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The Effect of Environmental Protection Expenditures on Industrial Employment in Sweden

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Abstract
In this paper, we empirically investigate how environmental protection expenditures affect sector-level employment within manufacturing industries, using detailed firm-level data for Sweden for the years 2002–2021. We use a structural model that allows for a decomposition of the total employment effect of environmental protection expenditures within a sector into a cost effect, a factor shift effect, and a demand effect. We add to previous literature by using instrumental variables in our empirical framework, to account for endogenous environmental spending stemming from, e.g., corporate social responsibility and self-regulation. Our results reveal that increased environmental protection expenditures generally have no statistically significant effect on employment among the sectors studied, with the paper and pulp sector being the exception, showing non-negligible negative effects on employment.

Keywords Environmental protection · Labor demand · Environmental regulation

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1 Introduction

In this paper, we investigate the effect of environmental regulation on sector-level employment levels for the Swedish manufacturing industry, using self-reported environmental protection expenditures to measure regulatory burden. This paper contributes to previous literature by providing estimates of the employment effects of increased environmental protection expenditures[1] in a European context, using a rich data set that spans several sectors and years. We also add to previous literature by taking into account that environmental protection expenditures may be partly endogenous if firms choose to self-regulate, e.g., engage in corporate social responsibility (CSR), thereby incurring costs beyond what environmental regulation stipulates. This endogeneity in environmental protection expenditures has been repeatedly highlighted in previous literature as a potentially important feature (see, for example, the discussion in Belova et al. 2015), but to the best of our knowledge, no previous study has addressed this concern.

The motivation for studying how environmental protection expenditures affect employment originates from recent policy debates about environmental regulation, where concerns are raised about a potential "jobs versus the environment" conflict. Labor unions and trade groups argue that environmental regulation imposes extra costs on producers, which reduce production level and demand for labor. An alternative to this pessimistic perspective on environmental regulation is brought forward by the concept of "green jobs" which has become part of the policy discussion in recent years. This perspective argues that "green jobs" (i.e., jobs created directly or indirectly as a consequence of environmental regulation), can solve challenges related both to climate change and to high rates of unemployment in industrialized countries.[2]

In many cases, this debate concerns the effect of environmental regulation on the total employment level in the economy, even though such effects will only be present if the economy deviates from its normal rate of full employment (Belova et al. 2015). However, partial-equilibrium and sector-level effects are also important to policy makers, and these latter effects are what the current paper studies. For example, the size of sector-level effects may be important from the perspectives of labor unions and regional development, and can inform policy design regarding support for structural change following the green transition.

However, previous empirical studies on the sector-level employment effects of environmental regulation point to mixed results and apply different metrics and approaches when estimating these effects. For example, Berman and Bui (2001) and Morgenstern et al. (2002) do not find any substantial effects of environmental regulation on employment when looking at industry averages, although Morgenstern et al. (2002) find small positive and signifi-

[1] In previous literature, these expenditures are sometimes referred to as regulatory costs. However, both Eurostat and Statistics Sweden refer to these costs as environmental protection expenditures; see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Environmental_protection_expenditure_accounts and https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/environmental-accounts-and-sustainable-development/environmental-protection-expenditure/. We follow this notation.

[2] This policy debate can thus to some extent be tied to the Porter Hypothesis (PH) which states that well-crafted and well-enforced environmental regulation can benefit both the environment and firms' productivity by promoting innovation to overcome compliance costs (Porter 1991; Porter and Van der Linde 1995). However, while studies aiming to prove or disprove the PH analyze outcomes in terms of innovation (e.g., R&D investments, patent applications) and productivity (e.g., total factor productivity, export dynamics) (see, e.g., Rubashkina et al. 2015 and references therein), the current study focuses on the relation between environmental regulation and employment.

cant total employment effects for the individual sectors of plastic material and petroleum, respectively. Although using data and empirical approach that are similar to Morgenstern et al. (2002), Belova et al. (2013a) find substantially larger (positive) employment effects.

As pointed out in Belova et al. (2015), the variation in both metrics (gross vs. net effects) and estimated impacts (both in magnitude and direction) raises questions on how feasible it is to extrapolate from one study's context to other contexts. Since a majority of the empirical studies on this topic is based on data from the U.S., there is a current lack of studies from countries where the structure and composition of the labor market and industrial sector differ compared to the U.S. context. For example, differences in labor market structures between Europe and the U.S. have repeatedly been highlighted in the literature (e.g., Prescott, 2004; Rogerson and Wallenius, 2009), as well as differences in environmental regulations (e.g., Gouldson et al. 2015; Vogel, 2012). Such differences may influence the effect of environmental regulation on employment levels (Babiker and Eckaus, 2007). Finally, the fact that previous studies have ignored potential endogeneity in environmental protection expenditures raises concerns about the validity of existing evidence, and this concern is also highlighted by, e.g., Belova et al. (2015), Bénabou and Tirole (2010), and Heal (2005).

The current study uses the structural model approach of Morgenstern et al. (2002) and detailed Swedish firm-level data to decompose the sector-level employment effect of environmental protection expenditures (hereinafter referred to as EPE) into a cost effect, a factor shift effect, and a demand effect at the sector level.[3] While labor unions and trade groups tend to focus on the latter effect, the net, i.e., total, effect of increased environmental protection expenditures on employment may be positive if the cost effect is sufficiently large and/or if the factor shift effect is positive, i.e., if labor intensity increases due to increased environmental spending. Disentangling the three effects can thus aid in clarifying the complex relationship between environmental regulation and employment levels. Our main analysis focuses on the sectors in Sweden that are considered most energy-/pollution-intensive; chemical, iron and steel, paper and pulp and stone and mineral, usually referred to as basic heavy industry.

Importantly, we extend the empirical analysis in Morgenstern et al. (2002) and other related previous literature by allowing for environmental protection expenditures to be driven not only by external policy and regulation, but also by CSR and self-regulation, i.e., internal policy, so that environmental protection expenditures are endogenous to firms. As far as we are aware, the current study is the first to address this empirical concern in a partial equilibrium model of employment effects of environmental protection expenditures. Specifically, we employ an instrumental variables approach, where the sector-level average of the ratio of environmental protection expenditures to total costs is used as the excluded instrument.

In brief, we find that for the chemical sector, iron and steel sector and stone and mineral sector, the effect of environmental protection expenditures on sector-level employment is statistically insignificant, whereas for the paper and pulp sector, the effect is non-negligible. The differences across sectors are mainly explained by the varying magnitude of the demand effect and the varying direction of the factor shift effect. Furthermore, we also find that treating EPE as endogenous and using an instrumental variables approach to account for this changes the results relative to a model where EPE is treated as exogenous.

[3] A reduced-form approach to such decomposition can be found in Hille and Möbius (2019).

The rest of the paper is organized as follows: the institutional context of Sweden's labor market and policies regarding climate and environment are presented in Sect. 2, previous literature is reviewed in Sect. 3, followed by the theoretical framework in Sect. 4. We describe our empirical strategy in Sect. 5, the data are described in Sect. 6, and we present our results in Sect. 7. Section 8 concludes.

2 Institutional Setting

2.1 Swedish Labor Market and Manufacturing Industry

Sweden has a strong and successful manufacturing and industrial engineering industry that accounted for roughly 20 percent of the country's GDP, or approximately 115 billion Euro in 2020 (International Trade Administration, 2020). Furthermore, the manufacturing sector in Sweden directly employed about 530,000 people in 2019, corresponding to about 10 percent of total employment. Although this is lower compared to the EU level, where the manufacturing sector's share of total employment amounted to about 16 percent in 2019 (Eurostat, 2019), it is in line with numbers for the U.S., where the manufacturing sector's share of total employment amounted to about 10.6 percent in 2019 (U.S. Bureau of Labor Statistics, 2020).

The relationship between employers and employees and their organizations is regulated in Sweden in several laws. The labor market parties can make extensive deviations from the legislation through, so called, collective agreements, which is a written agreement on terms of employment between an employer-representative organization or an employer and a union organization. This may also regulate other conditions between employers and employees (see, for example, Carling and Richardson, 2004; Freeman et al. 2008). Furthermore, Sweden has a greater degree of labor market decentralization than many other EU countries: in Sweden, collective agreements do not extend to other parties, and government involvement in collective bargaining is very rare. Sweden has the third highest union density in the OECD, with approximately 68 percent of employees belonging to a union (Larsson, 2023). The corresponding number for the U.S. is about 10 percent (U.S. Bureau of Labor Statistics, 2019).[4]

2.2 Environmental regulation

While environmental policies have been in place since the early 1960's, the last two decades have seen an increased focus on issues regarding environmental protection and policies to mitigate climate change. With the 2015 Paris agreement, countries committed to drastically reduce greenhouse gas emissions and adapt society in response to climate change. While environmental protection and climate change are global issues, the EU has taken on a prominent role in this aspect, not least with the launch of the European Green Deal in 2019.

[4] Contrary to the widespread belief that highly unionized economies respond more slowly to shocks, Sweden's labor market dealt relatively well with, for example, the global financial crisis in 2008. In particular, the high level of cooperation between unions and employers' associations has been highlighted as factors that helped the Swedish economy work its way through the crisis (see the discussion in, e.g., Blanchard et al. 2014; Ulku and Muzi 2015).

Sweden has a long history of environmental regulation in the industrial sector; see, for example, Söderholm et al. (2022), and as of today, Sweden's long-term target is to have zero net greenhouse gas emissions by 2045 at the latest. In a global comparison, Sweden is considered relatively ambitious in terms of climate and environmental policy. To illustrate, according to the OECD environmental policy stringency index (OECD, 2024), Sweden is among the top 10 countries during the last 30 years, whereas, for example, the U.S. is placed among the bottom half for a large part of the same period.[5]

One of the major environmental policies in Sweden affecting the industrial sector is the EU-ETS, which covers more than 90 percent of all emissions from the Swedish industry (Swedish Environmental Protection Agency, 2024). For the four sectors that our study mainly concerns, approximately 20 percent of the firms (in our sample) are in the EU-ETS. The remaining firms are instead subject, to varying degrees, to a carbon tax which concerns driving fuels and other fossil fuels and amounts to approximately 0.1 Euro per kg of CO2 emissions. All firms pay the energy tax on their electricity consumption, which amounts to approximately 0.05 Euro per kWh of electricity consumed (see, e.g., the Swedish Environmental Protection Agency's website: www.naturvardsverket.se/amnesomraden/klimatomstallningen/omraden/klimatet-och-industrin/ for additional details). Other environmental and climate policies relevant for Sweden's industrial sector include, e.g., the Industrial Emissions Directive, which requires industries to use the best available technique to prevent and reduce pollution (European Parliament, Council of the European Union, 2010); Waste management regulations which prioritize waste prevention and minimization, and are implemented through the EU waste framework directive and the Swedish Environmental Code (Swedish Environmental Protection Agency, 2024); and Permitting processes for industrial activities regarding limits on emissions to air and water, noise level, and waste handling procedures.

Importantly, there are no differences across or within regions in Sweden when it comes to environmental regulatory stringency. In particular, the EU Commission regulates any state aid, support, or policy that may give competitive advantages to specific firms or industries (Article 107.1 in the Treaty on the Functioning of the European Union). This differs from, e.g., U.S. environmental regulation which can differ both within and across states (Greenstone, 2002; Levinson, 1996).

To illustrate Sweden's increasingly strict environmental regulation, Fig. 1 illustrates the development of environmental protection expenditures and investments in Msek among Swedish firms over the period 2001–2021 (aggregated for all sectors), separated into environmental areas in the left panel, and into cost type in the right panel. Environmental protection expenditures and investments are relatively evenly distributed across the areas Air, Water and Waste, while activities within the class Other receive less focus. In the right panel of the figure, we note that current expenditures is the largest cost type across the time period, and that treatment and preventive investments, respectively, are relatively similar in size. The reader should note that the graphs depict environmental protection expenditures and investments undertaken by the firms in order to comply with environmental policies such as those mentioned above and/or as a means of voluntary self-regulation (e.g., CSR). However,

[5] The same pattern is shown when looking at the index for stringency of environmental regulation, provided by World Economic Forum (World Economic Forum, 2018). This index is based on surveys with business executives that assess the stringency of the country's environmental regulation relative to other countries.

