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Transaction Costs of Upstream Versus Downstream Pricing of CO_2 Emissions

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Abstract To the best of our knowledge, this is the first paper comparing empirically the transaction costs of the monitoring, reporting and verification (MRV) required by two environmental regulations aimed to cost-efficiently reduce greenhouse gas emissions: a carbon dioxide (CO_2) tax and an emissions trading system. We do this in the case of Sweden, where a set of firms are covered by both types of regulations—the Swedish CO_2 tax and the European Union's Emissions Trading System (EU ETS). Our results indicate that there is a significant degree of heterogeneity in the transaction costs of the firms in our sample. Moreover, for some of the firms, the transaction costs are high when compared with the actual cost of the CO_2 tax and the price of the EU ETS. Furthermore, we find that the MRV costs are lower for CO_2 taxation than for the EU ETS, which confirms the general view that regulating emissions upstream via a CO_2 tax yields lower transaction costs vis-á-vis downstream regulation via emissions trading.

Keywords Climate change · CO_2 tax · Emissions trading · Firm-level data · EU ETS · Transaction costs · Sweden

JEL Classification D23 · H23 · Q52 · Q58

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1 Introduction

Much of the literature acknowledges the lack of a generally accepted definition and the wide use of the concept of "transaction costs." As pointed out by Krutilla and Krause (2010), in the environmental economics field, the term "transaction costs" first emerged in the literature on the Coase theorem to refer to the "costs of market transactions" following a rights assignment (Coase 1937, 1960). Yet over the years, the concept has been applied more expansively to account for the fact that environmental regulations establish use or quasi-ownership rights to polluters who are generally qualified for and subject to regulatory review or modification. In this context, "transaction costs" refer to the costs of the regulatory requirements implementing the policy objective (Krutilla and Krause 2010).

It is acknowledged that the regulatory design can be used to reduce transaction costs in two ways: choosing the point of obligation that minimizes transaction costs (Krutilla and Krause 2010; McCann 2013) and excluding smaller participants who pay disproportionately large transaction costs in relation to their pollution (Schleich and Betz 2004). For instance, when it comes to the climate change discussion, the general view is that regulating CO_2 emissions *upstream* in the fossil fuel chain yields lower transaction costs than regulating polluters *downstream* since consumption of fuel usually is much easier to monitor than emissions. Furthermore, the number of emitters is larger than the number of firms producing or importing fuel (Crals and Vereeck 2005; Keohane 2009; Metcalf 2009; Mansur 2012). It is also acknowledged that the administrative costs faced by smaller emitters can be disproportionately high compared with the costs for large emitters. One example of this is the Directive of the European Union's Emissions Trading System (EU ETS), which enables small emitters to be excluded from the EU ETS, with the primary aim of reducing the administrative burden on these installations (European Parliament and Council 2009). Nevertheless, the Directive requires that excluded installations are subject to a domestic scheme that will deliver an equivalent contribution to emission reductions as the EU ETS.

Despite a growing body of research on the advantages of emissions taxation vis-à-vis emissions trading, and some theoretical studies analyzing the implications of the existence of transaction costs for optimal taxation (e.g., Yitzhaki 1979; Polinsky and Shavell 1982) and emissions trading (e.g., Stavins 1995; Montero 1997), to the best of our knowledge there are no previous studies analyzing *empirically* whether carbon taxation entails lower transaction costs than emissions trading, mainly due to the absence of case studies where such a comparison is feasible. The present paper contributes to filling this gap by examining the case of Sweden, where a number of polluting firms have been subject to a CO_2 tax since 1991 and to the EU ETS since 2005. These policies have overlapped since 2005 implying that a large number of firms have complied with both regulations simultaneously. This provides us with an excellent case study as it allows us to measure transaction costs incurred by firms regulated by these two environmental policies and to disentangle transaction costs of a given policy from other firm-specific variables that might affect the costs themselves.

To empirically compare the transaction costs of the CO_2 tax and the EU ETS, we combine primary and secondary sources of information. Regarding the primary information, in 2013 we conducted a survey asking a relevant sample of Swedish firms a series of questions regarding the monitoring, reporting, and verification costs incurred as part of complying with the CO_2 tax and/or the EU ETS in 2012. Following previous studies, we proxy transaction costs of regulations with the time spent on these activities (internal costs) and the external

and capital costs they entail.[1] The primary information was combined with other firm-level data including data on CO_2 emissions, employment, and revenue. This combined dataset allows us to develop a comparative analysis of the MRV costs incurred by firms under carbon taxes and tradable emission permits. It also enables us to identify differences across sectors, economies of scale, and the rationality for exclusion of smaller participants.

From the perspective of firms, all regulations imply implementation costs, including establishing internal/external administration for monitoring, reporting, and verification, quantifying emissions for the base period, familiarization with allocation rules, software and trading platforms. The focus of our analysis is on transaction costs of monitoring, reporting, and verification (MRV) of emissions since these costs are relevant for both our studied instruments and since empirical evidence indicates that these costs, at least in the case of the EU ETS, are the most important costs of compliance, with a share that might exceed 70% of the total transaction costs (see, e.g., Jaraitė et al. 2010; Heindl 2012). Hence, our study does not concern implementation costs as both the CO_2 tax and the EU ETS have been in place for many years and trading costs only pertain emissions trading programs. Furthermore, it is worth noticing that our study does not aim to generalize about the transaction costs of taxation and emissions trading per se, since the point of regulation (e.g., upstream vs. downstream regulation) is not held constant between the Swedish CO_2 tax and the EU ETS. Rather, our aim is to describe the differences in transaction costs of MRV between two regulatory designs broadly discussed in the context of climate change mitigation.

Our results indicate that the MRV costs are lower for CO_2 taxation than for the EU ETS, which confirms the general view that regulating emissions upstream via a CO_2 tax yields lower transaction costs vis-á-vis downstream regulation by means of emissions trading. Additionally, our results indicate that there is a significant degree of heterogeneity in the transaction costs of the firms in our sample. Moreover, for some of the firms, the transaction costs are high, especially when we compare them with the actual price of CO_2 emissions under both policies. This is an interesting finding, especially considering that most studies comparing environmental regulations disregard the role of transaction costs.

The paper is organized as follows. In Sect. 2, we briefly describe the Swedish CO_2 tax and the EU ETS, as well as the main MRV procedures of these policies. In Sect. 3, we discuss the theoretical aspects of MRV costs. In Sect. 4, we present the primary and secondary data. Section 5 contains our empirical analysis of the data. Finally, Sect .6 synthesizes our findings and concludes the paper.

2 The Swedish CO_2 Tax and the EU ETS

In 1991, Sweden implemented the world's highest CO_2 tax. The tax is directly connected to the carbon content of the fuel and was initially equivalent to €25/tCO_2. After increasing it steadily over the last decade, at present the tax corresponds to €105/tCO_2. Since the tax is very high and Sweden is a small open economy, there has been quite some concern about the competitiveness of some energy-intensive industries and, hence, a series of reduced tax rates have been applied to sectors that are open to international competition. For example, Brännlund and Lundgren (2010) show that during the period 1990–2004, the effective CO_2 tax rate was on average €11/tCO_2; the CO_2 tax varied considerably across sectors, ranging from about €4/tCO_2 in the wood product sector to almost €15/tCO_2 in the food sector.

[1] See McCann et al. (2005) and Fowlie and Perloff (2013) for a review of methods to estimate transaction costs.

The CO_2 tax is imposed "upstream" in the fossil fuel supply chain regulating firms that produce or import fuels that generate greenhouse gas (GHG) emissions, e.g., coal, natural gas, and refined petroleum products. Therefore, though the tax applies to the fuel used by most industrial and energy-producing activities in the economy (with some exemptions for industrial sectors and combined heat and power production within the EU ETS),[2] the CO_2 tax is *only filed and paid* to the Swedish Tax Agency (STA) by firms referred to as authorized warehouse or stock keepers. In 2012, there were 223 firms registered as authorized warehouse keepers by the STA. These firms sell fuel to final consumers, adding the CO_2 tax to the price their customers pay. They may use fuel themselves too, paying the tax payments related to their consumption.

When it comes to the MRV requirements, to comply with the CO_2 tax regulation, the warehouse/stock keepers must apply for authorization from the Swedish Tax Agency to purchase, extract, process, and store fuel. Tax liabilities arise when warehouse keepers consume the fuel or sell the fuel product to final consumers. The warehouse keepers must keep monthly records of fuel handling and report the data to the authorities, implying an administrative burden. If the fuel is sold to final consumers, the firm must keep records of the buyer and provide information about the buyer's tax status, which is available from the authorities. The authorized warehouse keepers must secure payment of the tax in advance. To this end, the tax is calculated and reported together with the application for authorization. They are also required to record all purchasing and sales of fuel as well as all transfers of fuel products, and are obliged to take inventory on a regular basis.

The STA can make visits to ensure that the warehouse keepers comply with regulations. Otherwise, tax compliance is verified through random tax audits conducted by the tax authorities. The STA can also conduct audits if they suspect that a firm has misreported taxes. Before an audit, the authorities notify the firm in order for it to have all required documents accessible upon the visit. An audit report declares the results of the audit and suggests tax changes, if needed. If a firm is found misreporting taxes, it can either be subject to administrative penalties issued by the tax authorities or—in more serious cases of tax evasion—prosecuted in court.

The EU ETS is thus far the largest downstream emissions trading system in the world regulating the direct sources of GHG emissions including industrial sources, power plants, and other combustion installations with a rated thermal input exceeding 20 MW (European Parliament and Council 2003). It covers about 12,000 installations, representing approximately 45% of the EU's CO_2 emissions. In Sweden, the main sectors included in the EU ETS account for 35% of the country's total CO_2 emissions (Löfgren et al. 2014). These sectors correspond to the energy sector (15% of total Swedish CO_2 emissions), the metal industry (8%), the mineral industry (6%), refineries (4%), and the pulp and paper industry (3%). According to Jaraitė et al. (2013), in 2012 the number of Swedish installations included in the EU ETS was 853, corresponding to 264 firms as some firms owned several installations.

[2] Since January 2011, the entire Swedish industry within the EU ETS has been fully exempt from the CO_2 tax. The same exemption has applied to combined heat and power production (CHP) from 2013 onwards. From 2005 to 2012, some partial exemptions applied. For instance, in 2012, CHP plants only paid 7% of the CO_2 tax (for more details see IEA 2013). Exemptions from CO_2 tax liabilities for warehouse keepers within the EU ETS are implemented in the form of refunds. That is, they are still liable for MRV activities on the fuel sold and used, but can refund tax liabilities for the fuel used in their production processes. Therefore, tax exemptions do not affect our ability to compare the transaction costs of CO_2 taxation and the EU ETS for these firms.

