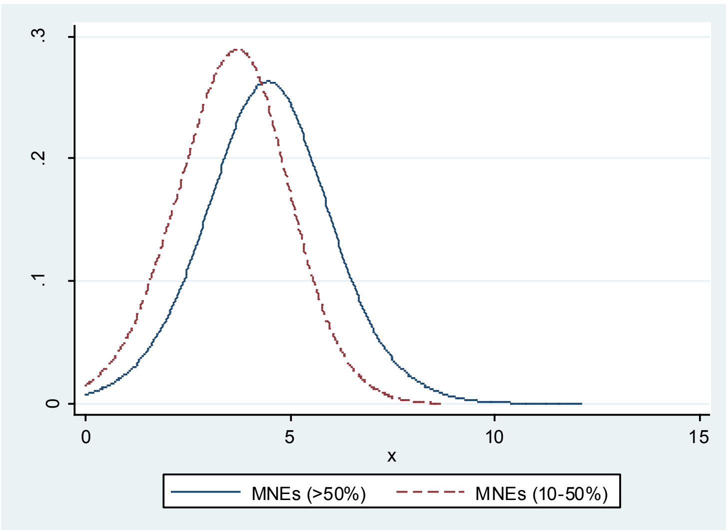
Figure 3.3: Distribution of the distance to frontier (MNEs 50).



a non-linear relationship of EPS and internationalization on productivity: only firms with high participation can actually exploit additional opportunities that allow them either to reach efficiency gains or to elude the domestic regulation. To investigate further

this difference, statistical properties of the main observables for two different groups of multinationals are presented: firms with medium international participation (> 50%) and firms with low linkages (between 10 and 50 percent). Statistics are reported for size, turnover growth, sectoral composition, EPS tightening exposure,distance to frontier and country composition over the two groups.
Basic statistics (Table 3.3) and kernel densities (Figure 3.4) suggest that the only observable difference between the two groups is the size (both number of employees and asset turnover): MNEss are on average bigger than MNEsw. In terms of the other covariates, the groups experience the same policy shocks and turnover growth. This evidence is confirmed by Kolmogorov-Smirnov tests and suggests that size, namely capacity and availability of resources, might allows firms to capture investment opportunities and scale-up energy efficiency gains. Considering sectoral composition there are no significant differences across the two groups. While looking at country composition, Italy has an extraordinary high portion of weak MNEs.[19]

Figure 3.4: Size distribution (MNEs 10-50 versus MNEs >50).



[19]As a robustness check Italy is dropped from the sample and the results are unchanged.

Table 3.3: Descriptive Statistics (MNEs 10-50 versus MNEs >50).

	Mean	Median	St.Dev.
MNEs (>50%)			
mfpg	-0.00958	0	0.25
ldtf	2.65	2.20	1.57
EMPLOYEES	276	91	1020
employ	4.52	4.51	1.43
assetg	0.024	0.021	0.252
EPS change (MA)	0.11	0.10	0.10
MNEs (10-50%)			
mfpg	-0.01871	-0.00061	0.25
ldtf	2.63	2.22	1.42
EMPLOYEES	91	46	185
employ	3.79	3.82	1.19
assetg	0.038	0.028	0.219
EPS change (MA)	0.11	0.10	0.10
Total			
mfpg	-0.01184	0	0.25
ldtf	2.65	2.21	1.54
EMPLOYEES	230	76	893
employ	4.34	4.33	1.41
assetg	0.027	0.023	0.245
EPS change (MA)	0.11	0.10	0.10

Main statistics (mean, median, sd) are reported for the variables of interests accordingly to the two groups of MNEs (between 10 and 50% of international participation and above 50%). The variables reported are: multi-factor productivity growth (mfpg), distance to frontier (ldtf), EMPLOYEES (number of employees), employ (logarithm of the number of employees), turnover growth (assetg), three-year moving average of the change in EPS (EPS change (MA)).