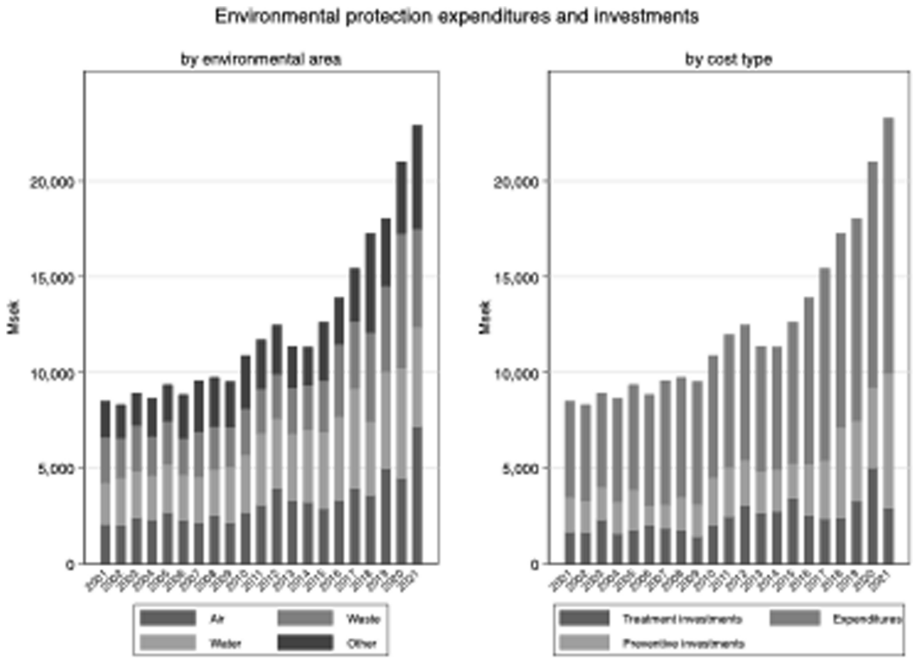

Fig. 1 Environmental protection expenditures and investments 2001–2021

costs associated with non-compliance, such as paying a carbon tax or purchasing tradable emission permits, are not included in these expenditures and investments.

3 Previous Literature

Survey-based measures of environmental protection expenditures suggest that environmental regulation imposes additional operational and capital costs for manufacturers. For instance, a study by the United States Census Bureau (2008) shows that the Clean Air Act (CAA) in the United States introduced costs amounting to $5.9 billion in capital expenditures. Manufacturers generally argue that these costs place them at a competitive disadvantage to such an extent that plants might decrease production or even close. In either case, these costs are argued to have negative impacts on employment.

Relatively few empirical studies have investigated how regulatory-induced environmental protection investments and expenditures affect demand for labor in regulated sectors. By far, most of these studies have been performed on data from the U.S. For example, Morgenstern et al. (2002) investigate the trade-off between environment and jobs by taking pollution abatement operating costs as a proxy for environmental regulation and analyzing how these regulations affect employment. They use plant-level panel data from four manufacturing sectors in the U.S: pulp and paper, plastic material, petroleum, and steel. They find that increased regulatory costs do not cause any notable changes in employment. Statistically significant and small positive total effects are found in the sectors petroleum and plastic material; sectors where abatement activities are relatively more labor-intensive compared to production activities. Furthermore, the authors find that the positive total employment effect is not offset by a demand response, due to demand for output being relatively price inelastic within these sectors. Belova et al. (2013a) use the same empirical approach as in Morgenstern et al. (2002), but with more recent data and more plants, and Belova et al. (2013b) extend the analysis to include the exit of plants in response to environmental regulation. Both these papers find somewhat larger effects than those found in Morgenstern et al. (2002).

Some other studies find that regulation has negative effects on industrial employment. For example, Kahn (1997) uses annual data on U.S. manufacturing employment at the county-level and shows that non-attainment counties (i.e., those with lower air quality than national standards) have lower employment growth rates. Attainment counties are less regulated because they comply with the CAA standards. Less regulation may lower production costs and encourage economic growth in such counties because producers prefer to be located there, which has the overall effect of diverting economic activities to attainment counties.

Greenstone (2002) uses plant-level observations to compare the pollutant-specific effects of the CAA on industrial activity between non-attainment counties (with air quality below the CAA standard) and attainment counties. He finds that non-attainment counties loose about 590,000 jobs during the first 15 years of CAA amendments (1972–1987) compared to the non-regulated counties. This loss is less than 4 percent of the total employment in the manufacturing sector over the studied period. Note, however, that these results do not represent the total effects of environmental regulation on employment, but rather indicate the relative growth of pollution-intensive manufacturing activities in non-attainment counties compared to attainment counties.

Another pair of studies (Walker, 2011, 2013) study whether higher emission standards under the CAA amendments affect employment. Walker (2011) applies a plant-level U.S. data set for the period 1985–2005 and show that the more restrictive emission standards introduced in the early 1990s permanently end certain jobs instead of merely reducing hiring rates in the regulated sectors, leading to a shift in production and employment away from newly regulated sectors. He shows that the size of the regulated polluting sector is reduced by 15 percent over ten years after the change in regulation. This job loss is linked to a major adjustment in employment through an almost doubled rate of lay-offs at the newly regulated plants. In a later study, Walker (2013) estimates the transitional costs related to the reallocation of labor from newly regulated industries to other sectors due to environmental regulation in the 1990 CAA amendments. He uses worker-firm level data and finds that workers experienced forgone earnings of more than \$5.4 billion, mainly due to non-employment and lower earnings in future employment for the years after the policy change. However, in relation to the estimated benefits of the 1990 CAA amendments, these one-time transitional costs are small. He also estimates how firms and workers respond to gradual changes in regulation, concluding that at the aggregate level, employment decreases in the regulated sector.

Kahn and Mansur (2013) employ U.S. plant-level data for the years 1998–2009 and show that employment within pollution-intensive industries is higher among counties with less strict CAA regulations. Berman and Bui (2001) use plant-level data to estimate the effects of increased air quality regulation in Los Angeles on pollution control capital investments, employment, and value added during the period 1979–1992. Although the regulation reduced NOx emissions and increased abatement investments, the authors find that local air quality regulation has no substantial negative effect on employment, since regulated plants belong to capital-intensive industries rather than labor-intensive ones.

Gray et al. (2014a) use U.S. plant-level data from the Census of Manufacturers and the Annual Survey of Manufacturers from 1992 to 2007 to examine how the "Cluster Rule" affects labor demand within the paper and pulp sector. The "Cluster Rule" is the Environmental Protection Agency's (EPA) first integrated regulation aimed at mitigating both air and water pollution within the paper and pulp sector. The authors find small negative effects on employment, ranging from 3 to 7 percent.

Ferris et al. (2014) use a panel data set consisting of fossil fuel fired power plants to study how phase 1 of EPA's SO2 trading program affects employment among electric power plants. The study finds little evidence of significant changes in plants' employment levels relative to the power plants that were not included. Gray and Shadbegian (2014b) analyze the effect of environmental regulation on employment in the U.S. manufacturing sector using data from 1973 to 1994. Their estimates suggest that higher levels of environmental regulation reduce the level of employment, but that the effects are very small in magnitude.

As previously mentioned, studies outside the U.S. on employment effects from environmental regulation are rare. However, there are a few more or less recent attempts studying this question in a non U.S. context. For example, Golombek and Raknerud (1997) study polluting firms in three sectors in Norway: pulp, paper, and paperboard; iron, steel, and ferroalloys, and basic industrial chemicals. They show that environmental regulation tends to have a positive impact on employment levels in the pulp, paper, and paperboard and iron, steel, and ferroalloys sectors. Cole and Elliott (2007) use a study design similar to Berman and Bui (2001) on UK industry-level data, covering 27 industries during the period 1999–2003. They conclude that environmental regulation costs generally have no effect on employment. Liu et al. (2017) use Chinese firm-level data to estimate the effects of a stricter wastewater discharge standard on textile printing and dyeing firms. They show that firms facing the more stringent standard reduce their labor demand by about 7 percent.

Another group of studies estimates the effects of participation in the European Union Emissions Trading Scheme (EU-ETS) on employment. Anger and Oberndorfer (2008) use data from 419 firms in Germany during the first phase (2005–2007) of the EUETS to study how this scheme affects employment levels in Germany. They find no significant effects on employment levels among the regulated firms during the first phase. Abrell et al. (2011) use firm-level panel data on emission levels and performance of more than 2000 European firms from 2005 to 2008 to investigate the effect of EU-ETS participation on employment. They find that EU-ETS does not affect firms' employment levels during the studied period. Chan et al. (2013) use panel data from about 6000 firms in 10 European countries from 2005 to 2009 and investigate the effects of EU-ETS participation on firms' employment levels for the three most polluting sectors (power, cement, and iron and steel). They conclude that EU-ETS has no negative effects on employment levels during the studied period.

In this paper, we use survey-based data on environmental protection expenditures (see Eurostat (2017)) as a proxy for environmental regulation, which is in line with much of the previous literature. In the U.S., pollution abatement cost and expenditures (PACE) data on manufacturing firms have been used to estimate the impact of environmental regulation on innovation (Jaffe and Palmer, 1997), trade (Ederington and Minier, 2003) and employment (Morgenstern et al. 2002; Belova et al. 2013a). Another study using the environmental protection expenditures, as defined in the Eurostat handbook (Eurostat, 2017), as a measure of environmental regulatory pressure, is Rubashkina et al. (2015) who estimate effects of environmental regulation on innovation for 17 European countries.

The main advantage of using survey-based cost data as a measure of regulatory stringency is that it usually varies across sectors, which other measures, such as energy prices, tend to do to a lesser extent. As Brunel and Levinson (2016) points out when comparing different measures of environmental stringency, the main disadvantage of using survey-based measures of regulatory costs is that it is not always clear that the respondent's view of the firm's environmental protection expenditures corresponds to the statistician's.[6] On the other hand, Becker (2005) finds that changes in environmental regulation are reflected in reported compliance costs.

3.1 Our Contribution

Several conclusions can be made from this literature review: First, empirical evidence suggest a range of positive and negative regulatory-induced effects on employment, but these effects are always relatively small in magnitude. Second, and most importantly, it is interesting to note that as far as we are aware, none of the previous studies have acknowledged that environmental protection expenditures may not only be driven by policy and regulation, but that firms may engage in CSR and self-regulation.

For example, several previous papers refer to environmental protection costs as regulatory costs (e.g., Morgenstern et al. 2002), which implicitly rest on the assumption that all these expenditures are driven by regulation; an assumption that has little support in neither previous literature nor our data. For example, Bénabou and Tirole (2010) and Heal (2005) argue that CSR is an important part of corporate strategy and that it can even be considered a mainstream business activity nowadays (Kitzmueller and Shimshack, 2012). Furthermore, as we illustrate in Sect. 6, environmental protection expenditures vary substantially within a sector, even when firms face the same regulation, again suggesting that some firms do more than others. This claim is also supported by Belova et al. (2015). If environmental protection expenditures are to some extent voluntary, treating environmental protection expenditures as exogenous may produce biased estimates. In particular, it seems likely that the effects associated with such expenditures may have very different effects on employment compared to regulation-driven environmental expenditures.

We contribute to the existing literature by explicitly acknowledging this endogeneity, and we use an instrumental variables approach to single out the variation in environmental protection expenditures that is driven by regulation (i.e., exogenous to the firm), and subsequently measure how this variation influences employment.

Furthermore, we contribute to the previous literature by studying the effects of environmental regulation on employment in Sweden, which differs from many other contexts studied in terms of both environmental regulation, labor market structure, and type of industries and costs (e.g., wages). As noted by Deschenes (2018), empirical evidence is limited to a few studies and most of them evaluate the effect of air quality regulations on employment outcomes in the U.S. A significant research agenda is needed to expand this knowledge to other settings, and more importantly, to other countries. In particular, it is of importance to study firms facing stricter environmental policies (both public and external policy as well as

[6] For example, Gallaher et al. (2008) cite sources that examine reasons to both under- and overestimation of PACE compared to the true costs of pollution abatement.

firms' own internal policy), as in European countries, where environmental regulation, and worker protection laws are typically stronger.[7] This paper aims to provide such evidence for the Swedish context.

4 The Effect of Environmental Regulation on Employment

The objective of this paper is to understand the effect of firms' efforts to comply with environmental regulation on aggregate sector-level employment. Following Morgenstern et al. (2002), we assume that each firm minimizes its costs with respect to two main distinct activities: conventional production activities to produce marketed goods Y, and environmental protection activities to produce an environmental output R. As environmental regulation becomes more strict, firms produce more R. However, as we discuss in Sect. 5, firms may also increase the production of R voluntarily, as a form of corporate social responsibility. Costs related to producing output R are referred to as environmental protection expenditures, or EPE. Firms use the same type of inputs (capital, labor and energy) to produce R as they use to produce Y.

The firm's total cost (TC) is the sum of production costs (PC) and EPE associated with production of Y and R, respectively, i.e., $TC = PC + EPE$. The way in which a marginal increase in EPE affects employment may differ depending on the extent to which the firm rearranges its production activities and changes its production level. Theoretically, changes in EPE initiate a sequence of changes that may ultimately change demand for labor, a process that is detailed below. First, we consider the effects of EPE on employment, holding output Y constant, and then proceed to extend the effects to a situation where also output changes.