Regarding MRV activities, annual reports are mandatory and must be verified by an accredited verifier, which regulated firms have to pay for.[3] In particular, each operator of an EU ETS installation, according to the monitoring rules outlined in the legislation (European Commission 2012a, b), must write, implement and update a monitoring plan containing all the elements necessary to understand the monitoring of his emissions. Once monitoring is completed, the operator must report the annual emissions of his installation to the Swedish Environmental Protection Agency (SEPA). The emissions must be calculated using the methods described in the monitoring plan, and the report for a given year must be submitted by March 31 of the following year. Before this deadline, the annual emissions report must be verified by the independent accredited verifier. Once verified, the operator must surrender the equivalent number of tradable emission rights by April 30 of the same year. Any firm that does not surrender a sufficient number of tradable emission rights by April 30 is liable for payment of an excess emissions penalty. The current penalty is €100 per ton of CO_2 emitted for which the firm has not surrendered permits (European Parliament and Council 2008).

Note that in Sweden in 2012, the number of authorized warehouse keepers was similar to the number of firms included in the EU ETS. This is to say, a relatively small number of facilities account for the majority of fuel production/distribution and industrial emissions. Moreover, both the Swedish CO_2 tax and the EU ETS regulate and place monetary value on CO_2 emissions. However, the procedures for MRV under both regulations are independent. Not only must Swedish firms report to different authorities (STA vs. SEPA), but the MRV requirements of the CO_2 tax and the EU ETS are also defined in terms of different measurement units (fuel handling vs. verified emissions) and different time frames (monthly vs. annual reporting and random vs. annual verification).

3 Transaction Costs and Policy Instruments Choice

This paper aims to compare empirically the transaction costs of the Swedish CO_2 tax and the EU ETS in order to answer the following questions:

- Are the total MRV transaction costs higher under the EU ETS than under CO_2 taxation?
- Are the total MRV transaction costs under CO_2 taxation and the EU ETS fixed or do they increase with the level of emissions?
- Are there any economies of scope of the interaction of CO_2 taxation and the EU ETS on MRV costs?

Regarding the first question, the prevalence of transaction costs is largely dependent on the design of the policy instrument. A key element of regulatory design is the point of regulation. For instance, a target level of pollution reduction can be implemented *upstream* or *downstream* in the fossil fuel chain. Significant differences between the two approaches exist with regards to the type and number of market firms that need to be monitored. Whereas an upstream scheme has fewer and larger firms, a downstream scheme involves often more firms, and hence, higher transaction costs reducing the extent to which potential cost-effectiviness of market-based instruments is realized. As discussed in the introduction, this study does not aim to generalize about the transaction costs of taxation vs. trading of emissions per se, since the point of regulation is not held constant between the Swedish CO_2 tax and the EU ETS. Our study aims, instead, to provide empirical evidence on the differences in transaction costs between two regulatory designs broadly discussed in the context of climate change

[3] For an excellent detailed overview of the EU ETS's MRV activities, see Bellassen and Stephan (2015).

mitigation. In particular, the general view is that the transaction costs of an upstream carbon tax are lower than the transaction costs of a downstream emissions trading scheme since consumption of fuel usually is much easier to monitor than emissions. Furthermore, carbon taxation can be administered through government tax collection institutions that are more established and effective than environmental regulatory institutions, entailing lower MRV costs to firms (see, e.g., Coria 2009; Pope and Owen 2009; Kerr and Duscha 2014). Thus, it is clear that the comparison between CO_2 taxes and the EU ETS comes down to empirically comparing the transaction costs of the policies, and our study aims to provide empirical evidence to fill in this gap.

Regarding the second question, in deriving marginal conditions to find the efficient level of pollution reduction, it is usually assumed that the transaction costs of implementing environmental policies are zero. However, as shown by Stavins (1995), if marginal transaction costs are nonzero, the "cost-effective" solution (in the absence of transaction costs) will not be achieved, regardless of the specific forms that the marginal transaction cost function take. Whether transaction costs are of a fixed or variable kind and whether they increase or decrease with the quantity of emissions is an empirical question. Moreover, there is no theoretical reason to believe that the specific forms of marginal transaction costs under carbon taxation and downtream tradable permits are the same. Our study aims to shed light on this issue by providing estimates on the nature of the transaction costs under these instruments.

Finally, as described in Sect. 2, Swedish warehouse keepers included in the EU ETS must comply not only with the MRV requirements of the CO_2 tax but also with the EU ETS requirements. This implies that in absence of economies of scope between the requirements of both policies, their overall MRV costs would correspond to the sum of the MRV costs under carbon taxation and emissions trading. In the paper, we test whether such economics of scope exists in practice.

In the subsequent sections we first describe the data we use to answer our research questions and then present the results.

4 The Data

To develop the empirical analysis described above, we need to combine primary and secondary sources of information. Regarding the primary information, after a set of exploratory interviews with policymakers and firms, we developed a questionnaire and conducted a survey (in collaboration with SEPA) from late April to September 2013.[4] We asked a sample of Swedish firms a series of questions regarding the monitoring, reporting, and verification costs incurred as part of their compliance with the CO_2 tax and/or the EU ETS in 2012.[5]

The population of the study consisted of 379 firms covered under the Swedish CO_2 taxation and/or the European Union Emissions Trading System in 2012. Two hundred and twenty-three of these firms were registered as authorized warehouse keepers by the Swedish Tax Agency (around 58.8%), 264 firms were included in the EU ETS (around 69.7%), and 108 firms (around 28.5%) were covered by both policies and were thus registered as authorized warehouse keepers and included in the EU ETS in the same year. In total, 130 firms completed the survey (approximately 34.3%). Of the firms that responded to the survey, 67 (51.5%) were both authorized warehouse keepers and in the EU ETS in 2012 and 23 firms (17.7%) stated that they were authorized warehouse keepers but not in the EU ETS. The remaining 40 firms

[4] The exploratory interviews took place from November 2012 to February 2013.

[5] The survey translated into English is presented in "Appendix A".

Table 1 Survey respondents. *Sources*: survey and the authors' calculations

	Single regulation	Double regulation	Total
No. of CO_2 tax firms	23	67	90
No. of ETS firms	40	67	107

(30.8%) stated to be in the EU ETS but not registered as warehouse keepers in 2012 (see Table 1).

To complement the data gathered through our survey, we collected additional information from various sources including verified CO_2 emissions under the EU ETS taken from the European Union Transaction Log, the number of employees, revenue, and firm size categories taken from the Orbis database. The Orbis database classifies firms as small, medium, large, or very large depending on a series of criteria regarding operation revenues, total assets, and number of employees.[6] Finally, we collected information on the Swedish sector codes (SNI) and CO_2 emissions from fuel combustion from Statistics Sweden (SCB). Disentangling CO_2 emissions from fuel combustion is important since even if carbon taxation overall implies lower MRV costs, emissions trading might lead to larger emissions reductions as it is based on a broader definition of source stream. Under the EU ETS definition, a source stream includes all fuel or material that enters and leaves the installation and has a direct impact on emissions (European Parliament and Council 2003). In the simplest case it means the fuels streaming into the installation. However, it also covers raw materials that give rise to process emissions (which are included in the calculation of GHG emissions using a mass balance method).

Although we contacted all relevant firms, response rates can always introduce some bias as firms willing to answer may be distinct from the average. Table 2 provides the descriptive statistics for the entire population of firms and those firms that actually completed the survey. It is evident that the latter group includes the slightly smaller shares of small, medium and very larger firms and a slightly large share of large firms. Also, our firm sample consists of a larger proportion of firms that are subject to both regulations and a larger share of firms that belong to the energy sector. This needs to be taken into account yet this is not necessarily unexpected or negative. The regulations are complex and the firms that were subject to both CO_2 taxation and the EU ETS might have felt they had more to contribute. From a statistical point of view, the information provided by these double-regulated firms is very valuable as it allows disentangling the costs of each regulatory design from other firm-specific variables that might affect the overall cost of MRV procedures regardless of the regulation in place.

Regarding size, besides the size categories from the Orbis database, we grouped the firms into three categories according to their verified CO_2 emissions under the EU ETS relative to the total verified emissions of the whole country. Thus, small emitters are those whose emissions represent up to 0.1% of the country total, medium emitters are in the 0.1–1% range, and large emitters have emissions corresponding to more than 1% of the country's total verified emissions. As shown in Table 2, most firms in our sample and most of the respondents are classified as small emitters in this respect. This is consistent with the fact that the EU ETS is dominated by very few large emitters and a large number of smaller emitters (e.g., Schleich and Betz 2004; European Commission and Ecofys 2007).

[6] For example, firms in Orbis are considered to be large when they match at least one of the following conditions: operational revenue above 10 million euro, total assets above 20 million euro, and more than 150 employees. Similar definitions apply for medium and very large firms, while those that are not included in another category are classified as small firms.

Table 2 Summary of the descriptive statistics as for the year 2012

Variable	Unit	Population		Sample of respondents		CO_2 tax firms		EU ETS firms		Double-regulated firms	
		N	Mean	*N*	Mean	*N*	Mean	*N*	Mean	*N*	Mean
CO_2 tax firms[c]	Dummy	379	0.588	130	0.692	90	1	107	0.626	67	1
EU ETS firms[b]	Dummy	379	0.696	130	0.823	90	0.744	107	1	67	1
CO_2 tax and EU ETS firms[b,c]	Dummy	379	0.285	130	0.515	90	0.744	107	0.626	67	1
Energy sector firms[a]	Dummy	379	0.346	130	0.5	90	0.444	107	0.551	67	0.507
CO_2 emissions, fuel combustion[a]	Ton	244	65,528	103	61,525	70	74,206	95	63,767	62	80,407
Verified CO_2 emissions[b]	Ton	264	69,994	111	65,871	71	67,197	106	67,827	66	70,484
Turnover[4]	Million €	357	3793.3	123	2226.1	86	2586.5	102	2082.5	65	2477.5
No. of employees[d]	Number	353	932	121	456	85	415	100	533	64	521
Small firms ORBIS[d]	Dummy	378	0.034	130	0.015	90	0.011	107	0.009	67	0
Medium firms ORBIS[d]	Dummy	378	0.138	130	0.123	90	0.078	107	0.112	67	0.045
Large firms ORBIS[d]	Dummy	378	0.423	130	0.508	90	0.478	107	0.501	67	0.462
Very large firms ORBIS[d]	Dummy	378	0.405	130	0.354	90	0.433	107	0.374	67	0.492
Small CO_2 emitters[b]	Dummy	264	0.72	111	0.685	71	0.563	106	0.679	66	0.545
Medium CO_2 emitters[b]	Dummy	264	0.216	111	0.243	71	0.338	106	0.245	66	0.348
Large CO_2 emitters[b]	Dummy	264	0.064	111	0.072	71	0.098	106	0.075	66	0.106

Sources: [a]Statistics Sweden; [b]European Union Transaction Log; [c]Swedish Tax Agency; [d]Orbis database

5 The Results

In this section we discuss the survey responses and the answers to the questions raised in Sect. 3. In Sect. 5.1 we provide a descriptive analysis of the data and in Sect. 5.2 we analyze the data by using econometric models.