3.6 Robustness checks and additional hypothesis

International ownership is not the only internationalization option for firms. This section provides further and robust evidence of the effect found by using two alternative industry-level measure of internationalization: a measure of participation in global value chains and the foreign outsourcing index.[20]

3.6.1 Integration in the global market

Global value chains have radically changed the organization and location of production processes. Baldwin and Yan (2014) report that in 2003 54% of the world's manufactured imports where actually intermediates (OECD data). The increasing fragmentation of the production into stages of the value chain as well the dispersion across countries provide firms with opportunities to elude environmental regulation through offshoring, or to capitalize on knowledge spillovers and to scale up energy-efficiency investments. Although MNEs still play an important role within the GVCs (OECD (2013)), international ownership is not a prerequisite and small-medium enterprises play an important role, in particular, in niche markets. Therefore, the analysis tests whether interacting the EPS change with a dummy for high GVC participation, as an alternative measures for internationalization, confirm the productivity effect of EPS tightening found using international ownership share. To identify which sectors have higher international decentralization of the intermediate stages of the production and consequent trade in intermediates, the index of foreign value added embodied in domestic final demand as a percentage of GDP (total value added) is ranked across sectors. This ratio is part of the OECD-WTO Trade in value added database (TiVa 2013) and provides information on how industries abroad (upstream in a value-chain) are connected to domestic demand and this ratio can most readily be interpreted as 'imports of value-added' (OECD-WTO TiVa 2013). Data are available for the following years: 1995, 2000, 2005, 2008 and 2009. Due to potential bias caused by the recent crisis, only the sectoral shares for 2005 are averaged across countries by industry.[21] This allows to divide the industry sample into two groups: industry with imports in domestic value-added which are more/less than the

[20]Table 3.5 in the Appendix reports the correlations across the main variables of interest.

[21]The groups would not change considering the mean over three years (1995, 2000, 2005), as the thresholds are practically the same, see Table 3.4.

50th percentile of the industry share distribution across countries (which corresponds to less than 1% of GDP). The "high GVC" group includes manufacturing of chemical, rubber, plastics and fuel products (2325), other non-metallic mineral products (2600), basic metals and fabricated metal products (2728), machinery and equipment (2933), transport equipment (3435); while the "low GVC" industries are textiles and footwear (1719), wood (2000), pulp, paper and printing (2122) and manufacturing n.e.c. and recycling (3637).[22] The former groups is expected to be able to experience relative cost advantages, and consequently higher productivity, due to higher offshoring possibilities from the GVC structure.

Table 3.8 reports the results of the main specification with the additional interaction between EPS changes and the dummy for industry with high foreign upstream participation. Column (1) does not include international ownership, while columns (2)-(7) add the MNEs dummies. The average positive effect of a tightening in EPS is still present and robust. Additionally the EPS effect in sectors with high share of foreign upstream participation in the production process is associated with higher MFP growth independently from the international ownership structure.

Insert Table 3.8 here

As a robustness check on the group definition, alternative GVC participation indexes has been considered. Sectors have been grouped according to two indexes from the OECD Global Value Chain database: the index of the number of international production stages and the participation index. According to the GVC dataset, the first indicator "measures the length of production processes when the intermediate inputs for the realization of a final product or service are sourced from foreign countries", while the second one, "as proposed by Koopman, Powers, Wang, and Wei (2010), is expressed as the share of foreign inputs (backward participation) and domestically produced inputs used in third countries' exports (forward participation) in a country's gross exports". The rationale is similar to the previous exercise: if a sector has a higher number of stages performed internationally or a high participation in GVCs, it may have additional opportunities of cost reduction compared to less globally integrated productions.

[22]TiVa has a different sector categorization than NACE 2, thus ad hoc adjustments have been made to match the two databases.

Moreover, a firm participating in GVCs may learn from foreign markets both directly, through buyer-seller relationships (learning by importing or exporting), and indirectly, through increased competition from foreign producers (Loecker (2010) and Gu and Baldwin (2005) among many others). Table 3.4 shows that the 50th percentile for each of the variables considered to build up the groups. Based on this criteria (median across countries by sector) the resulting groups' composition is invariant.

Table 3.4: GVC indexes.