4.1 The Effect of EPE on Firm-Level Employment

Assuming a translog cost function and a cost-minimizing behavior, firm-level employment for firm $i = 1, \ldots, N$ (in a given sector) in year $t = 1, \ldots, T$ can be written as (see, e.g., Morgenstern et al. 2002):

$$L_{it} = \frac{1}{P_{L,it}} v_{L,it} TC_{it} \tag{1}$$

where L is employment, P_L is the price of labor (i.e., wage), v_L is the labor cost share and TC is the total cost for firm i. Because both v_L and TC are functions of EPE,[8] the derivative of firm-level employment with respect to EPE (holding output constant so that $Y = \overline{Y}$) can then be written

$$\left.\frac{\partial L_{it}}{\partial EPE_{it}}\right| Y_{it} = \overline{Y}_{it} = \frac{TC_{it}}{P_{L,it}} \frac{\partial v_{L,it}}{\partial EPE_{it}} + \frac{v_{L,it}}{P_{L,it}} \frac{\partial TC_{it}}{\partial EPE_{it}} \tag{2}$$

[7] See, for example, Söderholm et al. (2022).

[8] $v_L = P_L L/(PC+EPE)$ and TC=PC+EPE.

where the first term on the right-hand side represents a factor shift effect, and the second term represents a cost effect. Under the assumption that firms hold output Y constant after incurring EPE, these effects can be explained as following:
First, using labor in the production of R may change labor intensity in total production activities, which means that the production of Y and R as a whole may become more or less labor-intensive than before incurring EPE. We refer to this process as the factor shift effect. If activities related to production of R within a sector are more labor-intensive relative to conventional production activities, the factor shift effect increases the level of employment relative to other inputs, which implies that $\partial v_L/\partial EPE > 0$, and vice versa. Whether the effect is positive or negative is ultimately an empirical question, which we aim to answer in this paper.

Second, when a firm decides to increase the production of R, thus incurring increased EPE, a firm demands more of all inputs including labor, which increases the total production costs and is referred to as the cost effect. The cost effect on a firm's employment may be small or large, but is always positive.

In line with previous literature (e.g., Belova et al. 2013a; Morgenstern et al. 2002), we assume that changes in EPE do not influence the prices of inputs, only the quantity of inputs.

4.2 The Aggregate Effect of EPE on Sector-Level Employment

Next, the effect of a marginal increase in *EPE* on sector-level employment, *Lagg*, can be obtained by aggregating the firm-level effects on employment.

$$\begin{aligned}\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}} &= \sum_{i=1}^{N} \frac{\partial L_{it}}{\partial EPE_{agg,t}} = \sum_{i=1}^{N} \frac{\partial L_{it}}{\partial EPE_{it}} \frac{\partial EPE_{it}}{\partial EPE_{agg,t}} \\ &= \sum_{i=1}^{N} \frac{TC_{it}}{P_{L,it}} \frac{\partial v_{L,it}}{\partial EPE_{it}} \frac{\partial EPE_{it}}{\partial EPE_{agg,t}} + \sum_{i=1}^{N} \frac{v_{L,it}}{P_{L,it}} \frac{\partial TC_{it}}{\partial EPE_{it}} \frac{\partial EPE_{it}}{\partial EPE_{agg,t}}\end{aligned} \tag{3}$$

where N is the number of firms in a given sector.
To simplify, we assume that regulations affect firms in proportion to their total cost. That is, we assume that an increase in the regulatory burden affects firm i by an amount equal to firm i's total costs as a share of the industry-wide total costs:

$$\frac{\partial EPE_{it}}{\partial EPE_{agg,t}} = \frac{TC_{it}}{TC_{agg,t}} \tag{4}$$

We can then re-write Eq. (3) as:

$$\begin{aligned}\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}} &= \sum_{i=1}^{N} \frac{TC_{it}}{P_{L,it}} \frac{\partial v_{L,it}}{\partial EPE_{it}} \frac{TC_{it}}{TC_{agg,t}} + \sum_{i=1}^{N} \frac{v_{L,it}}{P_{L,it}} \frac{\partial TC_{it}}{\partial EPE_{it}} \frac{\partial TC_{it}}{\partial TC_{agg,t}} \\ &= \frac{1}{TC_{agg,t}} \sum_{i=1}^{N} \frac{TC_{it}^2}{P_{L,it}} \frac{\partial v_{L,it}}{\partial EPE_{it}} + \frac{1}{TC_{agg,t}} \sum_{i=1}^{N} \frac{v_{L,it} TC_{it}}{P_{L,it}} \frac{\partial TC_{it}}{\partial EPE_{it}}\end{aligned} \tag{5}$$

Next, we also assume that the relation between total costs and changes in EPE are identical for all firms and equal to 1; $\partial TC/\partial EPE = 1$. That is, EPE provide no additional costs or benefits to the producer other than those satisfying the purpose of producing R. This assumption is in line with the approach in, e.g., Jorgenson and Wilcoxen (1990).[9] Equation (5) can then be written:

$$\begin{aligned}\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}} &= \frac{1}{TC_{agg,t}}\sum_{i=1}^{N}\frac{TC_{it}^2}{P_{L,it}}\frac{\partial v_{L,it}}{\partial EPE_{it}} + \frac{1}{TC_{agg,t}}\frac{\partial TC_{it}}{\partial EPE_{it}}\sum_{i=1}^{N}\frac{v_{L,it}TC_{it}}{P_{L,it}} \\ &= \frac{1}{TC_{agg,t}}\sum_{i=1}^{N}\frac{TC_{it}^2}{P_{L,it}}\frac{\partial v_{L,it}}{\partial EPE_{it}} + \frac{1}{TC_{agg,t}}\sum_{i=1}^{N}\frac{v_{L,it}TC_{it}}{P_{L,it}}\end{aligned} \tag{6}$$

Finally, we note that $\sum_{i=1}^{N}\frac{v_{L,it}TC_{it}}{P_{L,it}} = L_{agg,t}$. The impact of a marginal increase in EPE on aggregate sector-level employment for a sector with N firms is then given by:

$$\left.\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}}\right| Y_{it} = \overline{Y}_{it} = \frac{1}{TC_{agg,t}}\sum_{i=1}^{N}\frac{TC_{it}^2}{P_{L,it}}\frac{\partial v_{L,it}}{\partial EPE_{it}} + \frac{L_{agg,t}}{TC_{agg,t}} \tag{7}$$

4.3 The Aggregate Demand Effect of EPE on Sector-Level Employment

So far, we have modelled the effect of regulatory costs on aggregate employment, holding output constant. Next, we expand the model to include the effects that occur through changes in demand for the output of the firm. This demand effect of changes in environmental protection expenditures on aggregate employment can be described in the following way: increased regulatory costs lead to an increase in total cost, which the firm responds to by increasing the price of its output. This increase in price leads to a lower demand, which in turn leads to a reduction in employment. Intuitively, the size of this effect depends on the demand elasticity for the output good, as well as the labor intensity for the given sector.

More formally, and again following the approach in Morgenstern et al. (2002) and Oberfield and Raval (2021), we assume a market structure with monopolistic competition, thus reflecting, e.g., non-price differences among products within each sector. This assumption implies that if costs at individual firms increase by the same proportion, the market price of individual firms' output will increase by that same proportion. By the same logic, if demand for the sector-level output decreases by a certain proportion, demand for an individual firm's output will decrease by the same proportion. When formulating the sector-level aggregate demand effect, we further assume that the aggregate demand for sector-level output, q_{agg}

[9] Morgenstern et al. (2002) include the term α_r*EPE/PC in the production function to capture a potential non-zero effect of environmental protection expenditures on conventional production costs. However, we note that neither Morgenstern et al. (2002) nor Belova et al. (2013a) account for this term when deriving the cost-minimizing input cost shares. Accounting for this term would severely complicate the model, since EPE and PC are functions of prices. However, following exactly the approach in Morgenstern et al. (2002) and Belova et al. (2013a) and including the term (in the cost function but not in the cost shares) does not alter the qualitative results of our paper, and the elasticities of labor with respect to EPE are identical in sign and relatively similar in magnitude to our main specification. These results are found in the Appendix.

, exhibits a constant demand elasticity σ_d. The effect of a marginal increase in regulatory costs on output can then be written as:

$$\frac{\partial q_{agg,t}}{\partial EPE_{agg,t}} = -\sigma_d \frac{\partial TC_{it}}{\partial EPE_{it}} \frac{1}{TC_{agg,t}} q_{agg,t} \tag{8}$$

where σ_d denotes the sector-level elasticity of demand, and $(\partial TC/\partial EPE)(1/TC_{agg})$ denotes the proportional increase in costs at each firm and thus the proportional increase in the market price of each firm's output. This reduction in aggregate demand leads to a proportional reduction in output at each firm, corresponding to $\sigma_d(\partial TC/\partial EPE)(1/TC_{agg})$, which, in turn, leads to a proportional reduction in employment. Adding up these firm-level effects, the change in aggregate sector-level employment due to a change in output demand can be written as:

$$\left.\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}}\right| Demandeffect = -\sigma_d \frac{\partial TC_{it}}{\partial EPE_{it}} \frac{1}{TC_{agg,t}} L_{agg,t} = -\sigma_d \frac{L_{agg,t}}{TC_{agg,t}} \tag{9}$$

since $(\partial TC/\partial EPE) = 1$, by assumption.
The total effect of a marginal increase in EPE on aggregate employment within a sector is obtained by adding up the factor shift effect and cost effect represented by Eq. (7), and the demand effect represented by Eq. (9). Doing so results in:

$$\frac{\partial L_{agg,t}}{\partial EPE_{agg,t}} = \frac{1}{TC_{agg,t}} \sum_{i=1}^{N} \frac{TC_{it}^2}{P_{L,it}} \frac{\partial v_{L,it}}{\partial EPE_{it}} + (1-\sigma_d) \frac{L_{agg,t}}{TC_{agg,t}} \tag{10}$$

5 Empirical Framework

Given the availability of data on the number of employees, wages and other costs, all terms on the right hand side of Eq. (10) can be directly obtained from the data, except for $\partial v_{L,it}/\partial EPE_{it}$ and σ_d which will have to be estimated. To recap, $v_{L,it}$ is the labor cost share for firm i in year t, i.e., the cost share of labor engaged in the production of either marketed goods Y, or environmental output R, and σ_d is the demand elasticity of the aggregate output. We now present the framework used in this paper to estimate these quantities.

A first step is to estimate how the budget share for labor responds to a change in EPE, which requires an empirical functional form for the budget share for labor. We assume the following specifications for costs (PC) of conventional production and costs (EPE) of producing environmental output, respectively:

$$lnPC_{it} = \alpha_i + \boldsymbol{\alpha}_x ln\boldsymbol{P}_{x,it} + \alpha_y lnY_{it} + \frac{1}{2} ln\boldsymbol{P}'_{x,it}\boldsymbol{\beta}_{xx} ln\boldsymbol{P}_{x,it} + \frac{1}{2}\beta_y (lnY_{it})^2 + \boldsymbol{\beta}'_{yx} lnY_{it} ln\boldsymbol{P}_{x,it} + \alpha_t \tag{11}$$

and

$$lnEPE_{it} = \gamma_i + \boldsymbol{\gamma}_x ln\boldsymbol{P}_{x,it} + \gamma_r lnR_{it} + \frac{1}{2} ln\boldsymbol{P}'_{x,it}\boldsymbol{\delta}_{xx} ln\boldsymbol{P}_{x,it} + \gamma_t \tag{12}$$

$lnPC$ and $lnEPE$ are translog cost functions for producing a given level of Y and R, respectively. $lnPC$ is a non-homothetic cost function and homogenous of degree one in input prices, while $lnEPE$ is a homothetic function (i.e., has no scale bias) and homogeneous of a constant degree. $\boldsymbol{P}$ is a vector of input prices for labor (L), capital (K) and energy (E), where subscript $x \in L, K, E$. α_i and γ_i are firm fixed effects, and α_t and γ_t denote year fixed effects. The firm fixed effects control for unobserved firm-level heterogeneity, while the year fixed effects control for, e.g., technological advancements. Because of the lack of data on environmental output R, the EPE function in Eq. (12) is assumed to be homothetic, which implies that the input cost shares associated with environmental protection activities are independent of R.

The reader should note that our specification of the production function differs from that of, for example, Morgenstern et al. (2002) and Belova et al. (2013a), as we do not include materials as an input factor. This decision is primarily motivated by two factors. First, our data lack information about material quantities and prices, and we only observe material costs for a few firms per sector, but neither quantities nor prices.[10] Second, materials are often found to be directly proportional to output, with little to no substitutability with other inputs (see, e.g., Fuss and McFadden, 1978; Mas-Colell et al., 1995).