5.1 Analysis of Transaction Costs under CO_2 taxation and the EU ETS

5.1.1 Taxonomy of the MRV Costs

As Jaraitė et al. (2010), in our analysis we consider three types of MRV costs: (1) *internal* costs, mainly management and staff time, measured as the number of full-time working days spent on all MRV procedures and, additionally, in monetary terms'[7] (2) *external* costs incurred in terms of consultancy services contracted to be MRV compliant, measured in monetary terms; and (3) *capital* costs, meaning emissions/fuel measurement, monitoring, recording, and data storage equipment needed to comply, measured in monetary terms. In Table 3 we report all these types of MRV costs, which we denote *internal costs*, *internal and external costs* (the sum of internal and external costs), and *internal, external and capital costs* (the sum of internal, external and capital costs).

Table 3 presents the MRV costs for five groups of firms: (1) all firms subject to the MRV requirements of the CO_2 tax, (2) all firms subject to the MRV requirements of the EU ETS, (3) firms subject to the MRV requirements of both regulations, (4) firms subject to only the MRV requirements of the CO_2 tax, and (5) firms subject to only the MRV requirements of the EU ETS. In Table 3, the five groups are denoted CO_2 *taxed all firms*, *EU ETS all firms*, *double-regulated firms*, and *single-regulated firms*, respectively. Note that these categories are not exclusive. However, they allow us to compare the MRV costs in several dimensions:

- Groups 1 and 2 represent our overall firm sample and allows us to compare MRV costs between all CO_2 taxed firms and all EU ETS firms,
- Group 3 allows us to compare MRV costs of CO_2 taxation versus EU ETS for the subsample of firms that are subject to both regulations.
- Furthermore, groups 3, 4 and 5 allows us to compare MRV costs of CO_2 taxation (or the EU ETS) between single-regulated firms and double-regulated firms.

Hence, we are to describe the differences in transactions costs between the two regulatory designs and to examine to what extent the MRV costs of CO_2 taxation and EU ETS vary when we look at a difference samples of firms. The results of the non-parametric Wilcoxon–Mann–Whitney and Wilcoxon signed-rank tests are summarized in "Appendix B".[8]

From Table 3 it is clear that firms spent a significant amount of time on MRV procedures and that there is substantial variation in the number of full-time working days firms in the

[7] The internal costs from total full-time days were converted into monetary values by assuming that a full-time working day is 8 h long and multiplying these hours by the average gross hourly wage of 396 SEK (about €44) for a qualified employee working in the environmental field in Sweden. This choice is based on the fact that most respondents to the survey stated that they work either as environmental engineers, energy engineers or as managers in the area of environment, energy or accounting. Since all of these occupations would require higher university education and since the Swedish labor market is rather competitive, we claim that the choice of homogenous wage rate is rather justified.

[8] We have consistently excluded unrepresentative firms that misreported the MRV costs and firms that reported no costs. We define a firm as unrepresentative if its reported MRV costs in terms of full-time working days are higher than 500. Two warehouse keepers were dropped from the sample for this reason. Six firms that reported zero full-time working days either for the CO_2 tax, EU ETS, or both were also excluded from the analysis.

Table 3 Annual MRV costs for CO_2 taxation and the EU ETS. *Sources*: survey and the authors calculations

	No. of firms	Mean	SD	Min	Max
Internal costs, full-time working days					
CO_2 tax all firms	80	30.7	44.2	0.75	215
EU ETS all firms	104	38.8	63	1	372
CO_2 tax double-regulated firms	59	33.8	49.5	1.5	215
EU ETS double-regulated firms	59	51.4	77.1	6	372
CO_2 tax single-regulated firms	20	20.5	21.7	0.750	100
EU ETS single-regulated firms	40	16.3	12.9	1.000	50
Internal costs, thousand €					
CO_2 tax all firms	80	10.8	15.6	0.264	75.7
EU ETS all firms	104	13.7	22.2	0.352	130.9
CO_2 tax double-regulated firms	59	11.9	17.4	0.528	75.7
EU ETS double-regulated firms	59	18.1	27.1	2.112	130.9
CO_2 tax single-regulated firms	20	7.2	7.6	0.264	35.2
EU ETS single-regulated firms	40	5.7	4.5	0.352	17.6
Internal and external costs, thousand €					
CO_2 tax all firms	80	12.7	17.6	0.264	97.9
EU ETS all firms	104	23.2	29.7	1.056	166.1
CO_2 tax double-regulated firms	59	13.7	19.9	0.528	97.9
EU ETS double-regulated firms	59	29.7	36	2.464	166.1
CO_2 tax single-regulated firms	20	9.7	8.4	0.264	35.2
EU ETS single-regulated firms	40	11.7	8.1	1.056	39.7
Internal, external and capital costs, thousand €					
CO_2 tax all firms	80	15	22.2	0.264	114.6
EU ETS all firms	104	26.5	36.3	1.056	221.7
CO_2 tax double-regulated firms	59	16.7	25.2	0.528	114.6
EU ETS double-regulated firms	59	34.1	44.7	2.464	221.7
CO_2 tax single-regulated firms	20	9.8	8.5	0.264	35.2
EU ETS single-regulated firms	40	13.6	11	1.056	50.8

The results of the non-parametric Wilcoxon–Mann–Whitney tests are summarized in Tables 9, 10 and 11 of "Appendix B"

sample spent on all MRV procedures. On average, firms spent more time on MRV procedures under the EU ETS than under CO_2 taxation (38.8 vs. 30.7 days). The difference in internal costs is, however, much larger and statistically significant[9] when we look at the sample of firms subject to both regulations (on average 51.4 versus 33.8 days). This is to say that for the exact same firms, the MRV procedures for the CO_2 tax take, on average, 18 days less than those under the EU ETS. This finding suggests that the MRV requirements are more demanding to comply with under the EU ETS. In addition, when we compare the sample of *single-regulated* firms with the subsample of firms subject to *both* policies, we see that the firms in the latter group spend, on average, more time on MRV procedures (20.5 vs. 33.8 days under the CO_2 tax; 16.3 vs. 51.4 days under the EU ETS). The difference in time

[9] See Table 9 in "Appendix B".

spent is only statistically significant in the case of the EU ETS.[10] The fact that firms subject to both regulations are larger in terms of economic activity and CO_2 emissions than those in the EU ETS all firms group might explain this result.[11] Moreover, this finding points to a lack of economies of scope or synergies between the MRV procedures required under the two regulations.

The cost wedge between the two policies remains when we take into account the remaining categories of MRV costs—external MRV costs and capital MRV costs. In both cases (i.e., internal and external costs and internal, external and capital costs), the cost wedge is statistically significant when we compare the CO_2 tax double-regulated firm group and the EU ETS double-regulated firms group.[12]

The MRV costs of the CO_2 taxation are not statistically different between the subsample of CO_2 tax *single-regulated* firms and the subsample of firms subject to *both* policies. However, the MRV costs of the EU ETS are significatly larger for the subsample of *double-regulated* firms than for the subsample of *single-regulated* EU ETS firms.[13] Again, this result supports our earlier statement that firms regulated by both policies do not benefit in terms of lower transaction costs from the interactions of the MRV procedures required under the two environmental policies.

5.1.2 The Composition of the MRV Costs

Figure 1 presents the composition of the average total MRV costs of both policies for the sample of firms that are double-regulated. It is evident that for both policies, on average, internal MRV costs are the most dominant type of costs and capital MRV costs account for about 5% of the overall MRV costs, which is not surprising knowing that capital MRV costs are the time-specific set-up costs incurred during the initial phases of policy implementation. Internal MRV costs make up a larger share of total MRV costs under the CO_2 tax than under the EU ETS (89 vs. 57%), while the opposite is found for external MRV costs (6 vs. 39%). This relative breakdown of MRV costs underlines the main difference between the MRV procedures of the two policies—the EU ETS implies mandatory verification requirements creating additional costs for firms under this policy.

This difference in MRV procedures between the two policies is further emphasized by Table 4, which presents the breakdown of the *internal* MRV costs of CO_2 taxation and the EU ETS for the firms that are subject to the MRV requirements of both regulations. We report the breakdown *estimated* by us as the number of full-time working days spent on monitoring, reporting, and verification, respectively, relative to the *total* number of full-time working days spent on all MRV procedures. Table 4 also shows the breakdown of total MRV costs (internal, external, and capital costs) *reported* by the firms (in response to questions A15 and B15 in the questionnaire, see "Appendix A").

From Table 4 it is clear that the largest differences between the studied policies are related to the costs of verification. That is, in relative terms, the costs of verification (both internal and total) are, on average, larger under the EU ETS. According to the non-parametric Wilcoxon signed-rank test, this difference is statistically significant.[14] This suggests that firms regulated under the EU ETS spend a significant amount of resources not only hiring external certified

[10] See Table 10 in "Appendix B".

[11] See Table 5.

[12] See Table 9 in "Appendix B".

[13] See Table 10 in "Appendix B".

[14] See Table 11 in "Appendix B".