Variable	Obs	Percentile	Centile
Foreign VA in domestic final demand (% of GDP) in 2005	297	50	0.96
Number of international production stages in 2005	297	50	0.59
Participation in 2005	297	50	2.34
Foreign VA in domestic final demand (% of GDP) - average	297	50	1.12
Number of international production stages -average	297	50	0.61
Participation - average	297	50	2.47

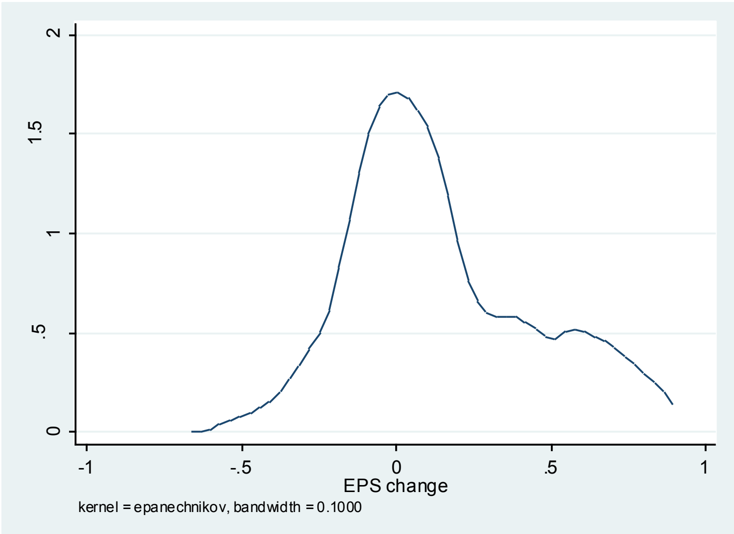
Finally, the same specification is tested by grouping industries according to the foreign intermediates outsourcing index (OECD). This industry index captures the intensity in intermediates use and it is constructed as the share of imported intermediates in the total intermediates expenditure. A high value of the index implies higher flexibility in offshoring intermediates production. Therefore, an EPS tightening is expected to have an additional positive effect on industries with high foreign intermediates outsourcing index: manufacturing of chemical, rubber, plastics and fuel products (2325), other non-metallic mineral products (2600), basic metals and fabricated metal products (2728), wood (2000), pulp, paper and printing (2122). As Table 3.9 shows, the average positive effect is no longer significant. However, the positive additional effect of EPS on MFP growth for international firms is confirmed also under this weaker definition of international linkages, which does not necessarily involve GVC or international ownership. This result proves even stronger the relevance of the trade channel for the productivity effect of EPS.

Insert Table 3.9 here

3.6.2 Additional hypothesis of EPS tightening intensity

This section presents the results of the analysis for different intensities of EPS tightening. The distribution of EPS changes is skewed to the right (Figure 3.5). Considering changes above the 85th percentile still covers 13% of the changes in the sample. Thus in the analysis only EPS changes over the 85th percentile are interacted with the MNEs dummy.[23]

Figure 3.5: EPS tightening distribution.



Insert Table 3.10 here

Table 3.10 shows that high changes in EPS have a positive and strongly significant effect for all three of the definitions on MNEs, differently from Table 3.6 and 3.7, where the full range of EPS changes is considered and the effect on MNEs 10 was only slightly significant. Different explanations for this result may apply. On the one hand, MNEs 10 may increasingly take advantage of their international channel when EPS tightening considerably raises the cost of polluting. On the other hand, it could be that high EPS tightening triggers (costly) investment in abatement which may lead to significant

[23]Different thresholds have been tested: below the 85th percentile the effect is not robust.

technology uptake and to substantial energy efficiency gains due to the complementarity between capital and abatement (Eskeland and Harrison (2003)).[24] However, further investigation is needed to under the channels grounding these results.

3.7 Conclusion

In light of the ongoing environmental policy tightening across OECD countries, this paper studies whether firms' economic performance may depend on their international ownership structure. Multinationals (MNEs) may adjust to an increase in Environmental Policy Stringency (EPS) through the following main channels: offshoring part of their production to affiliates in countries with lax environmental policy, exploiting intra-group technology transfers and scaling-up investments in energy-efficiency. MNEs may consequently experience higher productivity growth than domestic firms that are, instead, not able to exploit such international channels when facing an EPS tightening. Using a panel of 11 OECD countries and 22 sectors over the period 2000-2009, the analysis finds that the estimated effect of a change in EPS for the most productive multinational firms is 60 percent higher than for domestic firms. This positive effect is confirmed using two alternative measures to approximate the degree of integration in the global market at industry level: participation in global value chains and outsourcing of production of intermediates abroad. Additional evidence shows that larger changes in EPS are associated with higher boosts in MNEs productivity growth, suggesting possible non-linearity of the effect of EPS on productivity.