The standard approach for deriving a system of cost-minimizing input cost shares is to differentiate the logarithm of the cost function with respect to the logarithm of input prices, resulting in:

$$v_{x,it,Y} = \alpha_x + \beta^{'}_{xx} ln\boldsymbol{P}_{x,it} + \beta_{yx} lnY_{it} \tag{13}$$

and

$$v_{x,it,R} = \gamma_x + \boldsymbol{\delta}^{'}_{xx} ln\boldsymbol{P}_{x,it} \tag{14}$$

where, as before, $\boldsymbol{P}$ is a vector of input prices. Each input cost share, $v_{x,it}$, reflects the costs associated with the use of that input in conventional production activities, denoted as $v_{x,it,Y}$ as well as environmental protection activities, denoted as $v_{x,it,R}$.

Data on $v_{x,it,Y}$ and $v_{x,it,R}$ are not available separately, but the total cost shares $v_{x,it}$ can be observed from the data. Morgenstern et al. (2002) specify the observed cost share for input $x \in L, K, E$ as a weighted average of $v_{x,it,Y}$ and $v_{x,it,R}$:

$$v_{x,it} = \frac{EPE_{it}}{EPE_{it} + PC_{it}} v_{x,it,R} + \left(1 - \frac{EPE_{it}}{EPE_{it} + PC_{it}}\right) v_{x,it,Y} = v_{x,it,R} + \left(\frac{PC_{it}}{EPE_{it} + PC_{it}}\right)(v_{x,it,Y} - v_{x,it,R}) \tag{15}$$

Equation (15) expresses the total cost share for each input as a weighted average of the cost shares associated with environmental and conventional production activities, producing the outputs R and Y, respectively. The weights are the ratio of EPE and PC, respectively, to total costs (which, as before, is defined as $TC_{it} = EPE_{it} + PC_{it}$).

The cost function in Eq. (11) together with the input cost shares represented by Eq. (15) are estimated as a system of equations. For each firm and year, the sum of input cost shares

[10] This shortcoming of the Swedish registry data is reflected in the fact that none of the previous studies using Swedish firm-level manufacturing data, that we are aware of, include materials in their empirical work (see, for example, Brännlund and Lundgren 2007; Dahlqvist et al. 2021; Lundgren and Marklund 2015).

adds up to unity. Hence, with three input cost share equations for capital, labor, and energy, only two of them are linearly independent. For estimation, homogeneity restrictions are imposed by normalizing labor and energy prices as well as PC and EPE with respect to the capital price, and capital cost share is excluded from the system.

Because we use as weights the share of PC to TC in Eq. (15), this introduces endogeneity to the system of equations. In particular, for firms that engage in CSR and self-regulation (see Sect. 3.1), their share of PC to TC will be smaller than firms who only incur environmental protection expenditures to meet regulations (or alternatively, their share of EPE to TC is larger). We account for this endogeneity by instrumental variables regression, where we use as instruments the average ratio of $PC/(EPE + PC)$ among all other firms in the same sector in the same year. Specifically, our endogenous variables are $\left(\frac{PC}{TC}\right)_{it}$, $\left(\frac{PC}{TC}\right)_{it} lnP_{E,it}$, $\left(\frac{PC}{TC}\right)_{it} lnP_{L,it}$ and $\left(\frac{PC}{TC}\right)_{it} lnY_{it}$ and we use as excluded instrumental variables $\widetilde{\left(\frac{PC}{TC}\right)}_{it}$, $\widetilde{\left(\frac{PC}{TC}\right)}_{it} lnP_{E,it}$, $\widetilde{\left(\frac{PC}{TC}\right)}_{it} lnP_{L,it}$ and $\widetilde{\left(\frac{PC}{TC}\right)}_{it} lnY_{it}$ where $\widetilde{\left(\frac{PC}{TC}\right)}_{it}$ is the average ratio of $PC/(EPE + PC)$ among all other firms in the same sector in the same year.

The intuition behind this choice of instrumental variable is that it captures common determinants of EPE among firms in the same sector, i.e., common policies and regulations, and ignores across-firm variation that is driven by CSR and self-regulation. This is in line with previous assumptions we made, where we assumed that regulations affect firms in proportion to their total cost. Thus, if EPE was only driven by policy, we would then expect EPE/TC to be similar across all firms. Note that these excluded instruments vary both across firms, and across time.

There are possible alternative instruments, which at first glance might seem adequate. For example, EU-ETS is a key policy that affects many firms, and could therefore be considered a useful instrumental variable. A motivation could be that firms that are included in the trading scheme face a higher degree of policy pressure, and therefore are likely to have larger environmental protection expenditures relative to their production costs. However, we note that there are relatively many firms in our sample that enter and/or exit EU-ETS during the sample period. It might be the case that this results from strategic behavior, and that inclusion in EU-ETS therefore is endogenous. Specifically, whether a firm is part of EU-ETS depends on emission levels, which the firm may choose. Another alternative instrument could be some sort of policy stringency index, e.g., the OECD Environmental Policy Stringency Index.[11] However, while reflecting the regulatory burden, such indices do not vary across firms, which means that we cannot use it as an instrumental variable while controlling for year fixed effects.

All in all, this motivates our choice of using the average ratio of $PC/(EPE + PC)$ among all other firms in the same sector in the same year as excluded instrumental variable. As a robustness analysis, we also estimate our model using the minimum ratio of $PC/(EPE + PC)$ among all other firms in the same sector in the same year as an alternative instrument.

In contrast to EPE, we assume that input prices are exogenous to firms and motivate this in the following way: Energy mainly consist of fossil fuels and electricity, where the former is priced on the world market and the latter is mostly traded competitively on the Nordic electricity exchange Nordpool (approximately 90 percent of all electricity produced in the Nordic countries is traded here). We assume that workers can move between sectors, so that

[11] See https://www.oecd-ilibrary.org/environment/data/oecd-environment-statistics_env-data-en.

firms are price takers when it comes to labor, and finally; the user cost of capital is derived from the market interest rate, which is exogenous to the individual firm.

For estimation of the system of equations, we use the iterative 3-stage least square (3SLS) estimator while assuming cross-equation symmetry conditions and homogeneity of degree one in prices. The 3SLS estimator is chosen because it guarantees that parameter estimates are invariant to the choice of input cost share excluded from the system.

Next, to estimate the demand elasticity of aggregate output, we follow Morgenstern et al. (2002) and estimate the following specification:

$$\Delta\, ln\, Y_{it} = \sigma_d\, \Delta\, ln\, prod_{it} + \epsilon_{it} \tag{16}$$

where ΔlnY_{it} is the change in annual output, and $\Delta lnprod_{it}$ is the annual change in log productivity level measured by the following expression:

$$\Delta lnprod_{it} = \left(\frac{\boldsymbol{v}_{x,it} - \boldsymbol{v}_{x,it-1}}{2}\right)'(ln\boldsymbol{P}_{x,it} - ln\boldsymbol{P}_{x,it-1}) - (lnPO_{it} - lnPO_{it-1}) \tag{17}$$

where, as before, $\boldsymbol{v}$ is a vector of cost shares, $\boldsymbol{P}$ is a vector of input prices and PO is the output price, defined as the sector's producer price index. By multiplying cost-share averages with input prices, we calculate a divisia index of labor, capital and energy prices. The annual productivity growth is thus measured as the log difference between the change in input prices and the change in output price. ϵ is a random disturbance, and σ_d in Eq. (16) is the demand elasticity we wish to estimate.

5.1 Computing the Effect of EPE on Employment

Recall that in order to evaluate the total marginal effect of EPE on aggregate sector-level employment, $\partial v_{L,it}/\partial EPE_{it}$ must be obtained. Because the input cost shares $v_{L,it,Y}$ and $v_{L,it,R}$ do not depend on EPE, it follows from Eq. (15) that:

$$\frac{\partial v_{L,it}}{\partial EPE_{it}} = -\left(\frac{PC_{it}}{TC_{it}^2}\right)(v_{L,it,Y} - v_{L,it,R}) \tag{18}$$

Substituting Eq. (13) and Eq. (14) into Eq. (18);

$$\frac{\partial v_{L,i}}{\partial EPE_{it}} = -\left(\frac{\overline{PC_i}}{\overline{TC_i^2}}\right)\left(\alpha_L + \boldsymbol{\beta}'_{Lx} ln\overline{\boldsymbol{P}}_{x,i} + \beta_{yL} ln\overline{Y}_i - \gamma_L - \boldsymbol{\delta}'_{Lx} ln\overline{\boldsymbol{P}}_{x,i}\right) \tag{19}$$

where $\overline{PC_i} = \frac{1}{T}\sum_{t=1}^{T} PC_{it}$, $\overline{TC_i} = \frac{1}{T}\sum_{t=1}^{T} TC_{it}$, $\overline{\boldsymbol{P}}_i = \frac{1}{T}\sum_{t=1}^{T} \boldsymbol{P}_{it}$ and $\overline{Y}_i = \frac{1}{T}\sum_{t=1}^{T} Y_{it}$. This derivative is thus evaluated for firm-level means of costs, prices and output, which is why the index t is dropped.

Finally, Eq. (19) is substituted into Eq. (10) in order to evaluate the total effect of a marginal increase in EPE on sector-level employment. The total marginal effect can be written as:

$$\frac{\partial L_{agg}}{\partial EPE_{agg}} = \frac{1}{TC_{agg}} \sum_{i=1}^{N} \frac{TC_i^2}{P_{L,i}} \left(-\left(\frac{\overline{PC_i}}{\overline{TC_i^2}} \right) \left(\alpha_L + \boldsymbol{\beta}^{'}_{Lx} ln \overline{\boldsymbol{P}}_{x,i} + \beta_{yL} ln \overline{Y}_i - \gamma_L - \boldsymbol{\delta}^{'}_{Lx} ln \overline{\boldsymbol{P}}_{x,i} \right) \right) + (1-\sigma_d) \frac{L_{agg}}{TC_{agg}} \tag{20}$$

Equation (20) represents the specification used and is computed separately for the four most energy-intensive sectors in the Swedish manufacturing industry. We also compute Eq. (20) for the four sectors pooled together, as well as for all 16 sectors in the Swedish manufacturing industry pooled together. The first term in Eq. (20) represents the aggregate factor shift effect, while the second term expresses the joint aggregate cost and demand effects.

A standard bootstrap estimation procedure with 100 replications is used to estimate the standard errors of $\partial L_{agg}/\partial EPE_{agg}$ and each of its three components: cost effect, demand effect, and factor shift effect.

6 Data

We use firm-level unbalanced panel data sourced from Statistics Sweden. The data covers the Swedish manufacturing industry for the years 2002–2021 and contains detailed information on costs and quantities related to different inputs, sales, etc., as well as information on environmental expenditures and investments. In this paper, we focus on the following, energy-intensive sectors: chemical, iron and steel, paper and pulp and stone and mineral.

For each firm and year, output, Y, is defined as a firm's sales value (in Msek) divided by a sector-specific producer price index.[12] The inputs are energy, labor and capital. Energy quantity, E, is defined as the sum of all renewable and non-renewable energy sources used by a firm in a year. Renewable energy consists of electricity, district heating and wood fuel, while non-renewable energy consists of coal, solid fuel and gaseous fuel. Statistics Sweden converts both renewable and non-renewable energy quantities to energy equivalents (MWh) using the same conversion rates for all sectors. The energy price, P_E, for each firm is calculated by dividing total energy costs (in Msek) by total energy quantity used. Labor quantity, L, is defined as a firm's number of full-time, and part-time employees. Labor price (in Msek), P_L, is calculated for each firm by dividing yearly total salary costs by the firm's number of employees, thus reflecting the average salary paid per employee that year. Both energy price, P_E, and labor price, P_E, are deflated using sector-specific producer price index with base year 2020.

Furthermore, the data includes firm-specific capital gross investments, which enables us to create a firm-specific capital stock by applying the perpetual inventory method (Berndt, 1991).[13] Specifically, we compute the capital stock in time t as $K_{it} = I_{it} + (1-\psi)K_{it-1}$ where K_{it} denotes capital at time t, I_{it} denotes gross investments in inventories and machinery, and ψ the depreciation rate which we, following Dahlqvist et al. (2021), assume to be

[12] A firm's sales value equals revenues from sales, net of discounts, value added tax, and other taxes directly linked to revenues.

[13] This requires at least two observations on capital gross investments over two consecutive years for each firm. When this is not available, observations have been excluded.