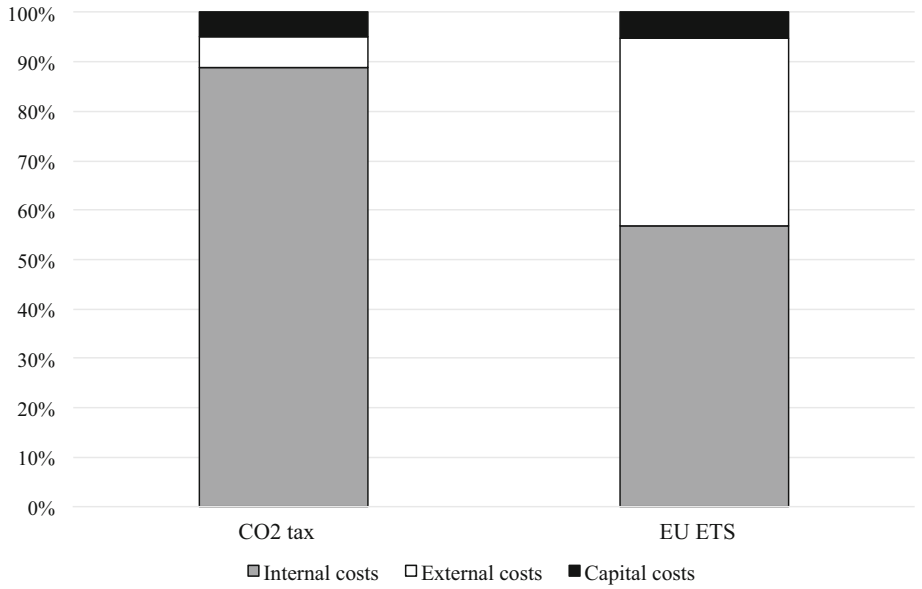

Fig. 1 Composition of the annual average total MRV costs for double-regulated firms. *Sources*: survey and the authors' calculations. *Note* As indicated in Table 3, there are 59 double-regulated firms

Table 4 Estimated and reported breakdown of the annual internal and total MRV costs for double-regulated firms. *Sources*: survey and the authors calculations

	Estimated breakdown of *internal* MRV costs (%)			Reported breakdown of *total* MRV costs (%)		
	No. of firms	Mean	SD	No. of firms	Mean	SD
CO_2 *tax firms*						
Monitoring	59	53.1	18.4	56	45.9	19.6
Reporting	59	39.7	17	56	42.5	20.4
Verification	59	7.1	15.5	56	11.6	16.4
EU ETS firms						
Monitoring	59	46.9	22.1	58	39.6	21
Reporting	59	30.5	17	58	29.8	18.2
Verification	59	22.6	13.9	58	30.6	21.3

The results of the non-parametric Wilcoxon–Mann–Whitney tests are summarized in Table 12 of "Appendix B"

verifiers but also on internal verification, which is used as an input by external verifiers. Moreover, both the internal and total resources devoted to reporting are (in relative terms) significantly larger under CO_2 taxation, which might be explained by the fact that reporting under this regulation occurs on a monthly basis, while the EU ETS requires firms to report their emissions only once a year. Finally, for both policies, monitoring is the activity that makes up the largest share of the MRV costs (on average, when we consider internal and total costs, this share is statistically larger under CO_2 taxation). Most of our respondents monitor fuel consumption and/or CO_2 emissions on a monthly basis. This is expected in the case of CO_2 taxation as it coincides with the frequency of reporting. In the case of the EU

ETS, firms monitor emissions more often than the required reporting frequency. Frequent monitoring might allow them to anticipate and adjust their purchases/sales of permits to ensure compliance with the regulation.

5.1.3 The MRV Costs per Ton of CO_2 Emissions

As mentioned, the EU ETS is based on a broader definition of source stream, as it includes the emissions from not only fuel combustion (covered under the CO_2 tax) but also emissions arising from raw materials or products. Hence, even if the total MRV costs are larger under the EU ETS than under CO_2 taxation, the costs per unit of emissions might be lower under the former as it covers a larger amount of emissions. To account for this, Table 5 summarizes our three measures of MRV cost (in thousand euro) per ton of CO_2 emissions, where CO_2 emissions under CO_2 taxation correspond to those of authorized fuel warehouse keepers provided by Statistics Sweden (fuel combustion) and CO_2 emissions under the EU ETS correspond to the verified emissions reported to the EUTL.[15]

Note that, with regard to Table 3, the number of observations in each group decreases since information on CO_2 emissions is unfortunately not available for all firms in our sample. It is evident that few firms in the sample report rather high MRV costs and rather low CO_2 emissions leading to very high MRV costs per ton of CO_2 emissions (see the mean values and the standard deviations in Table 5). Because of this, the mean value of MRV costs per ton of CO_2 emissions is not an informative measure of the central distribution of the data and to have a better description of the data we add to Table 5 the median values of MRV costs per ton of CO_2 emissions.

From Table 5 it is clear that the differences in MRV costs between the two policies remain even after dividing them by emissions. In all cases, the MRV costs per ton of CO_2 emissions are statistically higher under the EU ETS than under CO_2 taxation when we look at the sample of firms subject to both regulations.[16] For this sample we can see that the median internal costs are equal to 0.22€/tCO_2 under CO_2 taxation and 0.63€/tCO_2 under the EU ETS. If we consider also external costs, the median values increase to 0.26€/tCO_2 and 1.31€/tCO_2, respectively. Additionally, the comparisons between the sample of *single-regulated* CO_2 tax (EU ETS) firms and the subsample of *double-regulated* firms reveal that the median MRV costs per ton of CO_2 emissions of both regulations are lower for double-regulated firms. This supports our initial expectations of lower MRV costs for double-regulated firms.

In sum, our results indicate that there is a significant degree of heterogeneity in the costs, and that for some firms the MRV costs per ton of CO_2 emissions are very high, especially when we compare them with the actual historical prices of CO_2 emissions under both policies. For instance, the effective CO_2 tax rate over the period 1990–2004 corresponded to around 11€/tCO_2 (Brännlund and Lundgren 2010), while the price of EU ETS permits was persistently under 10€/tCO_2. This is by all means an interesting finding, especially considering that most studies analyzing or comparing environmental regulations disregard the role of transaction costs. Furthermore, some of the few studies analyzing MRV costs under the EU ETS report lower estimates. For instance, Jaraitė et al. (2010), King et al. (2010) and Heindl (2012) report that average EU ETS MRV costs per emitted ton of CO_2 are in the order of €0.04–0.08. One possible explanation for the lower MRV cost estimates reported by these earlier studies could be that they were performed when the EU ETS was in its first years of

[15] The verified average emissions for the sub-sample of 54 CO_2 tax firms that are subject to double regulation correspond to 69,699 t of CO_2. That is, in this group 99% of the total emissions stem from fuel combustion.

[16] See Table 9 of "Appendix B".

Table 5 Summarizing the annual MRV costs per ton of CO_2 emissions. *Sources*: survey and the authors calculations

No. of firms			CO_2 emissions, t	Internal costs, €/tCO_2	Internal and external costs, €/tCO_2	Internal, external and capital costs, €/tCO_2
CO_2 tax all firms	61	Mean	66,231	6.4	9.3	9.4
		Median	19,620	0.3	0.3	0.33
		SD	139,384	28.2	40.4	40.4
EU ETS all firms	101	Mean	70,052	10.6	37.6	38.3
		Median	4760	1.23	2.49	2.49
		SD	259,484	32.1	203	203
CO_2 tax double-regulated firms	54	Mean	69,068	6.6	9.1	9.3
		Median	20,346	0.22	0.26	0.31
		SD	145,779	29.9	42.3	42.4
EU ETS double-regulated firms	57	Mean	66,406	9.2	16.5	17.1
		Median	12,185	0.63	1.31	1.44
		SD	149,052	33.1	61.8	61.8
CO_2 tax single-regulated firms	6	Mean	46,485	5.8	12.2	12.2
		Median	4795	1.4	2.2	2.2
		SD	84	100	9.8	22.8
EU ETS single-regulated firms	39	Mean	65,068	13.9	72.2	73.0
		Median	1115	3.0	5.5	7.2
		SD	30,617	32.9	317.5	317.3

The results of the non-parametric Wilcoxon–Mann–Whitney tests are summarized in Tables 9,10 and 11 of "Appendix B"

operation and EU ETS firms at that time did not fully adjust their operations according to the MRV requirements of the EU ETS (e.g., hiring extra personnel).

5.1.4 MRV Cost Distribution and Economies of Scale

The fact that some small emitters have relatively high MRV costs brings us to the investigation of MRV cost distribution and the analysis of economies of scale.

Table 6 reports the carbon intensity (defined as the ratio of verified CO_2 emissions in the EU ETS to revenue, tCO_2/th€) and the sum of internal and external MRV costs per ton of CO_2 emissions for small, medium, and large emitters, where as described in Sect. 4 these categories are based on the firms' verified emissions under the EU ETS as a proportion of the whole country's total verified emissions. Here and in the rest of this study, we focus on the sum of internal and external costs since, as pointed out earlier, external costs are quite

Table 6 Summarizing the annual internal and external MRV costs for small, medium, and large emitters; all firms. *Sources*: survey and the authors calculations

	CO_2 Tax all firms				EU ETS all firms			
	No. of firms	Mean	Median	SD	No. of firms	Mean	Median	SD
Small firms								
CO_2 intensity (tCO_2/th€)	35	0.107	0.071	0.131	65	0.096	0.053	0.109
Internal and external costs (th€)	37	10.7	5.28	13.9	72	19.1	10.6	28.5
Internal and external costs (€/tCO_2)	36	26.5	1.86	67.5	70	54.1	6.96	242.5
Medium firms								
CO_2 intensity (tCO_2/th€)	24	0.906	0.211	2.207	26	0.870	0.222	2.121
Internal and external costs (th€)	20	12.6	7.74	17.4	23	24.1	19.6	26.4
Internal and external costs (€/tCO_2)	20	0.24	0.17	0.243	23	0.53	0.45	0.434
Large firms								
CO_2 intensity (tCO_2/th€)	6	3.014	2.712	3.020	8	3.660	2.712	3.834
Internal and external costs (th€)	6	28.6	7.13	39	8	49.7	39.1	33
Internal and external costs (€/tCO_2)	6	0.08	0.02	0.122	8	0.1	0.1	0.049

The firms were grouped into three categories according to their verified CO_2 emissions under the EU ETS relative to the whole country's total verified emissions. Thus, small emitters are those whose tCO_2 emissions represent up to 0.1% of the country total, medium emitters are in the 0.1–1% range, and large emitters have emissions corresponding to more than 1% of the country's total verified emissions

relevant in the case of the EU ETS due to external verification requirements. Moreover, we exclude capital costs since they are time-specific and do not occur on a regular basis.

Table 6 shows that, on average, the production activities of small emitters are less pollution intensive than those of medium and large emitters. We can also see that the total internal plus external MRV costs on average are larger for the largest firms (both under CO_2 taxation and under the EU ETS). However, the sum of internal and external costs per ton of CO_2 emissions are the largest for the smallest firms. Similar patterns were observed by Jaraitė et al. (2010) in the case of Irish firms under the EU ETS. We can also observe that for all firm categories, the internal plus external MRV costs are larger for firms under the EU ETS.