[24] As pointed out by Eskeland and Harrison (2003), neglecting the possible complementarity between capital and abatement may lead to biased estimates of the effect of EPS on offshoring decisions of firms. Eskeland and Harrison (2003) model shows, in fact, that such complementarity may decrease the opportunity cost of outsourcing production to foreign affiliates. If investments in domestic abatement also lead to substantial energy efficiency gains, the final adjustment cost (investment cost in equipment net of efficiency gains) may end up being smaller than the cost of moving part of the production abroad. Thus, when the EPS tightening is coupled with substantial energy efficiency gains, firms will invest domestically and will not offshore.

3.7.1 Annex I

Ordered probit: data and results

Data included in the probit model are: country multi-factor productivity index (Johansson et al. (2013)) from which the MFP growth of the leader is calculated as the country with the highest MFP in each year; the ratio of green patents over the total patents application under PCT in each country (OECD); the GHG emission level is expressed in billions of tons of CO2 equivalent (OECD).

Variable	Obs	Mean	Std. Dev.	Min	Max
GDPg	457	2.323	2.709	-8.538	10.730
GHGtot	462	0.621	1.355	0.011	7.22
MFPg Leader	439	0.005	0.015	-0.016	0.033
patents	255	0.07	0.013	0.056	0.101
MFPg	428	0.003	0.034	-0.192	0.125

Indicator variable: EPS tightening

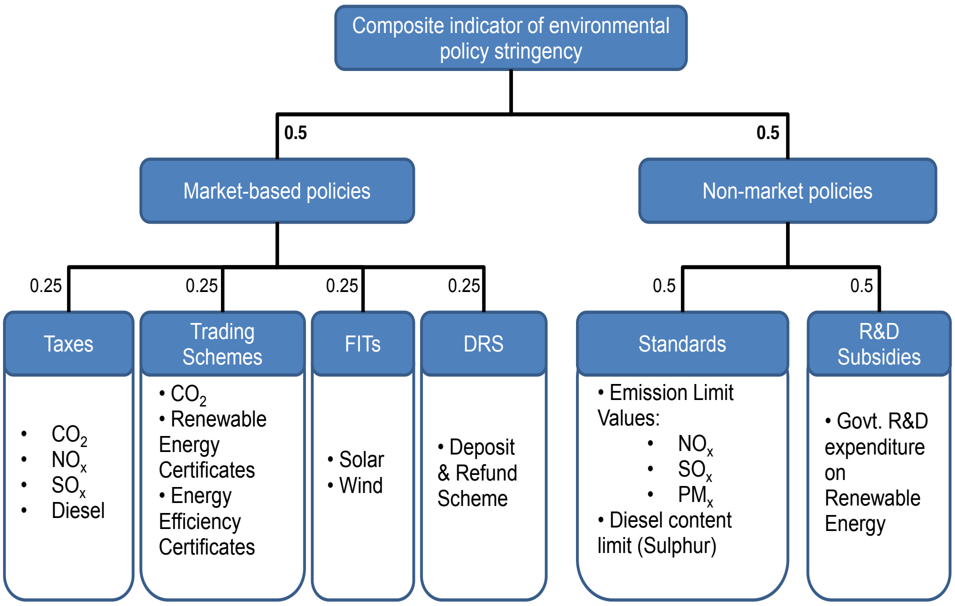
	L.GDPg	L2.GDPg	L.GHGtot	L2.GHGtot	L.MFPg Leader	L2.MFPg Leader
β	0.161	0.258	2.944	14.70***	-17.22	-46.43**
SE	(0.162)	(0.154)	(4.943)	(3.851)	(12.51)	(17.45)

	L.patents	L2.patents	L.MFPg	L2.MFPg	year	N
β	-135.7	628.0***	-12.81	-11.01	-1.010***	200
SE	(72.71)	(133.6)	(10.61)	(10.57)	(0.168)	