0.087.[14] For the first observation per firm i, we set $K_{i0} = I_{it}/\psi$. The price on capital is defined as $P_K = P_I/P_Y(r+\psi)$ where P_I and P_Y denote the investment good price index and the output price (sector-specific producer price index), respectively, r denotes the long-term market capital interest rate and $\psi = 0.087$ the depreciation rate.

6.1 Environmental Protection Expenditures

The data on environmental protection expenditures originates from the "Environmental protection expenditure in industry" survey, administered by Statistics Sweden since 1999, with mandatory participation from 2001. The survey collects information on firm-level environmental expenditures and investments related to environmental protection activities for a sample consisting of firms with at least 20 employees. Data collected in the survey are broken down by type of costs; pollution treatment investments, pollution prevention investments, and current expenditures, and by environmental domain to which the environmental protection activity is aimed; Air, Water, Waste, Other.[15]

Pollution treatment investments refer to activities that do not affect the production process, i.e., "end-of-pipe" solutions, which aim to deal with existing pollutants (Jaraite et al. 2014). Examples of such solutions include filters and scrubbers. In contrast, pollution prevention investments refer to activities that directly affect the production process in order to reduce pollution. Examples of such investments include optimizing the use of chemicals and increasing recycling. Finally, current expenditures relate to costs that are not considered to be investments but concern pre-existing equipment or operational activities. For instance, current expenditure can include costs of personnel, material, and energy used for existing environmental facilities and management. Financial costs like depreciation are not included, and neither are payments of environmental taxes or costs pertaining to the trade or administration of emission rights within EU-ETS (i.e., non-compliance costs; see, e.g., Jaraite et al. 2014).[16] However, payments related to waste treatment and sewage fees are included in current expenditures, which is in line with the U.S. PACE data (Statistics Sweden, 2021; Gallaher et al. 2008).

[14] For example, Edquist and Henrekson (2017) show that depreciation rates are very similar across sectors within the manufacturing industry. Figures from Statistics Sweden confirm this, see https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__NV__NV0109__NV0109O/BNTT01/. This motivates our assumption of a uniform depreciation rate.

[15] The classification of environmental protection activities (CEPA) within the environmental protection expenditure accounts consists of 9 classes. The first three are: Protection of ambient air and climate (Air), Wastewater management (Water), Waste management (Waste). The class titled "Other" in Fig. 1 comprises the remaining six classes, namely; Protection and remediation of soil, groundwater and surface water; Noise and vibration abatement; Protection of biodiversity and landscapes; Protection against radiation; Environmental research and development; Other environmental protection activities. A detailed explanation of activities included in the different classes can be found in Eurostat (2020).

[16] It is worth pointing out some differences and similarities between the U.S. PACE data and the Swedish EPE data. To the best of our knowledge, PACE includes information on pollution taxes starting from the 1999 survey. However, this information was reported through yes/no response and was intended to be kept separate from other operating and capital costs, since taxes represent costs for polluting, and not for abating (Ross et al. 2004). Costs for tradable permits for SO2 and NOx exercised in a given year are included in PACE (Gallaher et al. 2008). However, this started in the 1999 survey in the case of SO2 permits and in the 2005 survey for NOx permits, since trading programs for these pollutants were not implemented until 1995 and 2003, respectively. California's emission trading system was implemented in 2012. Thus, neither pollution taxes, nor costs for tradable permits were considered in the PACE data used in Morgenstern et al. (2002).

For this study's purpose, we only use the current expenditures data. It is denoted by the variable EPE, expressed in Msek and deflated using a sector-specific producer price index with 2020 as base year. The main reason for excluding investment spending is that it tends to be "lumpy". This can cause misleadingly large variation in EPE across firms and years if included in the sum and would require a modelling framework that factors in intertemporal investment decisions. When comparing within-firm and between-firm variation in investments, we note that for all sectors, the within-firm variation of investment expenditures is larger than the between-firm variation, whereas the opposite holds for current expenditures. This suggests that there is a "lumpiness" about investments which is not mirrored in the current expenditures.

6.2 Descriptive Statistics

Table 1 presents descriptive statistics for the variables used in the estimations. As visible in the table, the mean and the range of the variables differ both within and across sectors. For example, the sector-average number of employees ranges between 301 for the stone and mineral sector, and 522 for the iron and steel sector. However, the maximum number of employees is about 20 times its mean for the chemical sector, while the maximum number of employees in the paper and pulp sector and the stone and mineral sector, respectively, is just below four times the mean value. In absolute numbers, the average value of environmental protection expenditures ranges from about 8 Msek in the stone and mineral sector, to about 24 Msek in the paper and pulp sector. While the maximum value of EPE is about ten times the mean value for the chemical sector and the stone and mineral sector, the maximum value of EPE is about fifteen to twenty times larger for the sectors iron and steel and paper and pulp, respectively.

Figure 2 presents the percentage share of EPE of firms' total costs for the period 2002–2021, for each sector. For readability, the box plots exclude outside values. The share of EPE is generally quite low and varies between sectors, but not so much over years. Firms within the chemical sector devote, on average, the largest share of total costs to environmental protection expenditures (4.14 percent), followed by the iron and steel sector (3.26 percent), paper and pulp sector (3.09 percent), and the stone and mineral sector (2.23 percent). Cost shares for labor, energy and capital for firms in the sample are presented in Table 2. Compared to descriptive statistics in Morgenstern et al. (2002), the shares of firms' total costs allocated to labor and EPE are generally larger in our sample of firms. However, the reader should keep in mind that we do not include material as input factor in our production function, which Morgenstern et al. (2002) do. Furthermore, it is evident from Fig. 2 that EPE as a share of TC varies substantially within sectors; clearly, some firms do more than others in terms of environmental protection. If EPE was only determined by policy and regulation, we would expect this ratio to be relatively homogenous within a sector. One explanation to this within-sector variation is, as already discussed, CSR and self-regulation, and this suspicion motivates our instrumental variables approach.

Price per MWh is in Tsek in the table, for readability, but in Msek in estimations.

While the current paper is not concerned with explaining differences in CSR, it is interesting to note that previous literature (e.g., Cormier et al. 2005; Tagesson et al. 2009) has shown that key determinants of CSR include firm size and sector. However, in our data, there is no statistically significant difference in the share of EPE between small and large

Table 1 Descriptive statistics for firms, 2002–2021

	Mean	Min	Max	N
Chemical Net sales (in Msek)	2644.4	47.39	69,004.3	522
Number of employees	407.2	24	8502	522
Capital stock (in Msek)	1666.0	3.502	48,731.5	522
Energy use (MWh)	215,271.1	4.300	4,740,634	522
Yearly salary (in Msek)	0.924	0.136	5.849	522
Rental price of capital (0–1)	0.128	0.0866	0.166	522
Price per MWh (in Tsek)	0.569	0.000988	5.568	522
Environmental protection expenditure (in Msek)	20.16	0.0238	195.4	522
Iron and steel Net sales (in Msek)	2656.8	55.42	34,162.7	602
Number of employees	522.5	43	6123	602
Capital stock (in Msek)	1038.2	8.265	16,771.5	602
Energy use (MWh)	591,164.1	959.7	20,217,464	602
Yearly salary (in Msek)	0.689	0.177	2.155	602
Rental price of capital (0–1)	0.127	0.0780	0.228	602
Price per MWh (in Tsek)	0.566	0.0571	1.640	602
Environmental protection expenditure (in Msek)	18.27	0.00255	255.6	602
Paper and pulp Net sales (in Msek)	2530.1	0.00388	15,359.1	782
Number of employees	517.7	43	1892	782
Capital stock (in Msek)	1686.4	12.68	12,627.9	782
Energy use (MWh)	1,500,585.3	1202.4	11,210,408	782
Yearly salary (in Msek)	0.653	0.000000676	2.193	782
Rental price of capital (0–1)	0.112	0.0838	0.130	782
Price per MWh (in Tsek)	0.337	0.00714	1.163	782
Environmental protection expenditure (in Msek)	24.38	0.0299	468.0	782
Stone and mineral Net sales (in Msek)	1070.6	40.75	6267.4	462
Number of employees	301.4	11	1163	462
Capital stock (in Msek)	532.9	4.078	8406.2	462
Energy use (MWh)	177,448.5	784.4	3,192,168.5	462
Yearly salary (in Msek)	0.913	0.145	12.62	462
Rental price of capital (0–1)	0.112	0.0866	0.141	462
Price per MWh (in Tsek)	0.638	0.0110	1.316	462
Environmental protection expenditure (in Msek)	8.024	0.0321	77.30	462

Price per MWh is in Tsek in the table, for readability, but in Msek in estimations

firms (defined as below or above the median turnover) and the differences across sectors are either very small or statistically insignificant.

In order to describe the data in more detail for variables L and EPE, we present boxplots of these variables, including outliers, for all four sectors, over the period 2002–2021 in Appendix Figures 3 and 4, respectively, in Appendix. When comparing Figure 3 with the underlying data, we note that the observations for which the number of employees is markedly higher in the chemical sector (around 8000) all belong to the same firm. The same holds for the iron and steel sector, where the observations for which the number of employees is highest (>5000) all belong to the same firm. Within the paper and pulp sector and the stone

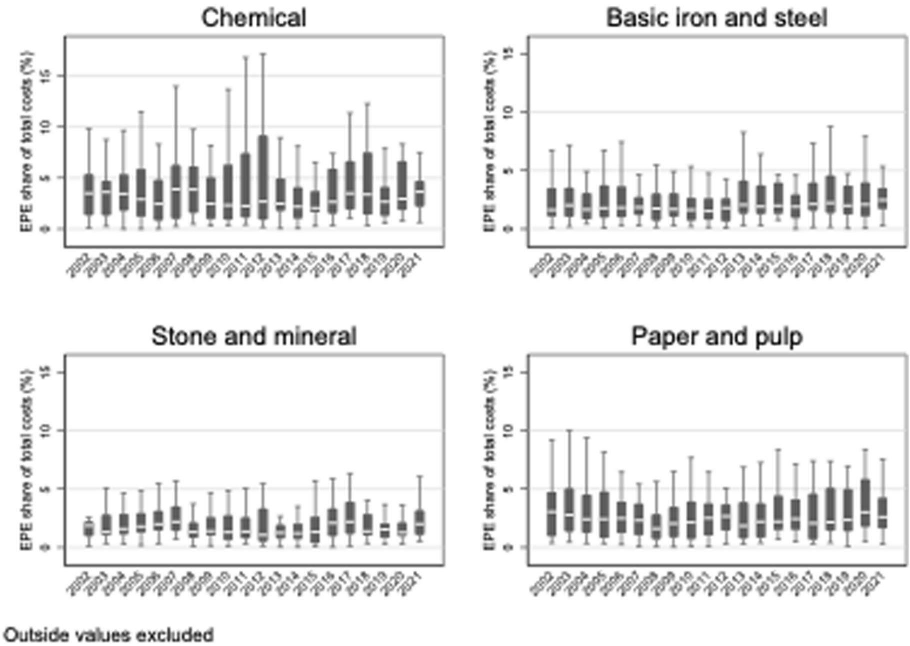

Fig. 2 Share EPE of total costs, by sector 2002–2021

Table 2 Cost shares for firms, 2002–2021

	Mean	Min	Max	N
Chemical Labor cost share	0.663	0.126	0.967	522
Energy cost share	0.106	0.0000269	0.751	522
Capital cost share	0.231	0.00265	0.777	522
Iron and steel Labor cost share	0.685	0.239	0.953	602
Energy cost share	0.151	0.00505	0.667	602
Capital cost share	0.165	0.0232	0.686	602
Paper and pulp Labor cost share	0.567	0.000000656	0.933	782
Energy cost share	0.218	0.00252	0.683	782
Capital cost share	0.216	0.0250	0.830	782
Stone and mineral Labor cost share	0.724	0.219	0.953	462
Energy cost share	0.111	0.00215	0.607	462
Capital cost share	0.165	0.00765	0.551	462

and mineral sector, outliers are less prominent, but it is still the case that the observations with markedly larger number of employees belong to the same firm(s). When comparing Figure 4 with the underlying data on environmental protection expenditures, the pattern is somewhat different. Although outside values in the graphs tend to be represented by the same firm(s) within the sector, it is relatively often the case that these are outside values also *within* the firm.

To test the robustness of our results, we also perform estimations where we exclude suspected outliers for variables L and EPE within each of the four sectors. We define outliers as values greater and smaller than the $99th$ and $1st$ percentile, respectively, and in another robustness check as values greater and smaller than the $95th$ and $5th$ percentile, respectively. This is done to ensure that possible outliers do not influence our results. Results from these estimations are presented and discussed in Sect. 7.2.