Since we have very few large firms in our sample, we merge firms into two groups in order to test whether the differences in MRV costs are statistically significant. Thus, we classify firms as small and large (where the large firms correspond to the medium and large firms in Table 6). Interestingly, we find that, in terms of the total internal and external MRV costs, the cost difference between small and large firms is only statistically significant in the case of the firms regulated under the EU ETS.[17] However, we observe that under both regulations, these costs per ton of CO_2 emissions are statistically lower in the case of the large firms.[18] These results highlight the importance of measuring transaction costs associated with environmental regulations not only per firm but also per unit of pollution released in order to understand the underlying structure of the costs.

Thus, our findings hint that under upstream CO_2 taxation, the amount of CO_2 emissions does not affect the total MRV costs. This is consistent with a cost structure characterized by a fixed component that can be denoted F_T, where the total MRV costs do not depend on size whereas the costs per unit of CO_2 emissions do. In contrast, the statistical evidence in the case of the EU ETS suggests a cost structure of the type $F_P + f_P(e)$, where F_P corresponds to the fixed component and $f_P(e)$ to a variable component that increases with emissions e at a decreasing rate. This is to say, our results point to a different structure of the transaction costs under the analyzed policies.

By comparing double-regulated firms of similar size across the two regulations,[19] we can argue that $F_T < F_P + f_P(e)$ for both small and large firms, implying that for small emitters the transaction costs of CO_2 taxation are lower than those under the EU ETS. This bring us to the conclusion that, despite the existence of economies of scale for both regulations, the costs of MRV activities under the CO_2 tax remain lower than under the EU ETS, and that even for large firms the MRV costs per unit of CO_2 emissions are larger under the EU ETS.

5.2 The Econometric Analysis of the MRV Costs

The descriptive statistical analysis in Sect. 5.1 reveals that internal and external MRV costs are increasing in emissions only for EU ETS firms, while for CO_2 tax firms these costs appear to be fixed. Thus, the evidence points to the existence of economies of scale under both policies. However, the results derived from the statistical tests should be interpreted with caution since they are based on small sample sizes and do not take into account other firm characteristics that might explain variation in the MRV costs. To further analyze the extent to which the internal and external MRV costs (hereafter the MRV costs) depend on CO_2 emissions and to identify other firm attributes that influence these costs, we estimate

[17] See Table 12 in "Appendix B".

[18] See Table 12 in "Appendix B".

[19] See Table 13 in "Appendix B".

separately several econometric models for each firm sample, initially assuming the following semi-parametric relationship between MRV costs and CO_2 emissions:

$$ln(MRV_i) = \alpha + X_i\gamma + f(CO_{2i}) + \epsilon_i, \quad (1)$$

where $ln(MRV_i)$ is firm i's log-linearized MRV costs, X_i is a matrix of other characteristics of firm i (described below), α is a constant term, and ϵ_i is the disturbance, which is assumed to to have zero mean and constant variance. The variable CO_{2i} corresponds to the CO_2 emissions of the firm i and enters the equation non-linearly according to a non-binding function f.[20] We estimate this model by using Robinson's (1988) double residual methodology to investigate whether the relationship between the log-linearized MRV costs and CO_2 emissions is non-parametric or may be approximated by some parametric polynomial alternative. The statistic developed by Hardle and Mammen (1993) allows us to test which relationship between the two variables of interest fits the data best.[21]

The results of the Hardle and Mammen (1993) test indicate that for both samples, there are no statistical differences between the second degree parametric polynomial and the non-parametric estimation, implying that we could represent our data through a parametric model with a polynomial function $f(CO_{2i})$ of second degree:

$$ln(MRV_i) = \beta_0 + X_i\gamma + \beta_1 CO_{2i} + \beta_2 CO_{2i}^2 + \epsilon_i. \quad (2)$$

Economies of scale from the above parametric regression model can be captured in two ways. Firstly, if the estimated coefficients β_1 and β_2 are statistically not different from zero, we can predict that the MRV costs are fixed and hence the MRV costs per ton of CO_2 emissions are decreasing in emissions. Secondly, if the β_1 coefficient is positive and the β_2 coefficient is negative, the MRV costs are increasing in CO_2 emissions at a decreasing rate. Given our descriptive statistical analysis, we expect the first relationship to hold for the CO_2 tax and second to hold for the EU ETS.

The remaining explanatory variables include the dummy variable $double_i$, which is equal to one if the firm i is subject to both the CO_2 tax and the EU ETS. From the descriptive analysis in Sect. 5.1, we expect the MRV costs for double-regulated EU ETS firms to be higher. Another dummy variable, $energy_i$, identifies in which sector (energy vs. non-energy) the firm i is operating.[22] A priori we might expect firms in the energy sector to be more experienced in monitoring fuel combustion and related CO_2 emissions and hence to have lower MRV costs. The number of plants (measured as the number of EU ETS installations) within firm i, $plants_i$, might also explain the MRV costs. Holding all other factors constant, multi-plant firms might be more experienced and hence more efficient in complying with environmental regulations. Also, we might expect firms with higher revenue ($turnover_i$) as

[20] We chose to log-linearize the MRV costs (dependent variable) to reduce its variation since it is evident that MRV costs vary a lot across firms. Log-linear model specification was preferred over log-log model specification for two reasons. First, it is evident that the relationship between log MRV costs and level of CO_2 emissions is more linear than the relationship between log MRV costs and log CO_2 emissions. Second, the interpretation of the log-linear model is more helpful for our research purposes as from the estimation results we can easily identify the level of CO_2 emissions at which, ceteris paribus, the MRV costs start increasing or decreasing.

[21] The semi-parametric Robinson's model and Hardle and Mammen's test were estimated using the Stata command *semipar* (Verardi and Debarsy 2012).

[22] Energy firms correspond to SNI code 35 and non-energy firms correspond to all the other SNI codes.

well as more employees ($empl_i$) to incur lower transaction costs as we expect these firms to have higher in-house capacity to comply with the MRV procedures.[23]

From the discussion in Sect. 5.1 it is evident that the MRV costs vary substantially across firms, suggesting that the OLS regression model might be inappropriate due to potentially large residuals and distorted estimation of parameters in case of outliers. We detected two influential observations for each sample by using the Cook's D and DFITS measures (e.g., see Cameron and Triverdi 2009). We performed the Breusch-Pagan and Cook-Weisberg test and the White test for heteroscedasticity, after which we dropped the influential observations. The estimation of OLS models reveals that the H_0 of constant variance cannot be rejected for either sample. However, the test of normality of residuals shows that in the case of the EU ETS firm sample, the residuals are close to normally distributed, but this is not the case for the CO_2 tax firm sample, suggesting that other regression techniques should be also considered.

To address these data issues, we estimate five regression models for each firm sample. Model 1 is the OLS regression *without* the influential observations; Model 2 is the OLS regression *without* the influential observations and *with* the robust standard errors; Model 3 is the OLS regression *without* the influential observations and *with* the standard errors clustered at industry level; Model 4 is the robust regression *without* the influential observations; and Model 5 is the MS-estimator model *without* the influential observations. In the literature, Model 4 and Model 5 are grouped as robust-to-outliers models, which are better than the OLS model when outliers are present and when residuals lack normality.[24] The estimated models, when possible, are compared based on model fit (R-squared), overall model significance (F-statistics), and information criteria (AIC).[25]

The results of the five models for the CO_2 tax firms and the EU ETS firms are summarized in Tables 7 and 8. It is evident that for both samples, Model 4 is to be preferred because of lower AIC values. Unfortunately, the Stata script *msregress* for the MS-estimator does not provide the data necessary for computation of R-squared and other fit measures. Therefore we cannot directly compare Model 4 estimators with Model 5 estimators. However, Verardi and Croux (2009) perform some simulations using contaminated data to show that their M-estimator is the least biased estimator when compared to the OLS and the robust regression estimators, suggesting that Model 5 should be preferred over Model 4. Therefore, the further discussions of the empirical results is based on Model 5 estimators.

In line with the findings from our descriptive statistical analysis, the regression analysis supports the existence of economies of scale in the case of both policies (see Model 5 estimators in Tables 7, 8). Internal and external MRV costs are non-linear in emissions: they increase with emissions at a decreasing rate. For instance, from Figure 2, which summarizes the partial marginal effects of CO_2 emissions on the MRV costs for both sets of firms based on Model 5-estimated coefficients, it is evident that, ceteris paribus, an increase in CO_2 emissions from 10 ktCO_2 to 20 ktCO_2 increases the MRV costs by about 6.2% for CO_2 tax firms and about 4.1% for EU ETS firms. In going from 500 ktCO_2 to 510 ktCO_2, the MRV costs are predicted to decrease by about 3.8% for CO_2 tax firms and increase by about 2.4% for EU ETS firms. Furthermore, from the estimated relationships we can find a turning point at which the effect of CO_2 emissions on the MRV costs is zero. Before this point,

[23] There might be other firm characteristics (observable and unobservable for researchers) that explain the MRV costs. In our models we include the variables that were available to us. The Ramsey RESET test shows that the estimated models for both firm samples are not misspecified.

[24] See Verardi and Croux (2009) and Baldauf and Silva (2012) for the properties and implementation of these estimators.

[25] The detailed results of the performed diagnostic tests and the estimated econometric models can be provided by the authors upon request.