Environmental policy stringency

Measures of environmental policies often lack a cross-country and/or time dimension (Dasgupta et al. (1995), CLIMI index (Climate Laws, Institutions and Measures Index) produced by the EBRD, the perceived environmental policy stringency by the World Economic Forum (WEF)). As mentioned, empirical analysis are often base on estimated cost of abatement in order to proxy for stringency. The EPS composite index, used in this paper, summarizes an aggregate environmental policy stringency of selected instruments in a tree-structure (Figure 3.6). The first two branches are market-based instruments, which assign an explicit price to the externalities, versus non-market based ones (taxonomy developed by De Serres et al. (2010)). The first sub-component includes: taxes (CO2, SOX, NOX, and diesel fuel), trading schemes (CO2), renewable energy certificates, energy efficiency certificates, feed-in-tariffs and deposit-refund-schemes. The non-market component consists of standards (emission limit values for NOX, SOX, and PM, and limits on sulphur content in diesel), and technology-support policies, such as government R&D subsidies.

Figure 3.6: Structure of the EPS index.



Industry environmental dependence

Pollution intensity data come from the IPPS Pollution Intensity and Abatement Cost World Bank dataset, which consists of data for US manufacturing sector in 1987. Industries are ranked based on pollution intensity (relative to value added) on seven pollutant categories (two water pollutants, four air pollutants and one toxic substance). The "environmental dependence" is then the simple average of these seven scores, and it can take values from zero (least polluting industry) to 1 (most polluting industry). Figure 3.4 reports the ED index by sectors.

Figure 3.7: Industry Environmental Dependence.

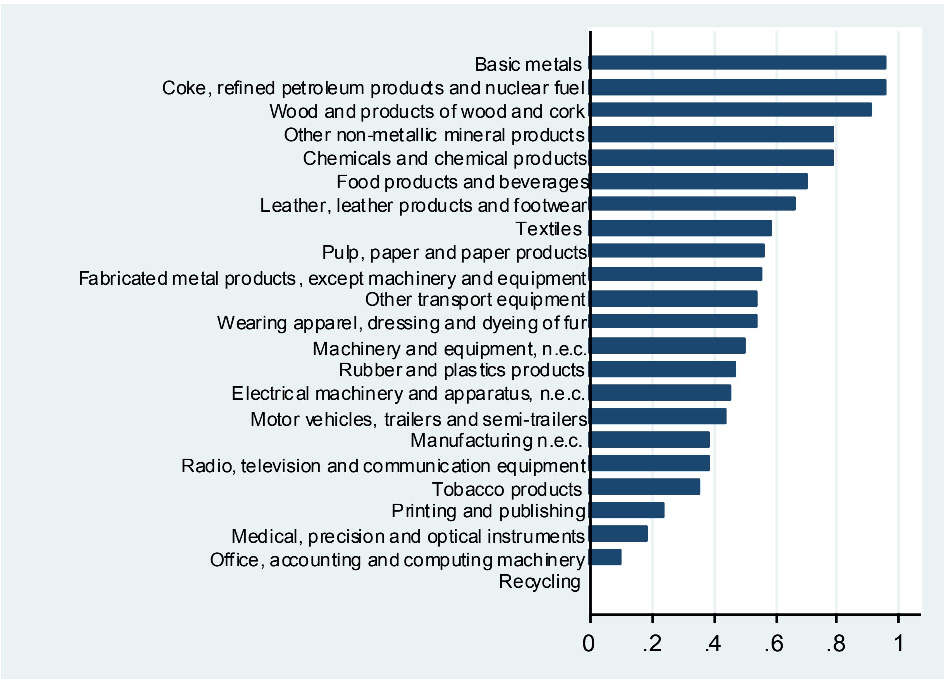


Table 3.5: Correlation among the main variable of interest.

	EPS	DTF	MNEs 10	MNEs 50	MNEs 90	Out	GVC
EPS	1						
DTF	0.8393	1					
MNEs 10	0.2465	0.1515	1				
MNEs 50	0.2125	0.1269	0.8661	1			
MNEs 90	0.1827	0.109	0.7547	0.8717	1		
Out	0.9418	0.8323	0.215	0.1865	0.158	1	
GVC	0.6208	0.677	0.2307	0.2086	0.1818	0.7186	1

The variables in the Table refer to the interactions with the 3-year moving average change in EPS.

Table 3.6: International ownership and EPS tightening (country and industry dummies).