7 Results

7.1 Results from main specification

Before presenting and discussing sector-level employment effects, we briefly discuss output pertaining to the system of equations described by Eq. (11) and Eq. (15), as well as results from estimating the output elasticity in Eq. (17).

The first-stage results from the 3SLS are presented in Tables 4, 5, 6, 7 in Appendix A. F-statistics vary between 58.212 and > 100,000 indicating that the average share of $PC/(EPE + PC)$ among all other firms in the same sector is a strong excluded instrument. Results from the second stage regression in the 3SLS are presented in Table 8 in Appendix A. A majority of the parameter estimates are estimated with precision.

With regards to Eq. (17), estimation results are presented in Table 9 in Appendix A. We find the output demand elasticity to be positive and significant for all sectors, ranging from very inelastic (0.109) for the stone and mineral sector, to relatively elastic (2.992) for the paper and pulp sector. The chemical sector and iron and steel sector both show demand elasticities that are more or less inelastic (0.378 and 0.174, respectively). Compared to demand elasticities reported in previous literature, the estimate for the paper and pulp sector is substantially larger compared to both Morgenstern et al. (2002) and Belova et al. (2013a). This could be explained by the fact that both papers use industry-level variables when estimating output demand elasticities, while we employ firm-level variables for all input factor variables. However, for the iron and steel sector, our demand elasticity estimate is substantially smaller compared to the estimate reported for the steel sector in Morgenstern et al. (2002) and somewhat smaller than the one reported in Belova et al. (2013a).

In Table 3, we present the estimation results for the total employment effect (both the marginal effect and as an elasticity) and its decomposition into a cost effect, demand effect and a factor shift effect, with separate estimates for each of the four studied sectors. A first thing to notice in Table 3 is that the cost effect is positive for all sectors, as expected, and statistically significant. The cost effect estimates indicate that the number of employees increases by approximately 0.689–0.873 for every million sek increase in environmental protection expenditure, holding output constant.[17]

The second line in Table 3 presents the demand effect, i.e., changes in employment due to the reduction in demand stemming from increased EPE. This is negative for all sectors, as expected, and statistically significant for all sectors but the stone and mineral sector. The numbers indicate that the number of employees decreases by approximately 0.260 for every million sek increase in EPE in the chemical sector, by 0.143 for the iron and steel sector, and by 2.157 for every million sek increase in EPE in the paper and pulp sector. This dif-

[17] 1 sek corresponds to approximately \$0.1.

Table 3 Estimated effects of EPE on employment, main specification

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	0.689***	0.821***	0.721***	0.873***
	(0.013)	(0.018)	(0.010)	(0.037)
Demand effect	−0.260**	−0.143***	−2.157***	−0.095
	(0.110)	(0.053)	(0.792)	(0.091)
Factor shift effect	0.692	−1.088**	−3.166***	−0.610
	(0.957)	(0.442)	(0.620)	(0.664)
Total (marginal) effect	1.121	−0.410	−4.603***	0.168
	(0.979)	(0.456)	(1.020)	(0.660)
Total effect (elasticities)	0.045	−0.014	−0.208***	0.004
	(0.039)	(0.016)	(0.047)	(0.015)
Observations	522	602	782	462

Note: * p<0.10, ** p<0.05, *** p<0.01

ference between sectors is consistent with the higher demand elasticity for the paper and pulp sector.

The third line shows the factor shift effect, i.e., changes in employment due to reallocation of labor when incurring EPE, holding output Y constant. Ex-ante, the direction of this effect is unknown and depends on the relative labor intensity of the production of R vis-á-vis the production of Y. Our results show that the factor shift effect is statistically significant for the sectors iron and steel and paper and pulp, where it is negative in both cases. This means that environmental protection expenditures reduces employment levels via the factor shift channel, thereby suggesting that production of environmental output, R, is relatively less labor-intensive than production of conventional output, Y, for these sectors.

Adding up the above-mentioned effects, the total marginal effect is statistically significant for only one of the sectors, paper and pulp, for which it is negative. The total marginal effect for the paper and pulp sector shows that a million sek increase in sector-level EPE is associated with a decrease in sector-level employment by 4.6 workers. Results suggest that this total effect is driven by relatively sizeable negative demand and factor shift effects for the paper and pulp sector.

Finally, at the bottom line of the table, we present elasticities which show that if sector-level EPE increases by 10 percent, the number of workers decreases by 2.08 percent for the paper and pulp sector, and increases for the chemical sector, by 0.45 percent, although the elasticity estimate is only statistically significant for the paper and pulp sector.

In summary, when comparing results across Swedish manufacturing sectors, we note that the effects of EPE on employment levels are statistically insignificant for the chemical sector, the iron and steel sector, and the stone and mineral sector, but significant and non-negligible for the paper and pulp sector. The variation in total marginal effects among the four sectors studied are mainly explained by the varying magnitude of the demand effect, and the varying direction of the factor shift effect. The demand effect is mainly driven by the demand elasticity of the sector, which is relatively large in absolute value for the paper and pulp sector. The sign and magnitude of the factor shift effect indicate that upon incurring EPE to increase the production of R, holding Y constant, firms within the iron and steel sector and paper and pulp sector will reduce their labor, substantially more so for firms in the paper and pulp sector.

In a model where we do not instrument for the share of EPE, we find that, for all sectors but the stone and mineral sector, the total marginal effect of EPE on employment is relatively closer to zero (see Table 10 in Appendix), compared to our main results in Table 3. This is expected, since firms engaging in CSR will, reasonably, cherry-pick to undertake those environmental protection activities that affect their operations to a relatively small extent. By not accounting for this source of endogeneity, we would expect estimated effects to be relatively closer to zero compared to when using IV to account for this bias. This finding is at least to some extent in line with the discussion in Belova et al. (2015). In particular, this difference in estimates highlights the importance of considering EPE as endogenous, as failing to account for this endogeneity biases the results. However, standard errors are relatively large for some sectors, and comparing results from two different specification should take heed of this.

When comparing our results to those in Morgenstern et al. (2002) and Belova et al. (2013a), the reader should note that there are important differences between the current sample and analysis and the previous ones, aside from the fact that we account for endogeneity in EPE. A first caveat is that the sectors, time periods and regulatory contexts studied differ. When comparing results, we mainly focus on the sectors paper and pulp, and iron and steel, since they are included in all three studies. However, even when the same sectors are included, it is indeed the case that there are large differences between the periods and contexts studied (Morgenstern et al. (2002) study U.S. firms prior to the year 1991, and Belova et al. (2013a) study U.S. firms prior to the year 2005), with regards to, e.g., environmental regulation, technologies, and labor market regulations. As noted in previous sections, environmental regulation in Sweden is considered more stringent compared to the US, and this may imply that environmental protection activities undertaken by Swedish firms in order to comply with regulation are more costly, on the margin. Secondly, variable definitions differ between samples. Both Morgenstern et al. (2002) and Belova et al. (2013a) report effects in terms of sector-level changes in the number of full-time jobs following a million-dollar increase in sector-level EPE, measured in 1987 dollars, and 1997 dollars, respectively. The current analysis' measure of the number of workers includes both full-time and parttime employees, and EPE is expressed in 2020 sek. Furthermore, the data set we use lack prices and quantities for materials, which means that we do not include this input in our production function estimation (see Sect. 5). Finally, we use firm-level data when estimating sector-level demand elasticities.

With these caveats in mind, we note that the cost effects found in the current paper are slightly larger for the paper and pulp sector and the iron and steel sector, compared to the cost effects reported in Morgenstern et al. (2002), for the corresponding sectors. The same holds for the comparison with Belova et al. (2013a) in the case of the paper and pulp sector. We find a significantly smaller cost effect for the iron and steel sector than the one reported in Belova et al. (2013a), although the authors of the latter study deem their estimate implausibly large.

While none of the demand effects reported in Morgenstern et al. (2002) and Belova et al. (2013a) are statistically significant, their magnitudes are on average smaller than for the Swedish sample. This is true for the paper and pulp sector in particular, but also for the iron and steel sector. This is likely due to the fact that they use data on sector-level when estimating demand elasticities, whereas we use firm-level data.

Whereas we find, generally, negative factor shift effects that are statistically significant for two of the sectors, Morgenstern et al. (2002) report, generally, positive factor shift effects, although for the sectors paper and pulp and steel, these factor shift effects are statistically insignificant. Factor shift effects estimated in Belova et al. (2013a) are generally positive and statistically insignificant. For the steel sector, the factor shift effect is positive, but deemed implausibly large by the authors. An important difference between the firms in the Swedish sample and the firms in the U.S. sample(s) is the labor cost shares within the different sectors. For example, Morgenstern et al. (2002) attribute the positive factor shift effects of the sectors petroleum and plastics material to the fact that their labor cost shares are very small (<10 percent), making environmental activities undertaken by the firms unlikely to be any less labor-intensive than conventional production. In our sample, labor cost shares range between 56.7 percent for the paper and pulp sector and 72.4 percent for the stone and mineral sector, as shown in Table 2.

When comparing the total marginal effects in our study with previous literature, we find that these total effects are more often negative (albeit most of them statistically insignificant) for the Swedish sample when compared to Morgenstern et al. (2002) and Belova et al. (2013a). This difference appears to be driven by the fact that factor shift effects are more often estimated to be negative for the Swedish sample compared to studies on U.S. firms.

We also estimate the system of equations described by Eq. (11) and Eq. (15) on two different pooled samples. One sample includes all sectors within the Swedish manufacturing industry.[18] The other sample includes the four most energy intensive sectors pooled together. Results are presented in Table 11 in Appendix. When pooling the four energy-intensive sectors, the cost effect is positive and significant, and the demand effect is negative and significant, in line with the results from the disaggregated sector analysis in the main specification. The factor shift effect in the four sector pooled sample is negative and statistically significant, although the total marginal effect is statistically insignificant. In terms of elasticities, the total effect is small (and statistically insignificant), and shows that an increase in EPE by 1 percent is associated with a decrease in the number of employed in these four sectors by 0.029 percent. When pooling all sixteen sectors, the cost effect and the demand effect remain somewhat similar to the smaller pooled sample with regards to magnitude, sign and significance. The point estimate of the factor shift effect is negative for the sample of all sectors, although statistically insignificant. The total marginal effect and the elasticity estimate remain statistically insignificant, with the same sign, but of lesser magnitude than those for the energy-intensive sectors.

7.2 Results from Robustness Analysis

We perform several robustness checks. First, we estimate the main specification but exclude suspected outliers in the variables L and EPE. In general, we find very small changes in our results when excluding outliers defined as values greater and smaller than the $99th$ and $1st$ percentile, respectively, see Table 12 in Appendix. The largest changes are seen for the

[18] The sectors included are the following: chemical, electro, fabricated metal products, food, iron and steel, machinery, mining, motor vehicles, other vehicles, paper and pulp, printing, refined petrol products, rubber and plastic, stone and mineral, textile, wood.

factor shift effect, which is statistically significant (on 10 percent significance level) and negative for the chemical sector, and relatively smaller in magnitude for the paper and pulp sector compared to the main estimations. This results in a relatively smaller total employment effect for the paper and pulp sector. We have also estimated the same model but this time excluded outliers defined as observations of L and EPE that are greater and smaller than the 95th and 5th percentile. Again, results are similar to the main results and are available upon request. Thus, it appears that while outliers in L and EPE have some marginal effects for some of the sectors, the main results are not driven by a few outliers.

As a second robustness check, we estimate our empirical model using alternative excluded instrumental variables. Instead of using the average ratio of $PC/(EPE + PC)$ of all other firms in the same sector as instrumental variable, we estimate the system of equations described by Eq. (11) and Eq. (15) using the minimum ratio of $PC/(EPE + PC)$ of all other firms in the same sector as instrumental variable. F-statistics from the first stage regressions and results in terms of employment effects are presented in Table 13 and Table 14, respectively, in Appendix. We note that the F-statistics from the first stage regressions using the alternative IV are substantially smaller, compared to the main specification. For one endogenous variable, the F-statistic is < 10, indicating that the minimum ratio of $PC/(EPE + PC)$ is a relatively weak instrument. This motivates the use of the average ratio of $PC/(EPE + PC)$ among all other firms in the same sector in the same year as the instrumental variable in our preferred specification. In terms of estimated employment effects when using the alternative IV, results are generally in line with those in the main specification, with an estimated elasticity of −0.224 to 0.059 using the alternative instrumental variable.

Finally, we have estimated a model in which we also include environmental investments in EPE in addition to current expenditure, even if such investments may be lumpy and vary substantially across years (see Sect. 6). In any case, we find that this does not affect our results to any large extent. Results from a specification where we include investments in the estimations are reported in Table 15. Note that the number of observations change marginally when also including investments, as some firms for some years only report environmental investments, and no expenditures.