Table 7 The results from the econometric models—CO_2 tax firms

Variables	CO_2 tax firms				
	The dependent variable is log (MRV)				
	Model 1	Model 2	Model 3	Model 4	Model 5
CO_2 emissions	1.30E−05**	1.30E−05**	1.30E−05***	1.48E−05***	6.57E−06***
	2.21	*2.03*	*3.14*	*2.36*	*3.58*
CO_2-squared	−1.30E−11	−1.30E−11	−1.30E−11	−1.61E−11	−1.02E−11***
	−1.32	*−1.29*	*−1.78*	*−1.54*	*−3.95*
Double-regulated firms	−0.125	−0.125	−0.125	−0.262	−0.671***
	−0.27	*−0.26*	*−0.28*	*0.603*	*−7.53*
Energy firms	0.585	0.585	0.585**	0.676*	0.278
	1.53	*1.49*	*2.20*	*1.66*	*1.48*
Employees	3.48E−05	3.48E−05	3.48E−05	4.49E−05	3.82E−04***
	0.15	*0.2*	*0.21*	*0.18*	*8.63*
Turnover	−6.75E−04*	−6.75E−04**	−6.75E−04**	−6.53E−04	−4.10E−04***
	−1.73	*−2.45*	*−2.41*	*−1.57*	*−10.16*
No. of plants	−0.052	−0.052	−0.052	−0.065	−0.095***
	−0.79	*−0.88*	*−1.76*	*0.36*	*−4.07*
Constant	1.498***	1.498***	1.498***	1.536***	2.301***
	3.00	*2.85*	*3.10*	*2.90*	*19.40*
No. of firms	58	58	58	58	58
F-statistic	2.02*	n/a	n/a	2.02*	n/a
R^2	0.22	0.22	0.22	0.20	n/a
AIC	179.8	179.8	179.8	71.3	n/a

(1) ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. (2) *t* values in italics. (3) Model 1: OLS regression; Model 2: OLS regression with robust standard errors; Model 3: OLS regression with standard errors clustered at industry level; Model 4: robust regression; and Model 5: MS-estimator. 4. Model 4 was estimated using the Stata commands *rreg* and *rregfit*. 5. Model 5 was estimated using the Stata command *msregress*. 6. All models estimated without influential observations

the CO_2 emissions have the effect of increasing the MRV costs; after this point, the CO_2 emissions have the effect of decreasing the MRV costs. In the estimated equation of Model 5, the turning point is 322,059 t of CO_2 emissions in the case of the CO_2 tax and 1,208,092 t of CO_2 emissions in the case of the EU ETS. Since the MRV costs for CO_2 tax firms decrease faster with emissions at lower CO_2 emissions levels than for EU ETS firms, we can infer that the fixed component of the MRV costs is the main component of the MRV costs under CO_2 taxation, and that in absolute terms, it is lower than the fixed component of the costs under the EU ETS.

The coefficients of some remaining explanatory variables estimated from Model 5 are individually insignificant but jointly different from zero, suggesting their importance in explaining variation in the MRV costs. The positive though insignificant coefficient for $double_i$ for EU ETS firms hints that double-regulated EU ETS firms may have higher MRV costs than EU ETS firms subject only to the MRV requirements of the EU ETS. However, for the sample of CO_2 tax firms, the estimated coefficient for $double_i$ is negative and significant. These findings suggest that the interaction of the MRV requirements of both policies

Table 8 The results from the econometric models—EU ETS firms

Variables	EU ETS firms				
	The dependent variable is log (MRV)				
	Model 1	Model 2	Model 3	Model 4	Model 5
CO_2 emissions	3.50E−06***	3.50E−06**	3.50E−06***	3.81E−06***	4.18E−06***
	3.18	*6.81*	*11.56*	*3.88*	*3.26*
CO_2-squared	− 1.44E−12***	− 1.44E−12***	− 1.44E−12***	− 1.60E−12***	− 1.73E−12***
	− 2.84	*− 6.53*	*− 10.78*	*− 3.53*	*− 3.17*
Double-regulated firms	0.347*	0.347*	0.347**	0.148	0.171
	1.88	*1.91*	*2.36*	*0.9*	*0.43*
Energy firms	0.243	0.243	0.243	0.155	0.302
	1.22	*1.20*	*1.62*	*0.87*	*0.89*
Employees	6.19E−05	6.19E−05	6.19E−05	− 7.12E−06	−3.54E−05
	0.74	*0.68*	*0.67*	*− 0.1*	*− 1.51*
Turnover	7.13E−05 l	7.13E−05	7.13E−05	1.65E−04	1.65E−04***
	0.32	*0.48*	*0.52*	*0.83*	*2.82*
No. of plants	0.029	0.029	0.029	0.028	0.028
	0.85	*1.01*	*0.93*	*0.369*	*0.58*
Constant	2.029***	2.029***	2.029***	2.159***	2.012***
	10.24	*11.21*	*13.04*	*12.23*	*8.40*
No. of firms	93	93	93	93	93
F-statistic	3.87***	n/a	n/a	4.46***	n/a
R^2	0.24	0.24	0.24	0.22	n/a
AIC	231.1	231.1	231.1	131.9	n/a

(1) ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. (2) t values in italics. (3) Model 1: OLS regression; Model 2: OLS regression with robust standard errors; Model 3: OLS regression with standard errors clustered at industry level; Model 4: robust regression; and Model 5: MS-estimator. (4) Model 4 was estimated using the Stata commands *rreg* and *rregfit*. (5) Model 5 was estimated using the Stata command *msregress*. (6) All models estimated without influential observations

reduces the MRV costs of CO_2 taxation, but there is no effect for the MRV costs of the EU ETS. An explanation for this is that—as discussed in Sect. 5.1.2—firms subject to the MRV requirements of both policies monitor emissions more often, which might somehow facilitate the monthly reporting under the CO_2 tax.

The positive coefficient for $energy_i$ hints that the MRV costs of both policies are higher for energy firms than for firms operating in other sectors. One explanation for this is the structure of energy firms—usually they run several plants located in different locations and this might require additional staff and other resources for the MRV procedures. For example, in the case of the EU ETS, each plant within a regulated firm is subject to the same MRV procedures. However, this statement is weakened by the fact that the estimated coefficient for $plants_i$ is individually insignificant for EU ETS firms, while the estimated coefficient of this variable for CO_2 tax firms is negative and significant, hinting that there is economies of scale in the MRV costs of CO_2 taxation in terms of the number of plants owned by the firm.

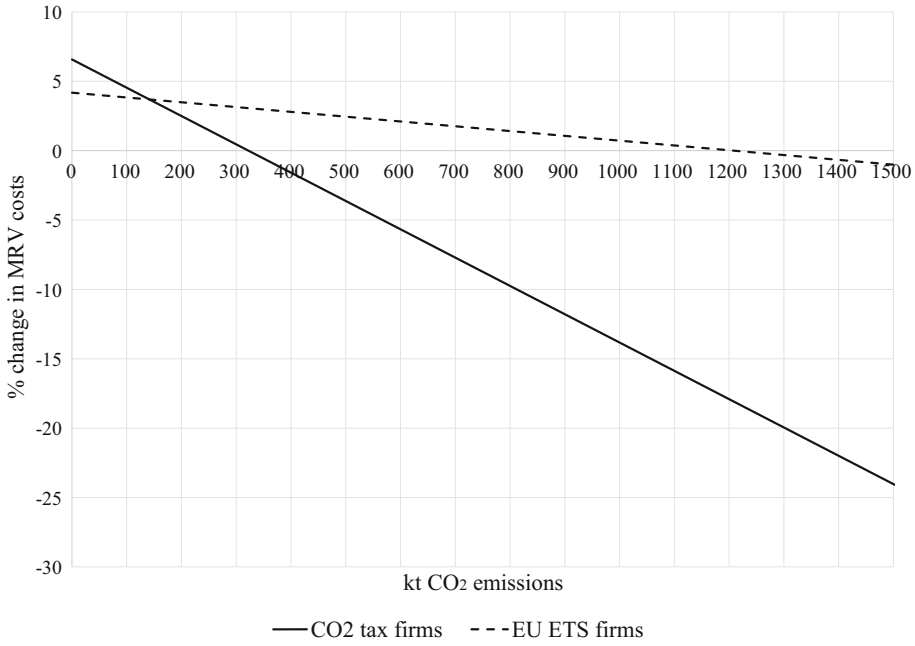

Fig. 2 The partial effects of CO_2 emissions on MRV costs. *Sources*: the authors' calculations. *Note* (1) The calculation of the partial effects is based on Model 5 estimates. (2) This figure summarizes, ceteris paribus, the percentage changes in the MRV costs when CO_2 emissions change by 10 ktCO_2

Another interesting result is that the MRV costs are decreasing with revenue in the case of CO_2 tax firms, while the opposite relationship holds in the case of EU ETS firms. The former might suggest that CO_2 tax firms that are large in terms of output have more experience complying with environmental regulations and hence incur lower transaction costs. The latter indicates that economies of scale in MRV costs in terms of output are not present for firms in the EU ETS.

In order to better control for firm-unobserved characteristics and to check whether there is no problem of endogeneity arising as a result of omitted variables, we also estimate a pooled regression model for the sample of double-regulated firms. With this exercise we are able to compare the MRV costs of the two policies for the exact same firms. The model takes the following form:

$$\begin{aligned} ln(MRV_i) = \beta_0 + X_i\gamma + \beta_1 \mathrm{CO}_{2i} + \beta_2 \mathrm{CO}_{2i}^2 + \beta_3 D_{TAX} \\ + \beta_4 D_{TAX} * \mathrm{CO}_{2i} + \beta_5 D_{TAX} * \mathrm{CO}_{2i}^2 + \epsilon_i. \end{aligned} \tag{3}$$

To capture economies of scales of both policies the pooled regression model contains the dummy variable D_{TAX}, which identifies the origin of the MRV costs (CO_2 taxation vs. EU ETS), and the two interaction terms—between the dummy variable D_{TAX} and CO_2 emissions CO_{2i} and the dummy variable D_{TAX} and squared CO_2 emissions CO_{2i}^2. The remaining explanatory variables are the same as before. We estimate five regression models as described above. The results of these models are summarized in Table 14 in the Appendix. As before, the discussion of the empirical results is based on Model 5 estimates.

This model, again, supports the existence of economies of scale in the case of both policies (see Model 5 estimators). The estimated coefficient β_1 for the level of CO_2 emissions is

positive and significant, while the estimated coefficient β_2 for the squared CO_2 emissions is negative and significant. Also, the negative and significant coefficient for the dummy variable D_{TAX} indicates that the MRV costs of the CO_2 taxation are lower. This is to say that for the exact same firms, the MRV procedures of CO_2 tax are less costly.

6 Discussion and Conclusions

In this paper we empirically compared the transaction costs of measurement, reporting, and verification of two regulatory designs aimed to cost-efficiently reduce GHG emissions: an upstream CO_2 tax and a downstream tradable emissions system. We chose to look at the case of Sweden, where a set of firms were for some years subject to both types of regulations: the Swedish CO_2 tax and the European Union's Emissions Trading System. This provided us with an excellent case study as it allowed us to disentangle the costs of each regulatory design from other firm-specific variables that might affect the overall cost of MRV procedures.

In particular, we aimed to answer the following questions: (1) Are firms' MRV transaction costs higher under CO_2 taxation or the EU ETS? (2) Do firms' MRV costs depend on CO_2 emissions? (3) Are there any economies of scope from the interaction of the CO_2tax and the EU ETS on firms' MRV costs? We focus our analysis on the MRV costs of warehouse keepers, who are the only firms that can file and pay the CO_2 tax. However, by buying fuel from authorized warehouse keepers, many firms and final clients pay the tax without incurring any MRV costs. Thus, by surveying warehouse keepers we focus on the only firms that have MRV costs related to compliance with the CO_2 tax.