Dependent variable: MFP growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Leader MFP growth	0.041*	0.043**	0.043**	0.043**
	(0.022)	(0.022)	(0.022)	(0.022)
DTF (lag)	0.099***	0.100***	0.100***	0.100***
	(0.013)	(0.013)	(0.013)	(0.013)
EPS tightening (3y ma)	0.096**	0.090*	0.090*	0.091*
	(0.047)	(0.048)	(0.049)	(0.048)
DTF*EPS tightening	−0.035**	−0.034**	−0.034**	−0.034**
	(0.013)	(0.014)	(0.014)	(0.014)
Cycle (lag)	0.667	0.666	0.660	0.661
	(0.616)	(0.621)	(0.621)	(0.621)
Crisis 2008	−0.086***	−0.086***	−0.086***	−0.086***
	(0.011)	(0.011)	(0.011)	(0.011)
Employment (ln)(lag)	0.012***	0.011***	0.012***	0.012***
	(0.002)	(0.002)	(0.002)	(0.002)
Turnover growth (lag)	0.010**	0.010**	0.010**	0.010**
	(0.004)	(0.004)	(0.004)	(0.004)
Capital account openness (lag)	−0.802	−0.735	−0.797	−0.821
	(3.342)	(3.386)	(3.383)	(3.384)
Employment protection (lag)	−0.252***	−0.252***	−0.252***	−0.249***
	(0.051)	(0.052)	(0.052)	(0.052)
Regulatory Impact (lag)	−0.209	−0.203	−0.205	−0.206
	(0.292)	(0.295)	(0.295)	(0.295)
Time trend	0.001	0.001	0.001	0.001
	(0.004)	(0.004)	(0.004)	(0.004)
MNEs 10 (dummy)		0.005		
		(0.003)		
MNEs 10*EPS tightening		0.035*		
		(0.020)		
tax diff (MNE 10)		−0.032		
		(0.046)		
MNEs 50 (dummy)			0.002	
			(0.004)	
MNEs 50*EPS tightening			0.051**	
			(0.024)	
tax diff (MNEs 50)			−0.030	
			(0.048)	
MNEs 90 (dummy)				0.001
				(0.004)
MNEs 90*EPS tightening				0.057**
				(0.026)
Tax diff (MNEs 90)				−0.034
				(0.054)
Observations	511897	505274	505274	505274
R^2	0.063	0.064	0.064	0.064
Country and Industry dummies	Y	Y	Y	Y

* p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses.

Table 3.7: International ownership and EPS tightening (country-industry fixed effect).

Dependent variable: MFP growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Leader MFP growth	0.066***	0.068***	0.068***	0.068***
	(0.019)	(0.019)	(0.019)	(0.019)
DTF (lag)	0.146***	0.149***	0.148***	0.148***
	(0.007)	(0.007)	(0.007)	(0.007)
EPS tightening (3y ma)	0.119**	0.114**	0.113**	0.114**
	(0.052)	(0.053)	(0.053)	(0.053)
DTF*EPS tightening	−0.052***	−0.051***	−0.051***	−0.051***
	(0.015)	(0.015)	(0.015)	(0.015)
Cycle (lag)	0.682	0.701	0.697	0.694
	(0.632)	(0.639)	(0.639)	(0.639)
Crisis 2008	−0.088***	−0.088***	−0.088***	−0.088***
	(0.011)	(0.011)	(0.011)	(0.011)
Employment (ln) (lag)	0.021***	0.019***	0.020***	0.020***
	(0.002)	(0.001)	(0.002)	(0.002)
Turnover growth (lag)	0.016***	0.017***	0.017***	0.016***
	(0.004)	(0.004)	(0.004)	(0.004)
Capital account openness (lag)	0.680	1.010	0.974	0.935
	(4.255)	(4.317)	(4.314)	(4.313)
Employment protection (lag)	−0.297***	−0.298***	−0.299***	−0.296***
	(0.039)	(0.039)	(0.039)	(0.039)
Regulatory Impact (lag)	−0.724	−0.764	−0.774	−0.777
	(0.788)	(0.787)	(0.786)	(0.786)
Time Trend	−0.001	−0.001	−0.001	−0.001
	(0.005)	(0.005)	(0.005)	(0.005)
MNEs 10 (dummy)		0.012***		
		(0.003)		
MNEs 10*EPS tightening		0.027		
		(0.020)		
tax diff (MNE 10)		0.020		
		(0.045)		
MNEs 50 (dummy)			0.008**	
			(0.004)	
MNEs 50*EPS tightening			0.040*	
			(0.024)	
tax diff (MNEs 50)			0.022	
			(0.046)	
MNEs 90 (dummy)				0.005
				(0.004)
MNEs 90*EPS tightening				0.048*
				(0.025)
Tax diff (MNEs 90)				0.005
				(0.052)
Observations	511897	505274	505274	505274
R^2	0.090	0.091	0.091	0.091
Country-Industry FE	Y	Y	Y	Y