8 Conclusions

In the “jobs versus the environment” debate, it is often claimed that environmental regulation increases total production costs and output prices, which in turn reduces the demand for output and thereby demand for labor (employment). In this paper, we contribute to this discussion with an empirical estimation of the effects of firms’ efforts to comply with environmental regulation, on employment for the Swedish manufacturing industry. In more detail, we use a unique and detailed firm-level data set on inputs, outputs and environmental protection expenditures, and use the approach suggested by Morgenstern et al. (2002) to measure how environmental-related regulatory costs affect sector-level employment. While job loss is not necessarily a real social cost to the extent that a job lost in one sector is quickly replaced in another, discussions of job loss, especially at the sector level, are often central to the policy process. Our paper shows that such discussions have at least some merit for Sweden.

Given that a large literature has shown that firms engage in CSR and self-regulation, and given that our data reveal large differences in environmental protection expenditures within a given sector, suggesting that these expenditures are not only driven by policy and regulation, we extend the framework in Morgenstern et al. (2002) to account for endogenous environmental protection expenditures. Specifically, we employ an instrumental variables approach, where sector-level average of the ratio of environmental protection expenditures to total costs is used as the excluded instrument.

The results of this study suggest that increased environmental protection expenditures generally have no statistically significant effect on employment among the sectors studied, with the paper and pulp sector being the exception, showing non-negligible effects. For example, given a 10 percent increase in sector-level EPE, sector-level employment for paper and pulp firms will decrease by approximately 2.08 percent, whereas the corresponding change in the other sectors ranges between a statistically insignificant decrease by 0.14 percent for the iron and steel sector to a statistically insignificant increase by 0.45 percent for the chemical sector. The variation in total marginal effects among the four sectors studied is mainly explained by the varying magnitude of the demand effect, and the varying direction of the factor shift effect.

While the demand effect is negative for all sectors and specifications, the size of the demand effect largely depends on the demand elasticity of the sector, which is relatively large in absolute value for the paper and pulp sector compared to the other sectors. The sign and magnitude of the factor shift effect tells us that, upon incurring EPE to increase the production of R, holding Y constant, firms within the iron and steel sector and paper and pulp sector will reduce their labor, somewhat more so for firms in the paper and pulp sector. While the chemical sector shows a positive factor shift effect in the main specification, this effect becomes statistically significant and negative when excluding outliers for variables L and EPE. This negative factor shift effect is substantially smaller, in absolute value, for the chemical sector, suggesting that production of R is relatively less labor-intensive vis-á-vis production of Y for the chemical sector, compared to the iron and steel and paper and pulp sectors.

In contrast to estimates using a similar empirical approach for U.S. data, the total marginal effects on employment are more often negative (albeit most of them statistically insignificant) for the Swedish sample when compared to Morgenstern et al. (2002) and Belova et al. (2013a). When comparing the compositions of this effect, it appears that the difference is mainly driven by the fact that factor shift effects are more often negative in the analysis of Swedish firms compared to the studies performed on U.S. firms. The difference in total effects and its compositions could stem from slightly different definitions of variables and sectors in the samples, as well as estimation techniques, but is most likely also related to the fact that firms in the U.S. sample and firms in the Swedish sample operate in largely different contexts and time periods with regards to, e.g., environmental regulation, technologies and labor market regulations. For example, the relatively larger, statistically significant, estimate for the paper and pulp sector relative to studies from the U.S. could be explained by a relatively more strict environmental regulation in Sweden, which may imply that environmental protection activities undertaken by Swedish firms in order to comply with regulation are more costly, on the margin. Also, automation may be more prevalent for the firms in the Swedish sample incurring EPE, given that we observe them at a later point in time compared to the U.S. firms. This could be part of the explanation to why we find, generally, negative factor shift effects whereas studies from earlier years find, generally, positive factor shift effects. Given the increasing focus on environmental regulation within the EU, and globally, for the coming years, we see the need for more research on the employment effects of such regulation for industrial sectors in other EU member states.

The current paper raises several interesting questions for future research. First, it is likely that different types of labor are affected differently by environmental protection expenditures and regulation. For example, the substitution possibilities between labor and energy may vary substantially across type of labor (e.g., white and blue collar), and this may in turn influence the effects of environmental protection expenditures on employment. A similar case can be made for capital, where substitution possibilities and adjustment costs may differ substantially across types of capital. Unfortunately, our data do not allow for such disaggregation, but this would be an interesting topic for future research, should such data be available.

Second, the reader should note that our study concerns sector-level, partial equilibrium analyses. This means that in the case of environmental regulation decreasing employment within a sector, we do not observe to what extent these workers are utilized in other sectors of the economy. It is also possible that a "green job" (created by policy) will come at the expense of a "brown job" (which is lost). That is, even if there is no net change in employment levels within a sector or in the economy as a whole, one may observe a shift from "brown" to "green" jobs, and this change is presumably beneficial to society as a whole. Therefore, although environmental protection spending may have a small or limited total marginal effect on sector-level employment, its effects on the structure of the wider economy might nevertheless be substantial.

Appendix A

See Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 and Figs. 3 and 4.

Table 4 Results from first stage of 3SLS, chemical sector

	(PC/TC)	$(PC/TC)lnP_L$	$(PC/TC)lnP_E$	$(PC/TC)lnY$
lnP_L	−0.326	0.106	1.990	−3.358*
	(0.250)	(0.464)	(1.731)	(1.960)
lnP_E	−0.456***	−0.887***	4.692***	−4.135***
	(0.165)	(0.305)	(1.140)	(1.291)
lnY	−0.037	−0.172	0.243	0.358
	(0.071)	(0.132)	(0.491)	(0.556)
$lnYlnY$	0.001	0.001	−0.005	0.006
	(0.001)	(0.002)	(0.009)	(0.010)
lnP_ElnP_E	−0.000	−0.000	0.001	−0.001
	(0.001)	(0.001)	(0.005)	(0.006)
lnP_LlnP_L	−0.001	0.027***	−0.005	0.031
	(0.005)	(0.010)	(0.036)	(0.041)
lnP_LlnP_E	−0.002	−0.006**	0.024**	−0.018*
	(0.001)	(0.003)	(0.009)	(0.011)
lnP_LlnY	−0.006***	−0.007	0.044***	−0.048***
	(0.002)	(0.004)	(0.015)	(0.017)
lnP_ElnY	0.002**	0.002*	−0.015***	0.018***
	(0.001)	(0.001)	(0.005)	(0.006)
$\left(\widetilde{\frac{PC}{TC}}\right)$	−17.440***	−36.399***	87.387***	−121.635***
	(1.035)	(1.920)	(7.165)	(8.114)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_L$	0.372	0.844*	−2.212	3.629*
	(0.257)	(0.477)	(1.780)	(2.016)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_E$	0.464***	0.920***	−3.811***	4.221***
	(0.171)	(0.317)	(1.184)	(1.341)
$\left(\widetilde{\frac{PC}{TC}}\right) lnY$	0.057	0.196	−0.399	0.786
	(0.073)	(0.136)	(0.507)	(0.574)
Constant	17.471***	34.691***	−82.435***	115.165***
	(0.996)	(1.847)	(6.893)	(7.806)
N	522	522	522	522
F	58.212	2090.701	499.616	993.681

Note: * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 5 Results from first stage of 3SLS, iron and steel sector

	(PC/TC)	$(PC/TC)lnP_L$	$(PC/TC)lnP_E$	$(PC/TC)lnY$
lnP_L	−0.178	1.235***	0.660	1.540
	(0.186)	(0.462)	(0.994)	(1.296)
lnP_E	0.338***	1.168***	0.849*	0.972
	(0.094)	(0.235)	(0.505)	(0.658)
lnY	0.009	0.053	0.051	0.860***
	(0.034)	(0.085)	(0.184)	(0.239)
$lnYlnY$	−0.000	0.007***	0.006	0.017***
	(0.001)	(0.002)	(0.005)	(0.007)
lnP_ElnP_E	0.001	0.006	0.025***	−0.012
	(0.002)	(0.004)	(0.009)	(0.011)
lnP_LlnP_L	0.001	−0.035**	−0.012	−0.061
	(0.007)	(0.017)	(0.036)	(0.047)
lnP_LlnP_E	−0.002	−0.007	−0.030*	0.032
	(0.003)	(0.008)	(0.017)	(0.022)
lnP_LlnY	0.002	0.002	−0.002	−0.009
	(0.002)	(0.004)	(0.008)	(0.011)
lnP_ElnY	0.000	0.006***	0.002	0.005
	(0.001)	(0.002)	(0.004)	(0.006)
$\left(\widetilde{\frac{PC}{TC}}\right)$	−31.318***	−54.222***	161.348***	−168.101***
	(0.605)	(1.504)	(3.234)	(4.217)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_L$	0.155	−0.263	−0.816	−1.228
	(0.185)	(0.461)	(0.990)	(1.291)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_E$	−0.343***	−1.191***	0.327	−1.155*
	(0.096)	(0.238)	(0.513)	(0.668)
$\left(\widetilde{\frac{PC}{TC}}\right) lnY$	−0.007	−0.078	−0.095	0.044
	(0.034)	(0.084)	(0.181)	(0.237)
Constant	30.828***	51.860***	−152.608***	159.434***
	(0.596)	(1.483)	(3.188)	(4.156)
N	602	602	602	602
F	365.338	1662.896	1941.798	3934.190

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 6 Results from first stage of 3SLS, paper and pulp sector

	(PC/TC)	$(PC/TC)lnP_L$	$(PC/TC)lnP_E$	$(PC/TC)lnY$
lnP_L	−0.782***	0.638***	5.652***	−5.346***
	(0.151)	(0.171)	(1.576)	(1.196)
lnP_E	−0.111**	−0.045	2.280***	−0.566
	(0.045)	(0.051)	(0.469)	(0.356)
lnY	0.047	0.019	−0.259	1.437***
	(0.033)	(0.037)	(0.343)	(0.260)
$lnYlnY$	−0.000	0.002**	0.004	0.009
	(0.001)	(0.001)	(0.008)	(0.006)
lnP_ElnP_E	−0.001*	−0.000	0.022***	−0.000
	(0.000)	(0.001)	(0.005)	(0.004)
lnP_LlnP_L	0.002	0.007***	−0.006	0.044***
	(0.002)	(0.002)	(0.018)	(0.014)
lnP_LlnP_E	−0.006***	−0.002*	0.033***	−0.046***
	(0.001)	(0.001)	(0.010)	(0.008)
lnP_LlnY	−0.001	−0.002**	0.000	−0.025***
	(0.001)	(0.001)	(0.010)	(0.008)
lnP_ElnY	0.001**	0.001*	−0.001	0.012***
	(0.000)	(0.000)	(0.004)	(0.003)
$\left(\widetilde{\frac{PC}{TC}}\right)$	−42.192***	−69.963***	295.619***	−304.352***
	(0.313)	(0.354)	(3.260)	(2.474)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_L$	0.769***	0.343*	−5.561***	5.284***
	(0.155)	(0.175)	(1.613)	(1.224)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_E$	0.113**	0.042	−1.265***	0.571
	(0.046)	(0.052)	(0.476)	(0.361)
$\left(\widetilde{\frac{PC}{TC}}\right) lnY$	−0.042	−0.030	0.224	−0.422
	(0.034)	(0.038)	(0.349)	(0.265)
Constant	41.479***	67.197***	−283.638***	292.178***
	(0.306)	(0.347)	(3.188)	(2.419)
N	782	782	782	782
F	733.059	109,975.193	3582.595	10,663.445

Note: * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 7 Results from first stage of 3SLS, stone and mineral sector

	(PC/TC)	$(PC/TC)lnP_L$	$(PC/TC)lnP_E$	$(PC/TC)lnY$
lnP_L	−0.012	0.347	−0.111	−0.202
	(0.055)	(0.275)	(0.371)	(0.447)
lnP_E	0.085	−0.326	1.189***	0.444
	(0.055)	(0.273)	(0.369)	(0.445)
lnY	0.010	−0.040	−0.066	0.933***
	(0.028)	(0.140)	(0.189)	(0.228)
$lnYlnY$	−0.000	0.005*	0.002	−0.003
	(0.001)	(0.003)	(0.004)	(0.004)
lnP_ElnP_E	0.001	0.002	0.006*	0.003
	(0.000)	(0.002)	(0.003)	(0.004)
lnP_LlnP_L	−0.001*	0.020***	0.002	−0.009*
	(0.001)	(0.003)	(0.005)	(0.005)
lnP_LlnP_E	−0.001	−0.006**	0.002	−0.002
	(0.001)	(0.003)	(0.004)	(0.005)
lnP_LlnY	0.001**	−0.010***	−0.002	0.011**
	(0.001)	(0.003)	(0.004)	(0.005)
lnP_ElnY	−0.001**	0.002	−0.007***	−0.002
	(0.000)	(0.002)	(0.002)	(0.003)
$\left(\widetilde{\frac{PC}{TC}}\right)$	−23.186***	−36.902***	122.244***	−160.098***
	(0.367)	(1.828)	(2.468)	(2.978)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_L$	0.004	0.635**	0.131	0.149
	(0.055)	(0.276)	(0.372)	(0.449)
$\left(\widetilde{\frac{PC}{TC}}\right) lnP_E$	−0.078	0.342	−0.133	−0.420
	(0.056)	(0.277)	(0.374)	(0.452)
$\left(\widetilde{\frac{PC}{TC}}\right) lnY$	−0.016	0.042	0.025	0.033
	(0.028)	(0.140)	(0.189)	(0.228)
Constant	23.712***	36.154***	−119.229***	156.813***
	(0.364)	(1.810)	(2.443)	(2.949)
N	462	462	462	462
F	516.109	11,255.730	7802.335	13,546.269