Our results indicate that there is a significant degree of heterogeneity in the transaction costs of the firms in our sample. Moreover, for some of the firms, the transaction costs are high, especially compared with the actual cost of the CO_2 tax and the price of the EU ETS permits. This is by all means an important finding considering that most studies analyzing or comparing environmental regulations disregard the role of transaction costs. When comparing MRV costs between policies, we find that the costs are generally higher under the EU ETS than under CO_2 taxation. Thus, regulation overlap has implied increased transaction costs compared with what the costs could have been with only one policy in place. Since the MRV costs of both policies are high, the recommendation is therefore to avoid such policy overlap.

A caveat of our analysis is that we compare the costs of two policies in place and hence disregard start-up costs, which might be quite large in the case of the EU ETS. We also disregard the trading costs under the EU ETS. Including such costs in the analysis could clearly increase the wedge between the transaction costs of the studied policies, increasing even further the administrative cost to firms of the EU ETS with regard to the administrative costs under carbon taxation. Moreover, unlike taxes, reducing the stringency of MRV activities can affect the incentives to comply with any regulation. In contrast to carbon taxation, under an emissions trading scheme the price of emission permits is affected by the strength of monitoring and enforcement activities; weak monitoring and enforcement reduces the demand for permits and the equilibrium market price. In addition, low permit price reduces incentives to invest in abatement technologies. Thus, the success of an emissions trading scheme will certainly depend on the strength of MRV. If not properly handled, this can affect the emission price and therefore the aggregate abatement level achieved by the policy in the long term. Hence, MRV procedures related to emissions trading are not only more costly than those related to CO_2 taxation but also much needed if the regulation is to provide real incentives for polluters to reduce emissions.

Though there are some design features which are not held constant between the Swedish CO_2 tax and the EU ETS (as for instance, higher frequency of reporting under CO_2 taxation and a broader definition of source stream under the EU ETS), our results confirm all in all the general view that regulating emissions upstream by means of a carbon tax decreases transaction costs vis-á-vis downstream regulation by means of emissions trading. Morover, our results also shed light on how the point of regulation can affect transaction costs of emissions trading. As discussed in the paper, the choice of point of obligation affects transaction costs and the amount of emissions covered by the regulation. Several studies (e.g., Stavins 2008 and Kerr and Duscha 2014) make a case for an upstream option in the United States and other countries. Our results provide empirical support for such an option. Based on our results for Sweden, we can argue that such an approach could lead to significant reductions in MVR costs and a larger number of firms being cost-effectively regulated. Regarding the transaction costs of the tax instrument, the design of the Swedish CO_2 tax involves a series of reduced tax rates that have been applied to sectors that are open to international competition. Beyond the effect of such exemptions affecting the the cost-effectiveness of the instrument, it is clear that the transaction costs of MRV might be affected by the complexity of the tax rule, and arguably, such exemptions make the recordkeeping more burdensome than in the case of a uniform carbon tax.

Last but not the least we acknowledge that our study is based on the analysis of the small data sample collected through the survey. It is very likely that the firms that answered the survey have higher MRV costs and/or are more concerned about this type of costs. However, we cannot confidently determine in which direction the sample selection issues affect the results of this analysis. More of similar case studies of other firms in other countries that also face similar regulations would strengthen our analysis and would contribute to the scant empirical literature on the measurement of transaction costs of environmental policy instruments.

Compliance with Ethical Standards

Funding Funding was provided by Instrument Design for Global Climate Mitigation (INDIGO).

Appendix A: Copy of the Survey

Note: This page is intentionally left blank. Please proceed to the next page to see the copy of the questionnaire.

Survey on Transaction Costs of Climate Policies.

The purpose of this survey is to gather information and compare transaction costs incurred by Swedish firms covered under the Swedish CO_2 tax and/or the European Union Emissions Trading System (EU ETS). Transaction costs, for the purposes of this analysis, are grouped into costs of **monitoring**, **reporting** and **verification (MRV)**. Costs of monitoring include staff and management time spent checking, observing and recording CO_2 emissions and/or fuel purchases, as well as purchases of equipment necessary to perform monitoring procedures. Costs of reporting include management and staff time spent performing necessary paperwork, writing reports for the regulator or for internal purposes. Costs of verification include staff and management time spent on verification procedures, such as organizing verification processes, contacting a verifier, and preparing necessary information for a verifier.

This survey is conducted by the XXX in collaboration with researchers at the XXX and XXX. It consists of short questions and should take no more than 30 minutes to complete.

The information you provide will be treated as strictly confidential. It will be used as an input into the evaluation of environmental policies. The data from this survey will be publicly available at aggregate level only.

We would be grateful if you could complete the survey before **May 23th, 2013**.

Many thanks in advance for your help. Your answer is very valuable to us. If you have questions regarding the survey, please contact XXX (email: XXX).

GENERAL DETAILS

Details of the person who led the completion of the questionnaire:	
Name	
Position	
Telephone number	
Fax number	
E-mail address	

Firm name	
Official registration number	
Number of employees	
Main economic activity	
NACE activity code (2 digit)	
If your firm is a part of a subsidiary, provide its name	

Unless otherwise stated please answer each question by marking X in the appropriate box(es).

Monitoring, reporting and verification (MRV) costs

Most environmental regulations require regulated firms to monitor and report their emissions or fuel consumption on a monthly or annual basis. In some cases, these reports might have to be verified by an accredited verifier.

In what follows, we would like to ask you a series of questions regarding the costs of monitoring, reporting, and verifications (MRV) that were incurred by your firm as part of the compliance with the CO_2 tax and/or EU ETS.

We assume that MRV costs can be divided into four categories:

- *internal* **costs, mainly management and staff time;**
- *external* **costs incurred in terms of consultancy services taken in to be MRV compliant;**
- *capital* **costs, meaning emissions/fuel measurement, monitoring, recording, and data storage equipment needed to comply.**
- *other* **costs not included in the above**

IMPORTANT:

Most questions refer to the decisions or actions taken in 2012. Please complete the questionnaire even if your firm opted out of the regulation in 2013.

If your firm paid CO_2 tax and participated in the EU ETS, please answer the questions presented in Section A, Section B, and Section C.

If your firm paid only the CO_2 tax (i.e., you firm is an authorized fuel warehouse keeper), please answer the questions presented in Section A and Section C.

If your firm participated only in the EU ETS, please answer the questions presented in Section B and Section C.

SECTION A MRV costs of CO_2 taxation

The Swedish CO_2 tax was introduced in 1991. The tax is differentiated according to carbon content of fuels and energy sources. Around 300 companies are authorized to produce and hold energy products without tax being charged and declare the tax upon the delivery outside the suspension regime.

Authorized fuel warehouse keepers should report their fuel expenditure and use, and calculate the related emissions to the Swedish Tax Agency on a monthly basis.

A0 Is your firm an **authorised fuel warehouse keeper** requested to report fuel purchase/use to the Swedish Tax Agency?

	Yes	CONTINUE
	No	GO TO SECTION B

MONITORING

A1 How frequently did your firm **monitor** (check/observe) its fuel purchase/use in the year **2012**?

Daily	
Weekly	
Monthly	
Quarterly	
Semi-annually	
Annually	
Ad hoc (please specify)	

A2 What is your estimate of the total number of full-time working days spent in **2012** by your firm's staff on the **monitoring** procedures related to the CO_2 tax? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

A3 Did your firm incur any **external** costs for the **monitoring** procedures related to the CO_2 tax in **2012**?

	Yes	CONTINUE
	No	GO TO A5

A4 Please provide the estimated overall **external** costs in **2012** for the **monitoring** procedures **in 000s of SEK**.

A5 Has your firm incurred any **capital** costs necessary to perform the **monitoring** activities related to the CO_2 tax?

	Yes	CONTINUE
	No	GO TO A8

A6 What necessary equipment or technology has your firm purchased to perform **monitoring**? **Please describe below.**

A7 Please provide the estimated total costs of acquiring equipment or technology necessary to perform **monitoring** activities **in 000s of SEK.**

REPORTING

A8 How frequently did your firm **report** its fuel purchase/use in the year **2012**?

Daily	
Weekly	
Monthly	
Quarterly	
Semi-annually	
Annually	
Ad hoc (please specify)	

A9 What is your estimate of the total number of full-time working days spent in **2012** by your firm's staff on the **reporting** procedures related to the CO_2 tax? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

A10 Did your firm incur any **external** costs for the **reporting** procedures related to the CO_2 tax in **2012**?

	Yes	CONTINUE
	No	GO TO A12

A11 Please provide the estimated overall **external** costs in **2012** for the **reporting** procedures **in 000s of SEK**.

VERIFICATION

A12 Were your firm's fuel purchase/use and CO_2 tax payments **verified** by the regulator in **2012**?

	Yes	CONTINUE
	No	GO TO A15

A13 Please describe below **the CO_2 tax verification process in you firm.**

A14 What is your estimate of the total number of full-time working days spent in the year **2012** by your firm's staff on the **verification** procedures related to the CO_2 tax? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

GENERAL

A15 Please provide a breakdown of your firm's total **MRV** costs related to the CO_2 tax in **2012**.

Monitoring	%
Reporting	%
Verification	%
Total MRV	**100%**

A16 Are there any other relevant costs related to the compliance with the CO_2 tax? **Please describe below.**

A17 Have the **MRV** related to the CO_2 tax increased/decreased over time? If yes, to what extent? **Please describe below.**

SECTION B MRV costs in the EU ETS

Installations in the EU ETS are required to monitor and report their annual emissions in accordance with legally binding guidelines adopted by the European Commission. Installations are required to have an approved monitoring plan, according to which they monitor and report their emissions during the year.

The data in the annual emission report must be verified before 31 March each year by an accredited verifier. Operators must surrender the equivalent number of allowances by 30 April of the same year.

This annual procedure of monitoring, reporting, and verification, as well as all processes connected to these activities, are known as the "compliance cycle" of the EU ETS.

NOTES:

1. **If your firm has several installations in the EU ETS, please provide your answers in such a way that they refer to all installations within your firm. If for some reason it is difficult to do that, please indicate here.**
   _____
   _____
   _____
   _____.
2. **If a question refers to the year 2012, please consider this year as the EU ETS compliance year.**

MONITORING

B0 Is you firm regulated by the EU ETS?