* p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses.

Table 3.8: GVC participation and high EPS tightening (country-industry fixed effect).

Dependent variable: MFP growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Leader MFP growth	0.065***	0.067***	0.067***	0.067***
	(0.021)	(0.021)	(0.021)	(0.021)
DTF (lag)	0.149***	0.151***	0.151***	0.150***
	(0.007)	(0.007)	(0.007)	(0.007)
EPS tightening (3y ma)	0.096**	0.096**	0.096**	0.096**
	(0.043)	(0.043)	(0.043)	(0.043)
DTF*EPS tightening	−0.074***	−0.074***	−0.074***	−0.075***
	(0.016)	(0.016)	(0.016)	(0.016)
Cycle (lag)	0.778	0.811	0.808	0.806
	(0.624)	(0.631)	(0.631)	(0.631)
Crisis 2008	−0.089***	−0.089***	−0.089***	−0.089***
	(0.010)	(0.010)	(0.010)	(0.010)
Employment (ln) (lag)	0.021***	0.019***	0.020***	0.020***
	(0.001)	(0.001)	(0.001)	(0.002)
Turnover growth (lag)	0.017***	0.017***	0.017***	0.017***
	(0.004)	(0.004)	(0.004)	(0.004)
Capital account openness (lag)	0.030***	1.298	1.263	1.233
	(0.009)	(4.353)	(4.350)	(4.349)
Employment protection (lag)	−0.346***	−0.345***	−0.345***	−0.345***
	(0.050)	(0.050)	(0.050)	(0.050)
Regulatory Impact (lag)	−0.576	−0.656	−0.655	−0.656
	(0.750)	(0.754)	(0.754)	(0.753)
High GVC participation (dummy)	1.920	−0.097***	−0.097***	−0.098***
	(10.460)	(0.009)	(0.009)	(0.009)
High GVC*EPS tightening	0.155***	0.153***	0.153***	0.153***
	(0.048)	(0.049)	(0.049)	(0.049)
Time trend	−0.001	−0.001	−0.001	−0.001
	(0.005)	(0.005)	(0.005)	(0.005)
tax diff (MNE 10)		0.026		
		(0.045)		
MNEs 10 (dummy)		0.014***		
		(0.002)		
tax diff (MNEs 50)			0.032	
			(0.045)	
MNEs 50 (dummy)			0.012***	
			(0.002)	
Tax diff (MNEs 90)				0.019
				(0.052)
MNEs 90 (dummy)				0.011***
				(0.002)
Observations	511897	505274	505274	505274
R^2	0.091	0.092	0.092	0.092

* p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses.

Table 3.9: Foreign intermediates outsourcing index and EPS tightening (country-industry FE).