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 8 Parameter estimates from second stage regression of 3SLS, main specification

	Chemical	**Iron and steel**	**Paper and pulp**	**Stone and mineral**
α_L	1.244***	0.975***	1.079***	0.988***
	(0.080)	(0.074)	(0.063)	(0.078)
α_E	0.036	−0.028	−0.252***	0.200***
	(0.052)	(0.063)	(0.052)	(0.069)
α_Y	0.388***	0.120	−0.686***	−0.102
	(0.116)	(0.104)	(0.125)	(0.183)
β_{YY}	−0.001***	0.078***	0.213***	0.111***
	(0.015)	(0.015)	(0.017)	(0.028)
β_{EE}	0.022***	0.022**	−0.008	0.021**
	(0.006)	(0.009)	(0.008)	(0.009)
β_{LL}	−0.033	0.023	0.057***	−0.134***
	(0.021)	(0.020)	(0.018)	(0.015)
β_{LE}	0.030***	0.002	0.027***	0.023**
	(0.008)	(0.010)	(0.010)	(0.010)
β_{LY}	−0.050***	−0.042***	−0.052***	0.017**
	(0.006)	(0.004)	(0.006)	(0.008)
β_{EY}	0.010**	0.026***	0.040***	−0.016***
	(0.004)	(0.004)	(0.005)	(0.006)
γ_L	5.367**	−0.865	−8.559***	9.755***
	(2.175)	(1.613)	(1.786)	(2.058)
γ_E	−4.331***	0.885	15.266***	−14.181***
	(1.529)	(1.464)	(1.557)	(1.826)
δ_{LL}	−1.055*	0.085	−0.069	0.410
	(0.548)	(0.343)	(0.330)	(0.459)
δ_{LE}	0.510*	−0.098	−1.074***	1.908***
	(0.262)	(0.222)	(0.206)	(0.305)
δ_{EE}	−0.680***	−0.026	1.724***	−2.307***
	(0.221)	(0.225)	(0.187)	(0.289)
$lnPC : R^2$ (#parameters)	0.954 (110)	0.959 (106)	0.927 (107)	0.948 (85)
$v_L : R^2$ (#parameters)	0.151 (6)	0.178 (6)	0.217 (6)	0.046 (6)
$v_E : R^2$ (#parameters)	−0.015 (6)	0.093 (6)	0.209 (6)	0.037 (6)
Observations	522	602	782	462

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 9 Demand elasticity estimates

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
σ_d	0.378***	0.174***	2.992***	0.109**
	(0.080)	(0.051)	(0.098)	(0.053)
Observations	377	452	636	350

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 10 Estimated effects of EPE on employment, no IV

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	0.689***	0.821***	0.721***	0.873***
	(0.013)	(0.018)	(0.010)	(0.037)
Demand effect	−0.260**	−0.143***	−2.157***	−0.095
	(0.110)	(0.053)	(0.792)	(0.091)
Factor shift effect	0.400	−0.663***	−2.492***	−0.452
	(0.553)	(0.252)	(0.282)	(0.431)
Total (marginal) effect	0.829	0.015	−3.928***	0.326
	(0.574)	(0.269)	(0.913)	(0.436)
Total effect (elasticities)	0.033	0.001	−0.178***	0.007
	(0.022)	(0.010)	(0.042)	(0.010)
Observations	522	602	782	462

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 11 Estimated effects of EPE on employment, pooled models

	All sectors	Energy intensive sectors
Cost effect	0.937***	0.758***
	(0.007)	(0.006)
Demand effect	−0.674***	−0.972**
	(0.178)	(0.460)
Factor shift effect	−0.519	−0.553**
	(2.878)	(0.259)
Total (marginal) effect	−0.256	−0.767
	(2.860)	(0.530)
Total effect (elasticities)	−0.005	−0.029
	(0.053)	(0.020)
Observations	8493	2368

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 12 Estimated effects of EPE on employment, outliers larger than 99th and smaller than 1st percentiles excluded

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	0.636***	0.819***	0.732***	0.872***
	(0.009)	(0.019)	(0.010)	(0.039)
Demand effect	−0.253**	−0.141***	−2.205**	−0.101
	(0.098)	(0.051)	(0.866)	(0.103)
Factor shift effect	−0.363*	−1.274***	−2.220***	−0.741
	(0.191)	(0.422)	(0.375)	(0.617)
Total (marginal) effect	0.019	−0.597	−3.692***	0.031
	(0.208)	(0.425)	(1.010)	(0.608)
Total effect (elasticities)	0.001	−0.019	−0.163***	0.001
	(0.011)	(0.014)	(0.045)	(0.013)
Observations	502	578	759	447

Lowest 1st percentile and highest 99th percentile dropped for variables EPE and L

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 13 F-statistics from first-stage regression of 3SLS, alternative IV

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
First stage equation				
PC/TC	8.872	49.830	58.625	15.641
$(PC/TC)lnP_L$	351.256	394.833	4134.565	2192.827
$(PC/TC)lnP_E$	143.340	229.755	705.045	431.809
$(PC/TC)lnY$	231.682	564.786	1150.990	714.732

Excluded instrumental variables are: $min(PC/TC)_{it}$, $(min(PC/TC)_{it})lnP_{E,it}$, $min(PC/TC)_{it})lnP_{L,it}$ and $min(PC/TC)_{it})lnY_{it}$ where $min(PC/TC)_{it}$ is the minimum of $PC/(EPE + PC)$ among all other firms in the same sector in the same year

Table 14 Estimated effects of EPE on employment, alternative IV

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	0.689***	0.821***	0.721***	0.873***
	(0.013)	(0.018)	(0.010)	(0.037)
Demand effect	−0.260**	−0.143***	−2.157***	−0.095
	(0.110)	(0.053)	(0.792)	(0.091)
Factor shift effect	1.044	−1.187**	−3.526***	−0.203
	(0.933)	(0.461)	(0.692)	(0.843)
Total (marginal) effect	1.473	−0.509	−4.962***	0.575
	(0.957)	(0.477)	(1.039)	(0.842)
Total effect (elasticities)	0.059	−0.018	−0.224***	0.013
	(0.038)	(0.017)	(0.048)	(0.019)
Observations	522	602	782	462

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 15 Estimated effects of EPE on employment, including investments in EPE

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	0.689***	0.800***	0.721***	0.872***
	(0.011)	(0.020)	(0.009)	(0.029)
Demand effect	−0.262***	−0.130**	−2.131***	−0.082
	(0.095)	(0.060)	(0.774)	(0.061)
Factor shift effect	0.802	−1.045***	−2.025***	−0.617
	(0.737)	(0.317)	(0.371)	(0.492)
Total (marginal) effect	1.228*	−0.375	−3.434***	0.173
	(0.740)	(0.326)	(0.880)	(0.478)
Total effect (elasticities)	0.063	−0.016	−0.260***	0.006
	(0.038)	(0.014)	(0.067)	(0.017)
Observations	530	612	791	479

Note: * p<0.10, ** p<0.05, *** p<0.01

Table 16 Estimated effects of EPE on employment, allowing for additional benefits and costs of EPE, with IV

	Chemical	Iron and steel	Paper and pulp	Stone and mineral
Cost effect	−0.101	0.629***	0.638	0.209
	(0.211)	(0.111)	(0.513)	(1.036)
Demand effect	0.038	−0.110**	−1.908	−0.023
	(0.086)	(0.044)	(1.558)	(0.221)
Factor shift effect	1.254	−0.910**	−1.656***	−0.157
	(0.886)	(0.428)	(0.359)	(0.634)
Total (marginal) effect	1.191	−0.391	−2.927**	0.029
	(0.888)	(0.409)	(1.270)	(0.869)
Total effect (elasticities)	0.047	−0.014	−0.132**	0.001
	(0.035)	(0.014)	(0.058)	(0.020)
Observations	522	602	782	462

Note: * p<0.10, ** p<0.05, *** p<0.01

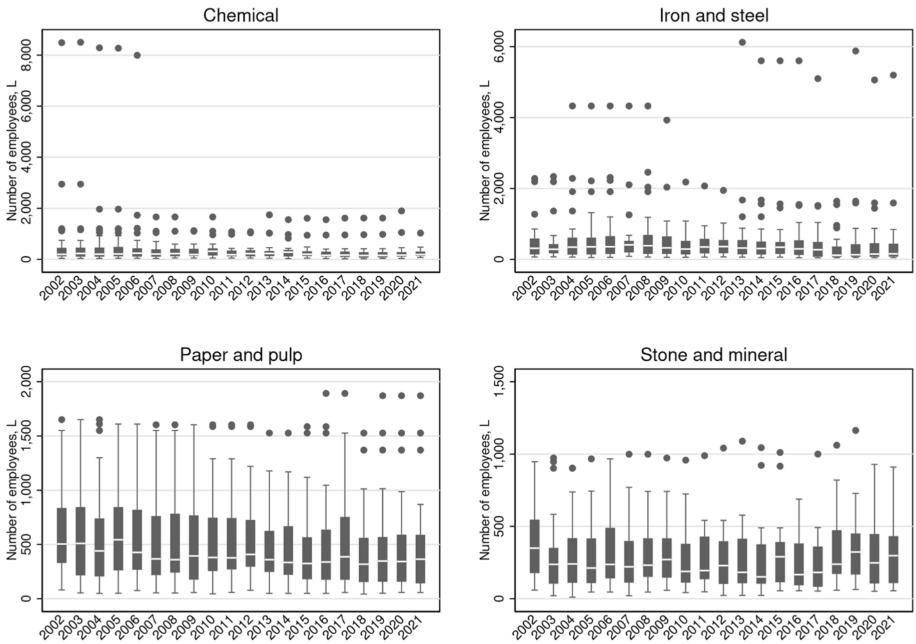

Fig. 3 Number of employees, L, by sector 2002–2021

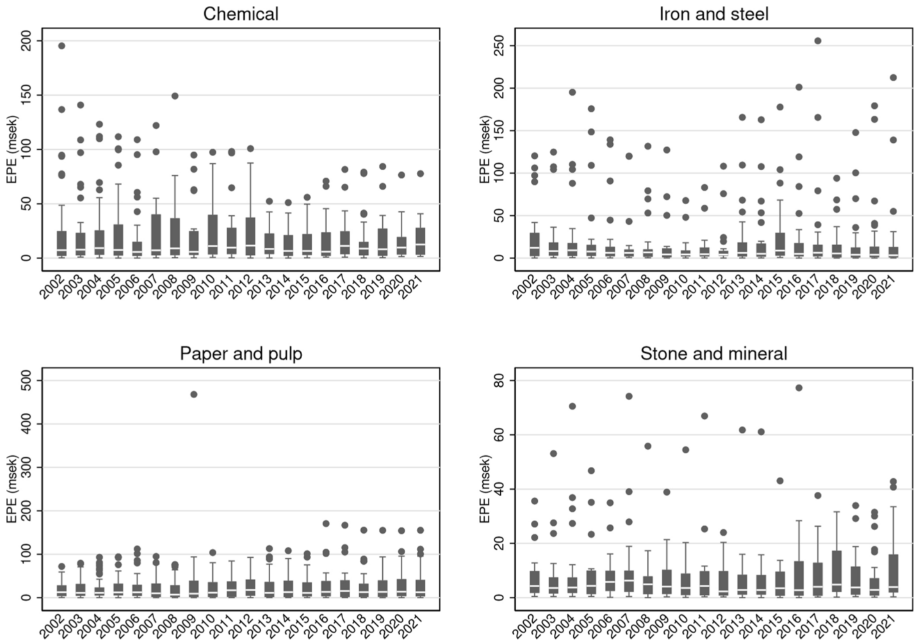

Fig. 4 Environmental protection expenditures, EPE, by sector 2002–2021

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Declarations

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