	Yes	CONTINUE
	No	GO TO SECTION C

B1 How frequently did your firm **monitor** (check/observe) its CO_2 emissions in compliance year **2012**?

Daily	
Weekly	
Monthly	
Quarterly	
Semi-annually	
Annually	
Ad hoc (please specify)	

B2 What is your estimate of the total number of full-time working days spent in compliance year **2012** by your firm's staff on the **monitoring** procedures related to the EU ETS? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

B3 Did your firm incur any **external** costs for the **monitoring** procedures related to the EU ETS in compliance year **2012**?

	Yes	CONTINUE
	No	GO TO B5

B4 Please provide the estimated total **external** costs in compliance year **2012** for the **monitoring** procedures **in 000s of SEK**.

B5 Has your firm incurred any **capital** costs necessary to perform the **monitoring** activities related to the EU ETS?

	Yes	CONTINUE
	No	GO TO B8

B6 What necessary equipment or technology has your firm purchased to perform **monitoring**?
Please describe below.

B7 Please provide the estimated total acquisition costs of equipment or technology necessary to perform **monitoring** activities **in 000s of SEK.**

REPORTING

B8 How frequently did your firm **report** its CO_2 emissions in compliance year **2012**?

Daily	
Weekly	
Monthly	
Quarterly	
Semi-annually	
Annually	
Ad hoc (please specify)	

B9 What is your estimate of the total number of full-time working days spent in compliance year **2012** by your firm's staff on the **reporting** procedures related to the EU ETS? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

B10 Did your firm incur any **external** costs for the **reporting** procedures related to the EU ETS in the compliance year **2012**?

	Yes	CONTINUE
	No	GO TO B12

B11 Please provide the estimated total **external** costs in compliance year **2012** for the **reporting** procedures **in 000s of SEK**.

VERIFICATION

B12 What is your estimate of the total number of full-time working days spent in compliance year **2012** by your firm's staff on the **verification** procedures related to the EU ETS? **PLEASE WRITE IN NUMBER – RECORD NONE AS '0000'.**

B13 Did your firm incur any **external** costs for the **verification** procedures related to the EU ETS in compliance year 2012? **NOTE: THESE COSTS SHOULD INCLUDE THE COSTS OF AN EXTERNAL VERIFIER.**

	Yes	CONTINUE
	No	GO TO B15

B14 Please provide the estimated total external costs in compliance year **2012** for the **verification** procedures **in 000s of SEK**. **NOTE: THESE COSTS SHOULD INCLUDE THE COSTS OF AN EXTERNAL VERIFIER.**

GENERAL

B15 Please provide a breakdown of your firm's total **MRV** costs related to the EU ETS in compliance year 2012.

Monitoring	%
Reporting	%
Verification	%
Total MRV	**100%**

B16 Are there any other relevant costs related to the compliance with the EU ETS? **Please describe below.**

B17 Have the costs of **MRV** related to the EU ETS increased/decreased since your firm joined the EU ETS? If yes, to what extent? **Please describe below.**

SECTION C GENERAL QUESTIONS

Please answer the questions below irrespectively of which environmental regulations your firm is subject to. When answering the questions below, please provide your own opinion rather than your firm's official position.

C1 Please indicate to what extent you agree with the following statement: "In terms of the administrative burden, if our firm was given an opportunity to be regulated by only the CO_2 tax or the EU ETS, we would prefer the CO_2 tax."

Strongly agree	Agree	Indifferent	Disagree	Strongly disagree

C2 Please indicate to what extent you agree with the following statement: "The EU ETS provides stronger incentives for firms to reduce their CO_2 emissions than the CO_2 tax."

Strongly agree	Agree	Indifferent	Disagree	Strongly disagree

C3 Please indicate to what extent you agree with the following statement: "The volatility of the price of the allowances in the EU ETS has provided firms with strong incentives to reduce their CO_2 emissions."

Strongly agree	Agree	Indifferent	Disagree	Strongly disagree

C4 Please indicate to what extent you agree with the following statement: "The EU ETS is too burdensome for small emitters." According to the EU ETS Directive (Article 27), small emitters are defined as having annual emissions below 25,000 tons of CO_2 and a thermal capacity not exceeding 35MW per year.

Strongly agree	Agree	Indifferent	Disagree	Strongly disagree

Appendix B: The Results of the Non-parametric Wilcoxon–Mann–Whitney and Wilcoxon Signed-Rank Tests

See Tables 9, 10, 11, 12, 13, and 14.

Table 9 Comparing the MRV costs between CO_2 tax *double-regulated* firms and EU ETS *double-regulated* firms, the results of the non-parametric Wilcoxon signed-rank test

	p value	No. of double-regulated firms
Internal costs	0.001	59
Internal and external costs	0.000	59
Internal, external and capital costs	0.000	59
Internal costs per tCO_2	0.001	53
Internal and external costs per tCO_2	0.000	53
Internal, external and capital costs per tCO_2	0.000	53

Table 10 Comparing the MRV costs between CO_2 tax (EU ETS) *single-regulated* firms and CO_2 tax (EU ETS) *double-regulated* firms, the results of the non-parametric Wilcoxon–Mann–Whitney test

	p value	No. of single-reg. firms	No. of double-reg. firms
CO_2 *tax firms*			
Internal costs	0.660	20	59
Internal and external costs	0.822	20	59
Internal, external and capital costs	0.987	20	59
Internal costs per tCO_2	0.445	6	54
Internal and external costs per tCO_2	0.349	6	54
Internal, external and capital costs per tCO_2	0.402	6	54
EU ETS firms			
Internal costs	0.001	40	59
Internal and external costs	0.001	40	59
Internal, external and capital costs	0.003	40	59
Internal costs per tCO_2	0.006	39	57
Internal and external costs per tCO_2	0.003	39	57
Internal, external and capital costs per tCO_2	0.003	39	57

Table 11 Comparing the shares of the internal and total MRV costs between CO_2 tax double-regulated firms and EU ETS double-regulated firms, the results of the non-parametric Wilcoxon signed-rank test

	p value	No. of double-regulated firms
Internal MRV cost breakdown		
Monitoring cost share	0.044	59
Reporting cost share	0.003	59
Verification cost share	0.000	59
Total MRV cost breakdown		
Monitoring cost share	0.007	56
Reporting cost share	0.000	56
Verification cost share	0.000	56

Table 12 Comparing the MRV costs between small and large firms within each regulation, the results of the non-parametric Wilcoxon–Mann–Whitney test

	p value	No. of small firms	No. of large firms
CO_2 *tax firms*			
Internal costs	0.133	37	26
Internal and external costs	0.468	37	26
Internal, external and capital costs	0.769	37	26
Internal costs per tCO_2	0.000	36	26
Internal and external costs per tCO_2	0.000	36	26
Internal, external and capital costs per tCO_2	0.000	36	26
EU ETS firms			
Internal costs	0.001	72	31
Internal and external costs	0.001	72	31
Internal, external and capital costs	0.002	72	31
Internal costs per tCO_2	0.000	70	31
Internal and external costs per tCO_2	0.000	70	31
Internal, external and capital costs per tCO_2	0.000	70	31

Table 13 Comparing the MRV costs for different size firms across regulations, the results of the non-parametric Wilcoxon signed-rank test

	p value	No. of double-regulated firms
Small firms		
Internal costs	0.039	34
Internal and external costs	0.000	34
Internal, external and capital costs	0.000	34
Internal costs per tCO_2	0.231	33
Internal and external costs per tCO_2	0.001	33
Internal, external and capital costs per tCO_2	0.002	33
Large firms		
Internal costs	0.060	25
Internal and external costs	0.003	25
Internal, external and capital costs	0.003	25
Internal costs per tCO_2	0.037	24
Internal and external costs per tCO_2	0.020	24
Internal, external and capital costs per tCO_2	0.002	24

Table 14 The results from the econometric models—robustness tests

Variables	Pooled sample—double-regulated firms				
	The dependent variable is log (MRV)				
	Model 1	Model 2	Model 3	Model 4	Model 5
CO_2 emissions	4.72E−06	4.72E−06*	4.72E−06*	1.03E−05	7.88E−06***
	1.40	*1.91*	*2.10*	*1.52*	*4.94*
CO_2-squared	−1.05E−12	−1.05E−12	−1.05E−12	−2.01E−11	−9.59E−12***
	−0.18	*−0.26*	*−0.28*	*−0.86*	*−4.15*
CO_2 emissions*CO_2 tax firms	4.11E−06	4.11E−06	4.11E−06	2.77E−06	−4.36E−06**
	0.89	*0.92*	*0.78*	*0.29*	*−2.28*
CO_2-squared*CO_2 tax firms	−9.75E−12	−9.75E−12	−9.75E−12	−6.77E−12	2.52E−12
	−1.24	*−1.51*	*−1.29*	*−0.21*	*1.00*
CO_2 tax firms	−0.971***	−0.971***	−0.971***	−0.974***	−0.831***
	−4.30	*−4.28*	*−6.76*	*−3.75*	*−3.52*
Energy firms	0.535**	0.535**	0.535***	0.551**	0.516*
	2.21	*2.27*	*3.63*	*2.20*	*1.65*
Employees	1.43E−04	1.43E−04	1.43E−04	1.62E−04	5.71E−04***
	1.33	*1.09*	*0.96*	*1.46*	*8.22*
Turnover	−2.93E−04	−2.93E−04	−2.93E−04	−3.63E−04	−2.35E−04*
	−1.24	*−1.30*	*−1.49*	*−1.39*	*−1.65*
No. of plants	−3.23E−04	−3.23E−04	−3.23E−04	−4.02E−03	−0.057
	−0.01	*−0.01*	*−0.02*	*−0.10*	*−1.42*
Constant	2.259***	2.259***	2.259***	2.149***	2.220***
	10.79	*12.67*	*19.11*	*9.36*	*7.61*
No. of firms	112	112	112	112	112
F-statistic	5.23***	n/a	n/a	4.52	n/a
R^2	0.32	0.32	0.32	0.25	n/a
AIC	322.0	322.0	322.0	133.8	n/a

(1) ***$p \leq 0.01$; **$p \leq 0.05$; *$p \leq 0.1$. (2) *t* values in italics. (3) Model 1: OLS regression; Model 2: OLS regression with robust standard errors; Model 3: OLS regression with standard errors clustered at industry level; Model 4: robust regression; and Model 5: MS-estimator. 4. Model 4 was estimated using the Stata commands *rreg* and *rregfit*. 5. Model 5 was estimated using the Stata command *msregress*. 6. All models estimated without influential observations.

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