Dependent variable: MFP growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Leader MFP growth	0.066***	0.068***	0.068***	0.068***
	(0.020)	(0.020)	(0.020)	(0.020)
DTF (lag)	0.147***	0.150***	0.149***	0.149***
	(0.007)	(0.007)	(0.007)	(0.007)
EPS tightening (3y ma)	0.069	0.069	0.069	0.069
	(0.044)	(0.045)	(0.045)	(0.044)
DTF*EPS tightening	−0.061***	−0.061***	−0.061***	−0.061***
	(0.016)	(0.016)	(0.016)	(0.016)
Cycle (lag)	0.689	0.724	0.721	0.719
	(0.619)	(0.626)	(0.626)	(0.626)
Crisis 2008	−0.089***	−0.089***	−0.089***	−0.089***
	(0.010)	(0.010)	(0.010)	(0.010)
Employment (ln) (lag)	0.021***	0.019***	0.020***	0.020***
	(0.001)	(0.001)	(0.001)	(0.001)
Turnover growth (lag)	0.016***	0.017***	0.017***	0.016***
	(0.004)	(0.004)	(0.004)	(0.004)
Capital account openness (lag)	0.035***	0.035***	0.035***	0.035***
	(0.009)	(0.009)	(0.009)	(0.009)
Employment protection (lag)	−0.316***	−0.316***	−0.316***	−0.316***
	(0.049)	(0.049)	(0.049)	(0.049)
Regulatory Impact (lag)	−0.905	−0.984	−0.984	−0.984
	(0.767)	(0.767)	(0.767)	(0.767)
High outsourcing (dummy)	2.063	3.166	3.080	3.004
	(10.330)	(10.489)	(10.482)	(10.479)
High Out*EPS tightening	0.119***	0.120***	0.120***	0.120***
	(0.044)	(0.044)	(0.044)	(0.044)
Time trend	−0.001	−0.001	−0.001	−0.001
	(0.005)	(0.005)	(0.005)	(0.005)
tax diff (MNE 10)		0.026		
		(0.045)		
MNEs 10 (dummy)		0.015***		
		(0.002)		
tax diff (MNEs 50)			0.032	
			(0.046)	
MNEs 50 (dummy)			0.012***	
			(0.002)	
Tax diff (MNEs 90)				0.019
				(0.052)
MNEs 90 (dummy)				0.011***
				(0.002)
Observations	511897	505274	505274	505274
R^2	0.091	0.092	0.092	0.092

* p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses.

Table 3.10: MNEs and high EPS tightening (country-industry FE).

Dependent variable: MFP growth	(1) β / (SE)	(2) β / (SE)	(3) β / (SE)	(4) β / (SE)
Leader MFP growth	0.066***	0.068***	0.067***	0.067***
	(0.019)	(0.019)	(0.019)	(0.019)
DTF (lag)	0.146***	0.149***	0.149***	0.148***
	(0.007)	(0.007)	(0.007)	(0.007)
EPS tightening (3y ma)	0.120**	0.120**	0.120**	0.120**
	(0.053)	(0.052)	(0.052)	(0.052)
DTF*EPS tightening	−0.052***	−0.052***	−0.052***	−0.052***
	(0.015)	(0.015)	(0.015)	(0.015)
High EPS	0.003			
	(0.038)			
Cycle (lag)	0.680	0.714	0.714	0.712
	(0.635)	(0.639)	(0.639)	(0.639)
Crisis 2008	−0.088***	−0.088***	−0.088***	−0.088***
	(0.011)	(0.011)	(0.011)	(0.011)
Employment (ln) (lag)	0.021***	0.019***	0.020***	0.020***
	(0.002)	(0.001)	(0.002)	(0.002)
Turnover growth (lag)	0.016***	0.017***	0.017***	0.016***
	(0.004)	(0.004)	(0.004)	(0.004)
Capital account openness (lag)	0.592	0.744	0.724	0.778
	(4.758)	(4.333)	(4.323)	(4.317)
Employment protection (lag)	−0.297***	−0.296***	−0.296***	−0.296***
	(0.039)	(0.039)	(0.039)	(0.039)
Regulatory Impact (lag)	−0.710	−0.740	−0.741	−0.754
	(0.866)	(0.784)	(0.784)	(0.785)
Time Trend	−0.001	−0.001	−0.001	−0.001
	(0.006)	(0.005)	(0.005)	(0.005)
MNEs 10 (dummy)		0.013***		
		(0.002)		
MNEs 10*High EPS tightening		0.186***		
		(0.058)		
tax diff (MNE 10)		0.029		
		(0.045)		
MNEs 50 (dummy)			0.011***	
			(0.002)	
MNEs 50*High EPS tightening			0.238***	
			(0.067)	
tax diff (MNEs 50)			0.036	
			(0.045)	
MNEs 90 (dummy)				0.009***
				(0.002)
MNEs 90*EPS tightening				0.245***
				(0.062)
Tax diff (MNEs 90)				0.022
				(0.051)
Observations	511897	505274	505274	505274
R^2	0.090	0.091	0.091	0.091

* p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses.

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