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Green public procurement and the innovation activities of firms

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Green public procurement and the innovation activities of firms

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Abstract

This paper provides first empirical insights on the relationship between green public procurement (GPP) and firms' innovation activities. Considering that the public sector is a large buyer in the economy, public procurement is able to work as demand-pull factor for new products and thus innovations – given that the procurement is aimed at such objectives. GPP is specifically implemented to contribute to more sustainable production and consumption. Using a novel firm-level dataset, this paper analyses whether GPP is able to trigger innovation activities within firms, and if so, whether these innovations are environmental innovations or not. The results show some support for a demand-pull effect of GPP on the probability of general product innovations but no conclusive evidence is found for environmental innovations.

Keywords: Green public procurement; Innovation; Demand-pull; Community innovation survey.

JEL Classification: H57, O38, Q55, Q58.

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1. Introduction

The public sector has a large potential as buyer to influence the production of more environmentally friendly products through public purchases. Public procurement accounted for 12% of GDP on average in the OECD countries in 2015 (OECD, 2017). Acknowledging that this demand could be directed towards the purchase of more environmentally friendly products opens a wide field of action for governments. However, little is known so far on the effects of using environmental criteria in public procurement, so-called green public procurement (GPP), on e.g. procurement practices of buyers, competition effects in the procurement auction, or effects on induced innovation at the firm-level.

Green public procurement falls into the category of strategic procurement, which aims at achieving additional, strategic policy goals through procurement.² In the case of green public procurement, the political goal is to achieve a more sustainable economy. This is done by explicitly including environmental criteria in the procurement process of works, services, and supplies. In practice, this might be done in form of technical requirements or, more flexibly, through additional selection criteria next to a price selection criteria.

Green public procurement can be considered as demand-side innovation policy tool. Demand-side innovation policies are considered to trigger innovations or spread the diffusion of new technologies through a demand-pull effect – in contrast to supply-side policies which work through technology-push effects (Edler and Georghiou, 2007). Public procurement might create this demand effect through the creation of lead markets or by overcoming market failures. One main argument for public procurement as innovation policy, which is especially relevant for the case of GPP, is that broader policy objectives such as sustainability might be achieved sooner with more innovation (Edler and Georghiou, 2007). The research question of this paper is thus whether green public procurement works as demand-pull factor for innovations.

This paper provides a first empirical analysis on the relationship between GPP and the probability of firms' innovation activities in Germany from 2006-2016 by using a binary response model. The analysis uses a new firm-level dataset which builds on the Tenders Electronic Daily (TED) database of the European Commission where green procurement awards³ are identi-

²Strategic procurement refers i.a. to innovative, green, and social procurement. These are forms of procurement which emphasise certain quality measures in the procurement process to achieve more innovation, sustainability or inclusiveness in the overall economy (European Commission, 2017b).

³The terminology of 'winning a GPP award' and 'winning a GPP contract' is used interchangeably in this paper.

fied and matched to the Mannheimer Innovation Panel, the German part of the European Community Innovation Survey (CIS). The combination of these two dataset allows to infer correlations between winning GPP contracts and firms' innovation activities. Firms' innovations are measured as indicator variable which measure whether a firm produced a general innovation or not. This indicator is further differentiated into general product and general process innovations. The dataset also offers a separate indicator for environmental innovations (environmental product and environmental process innovations) which is however only available for two out of ten survey waves.

The results show that winning a GPP contract is associated with a higher probability of generating product innovations while no significant correlation with the probability of process innovations can be confirmed. A more detailed look at the probability of environmental innovations shows no significant relationship with winning a GPP contract – neither for environmental product nor for environmental process innovations.

Sector heterogeneous results are found for general product and process innovations. While the water supply and waste industry show a positive correlation between winning a GPP contract and the probability of product innovations, the electricity and gas sector shows a positive correlation between winning a GPP contract and process innovations. The manufacturing sectors only shows a positive relationship between a cumulative GPP measure and product innovations, potentially indicating a slower but sustained effect of GPP.

Related literature

The paper is related to three literature streams and adds to them in the following three ways. First, the paper adds to the research on economic effects of GPP by providing first empirical evidence on firm-side effects of GPP. Second, it adds an additional type of procurement to the empirical literature on procurement and innovations. Furthermore, this paper uses a more direct way of measuring procurement as this analysis is based on actual contract data matched to firm-level data instead of relying on proxies of procurement, as e.g. Aschhoff and Sofka (2009) use. Third, the paper adds a missing piece to the literature around the drivers of environmental innovations by providing first empirical evidence on GPP as demand-side driver.

First of all, the paper relates to the literature around green public procurement. There is a growing field of literature around the implementation of GPP, but studies about the effect of GPP on firms' activities are still missing (see Cheng et al. (2018) for a review). The theoretical framework of GPP is related to preferential procurement (see Marion (2007) for the context of SMEs) and scoring auctions (Lundberg et al., 2011; Asker and Cantillon, 2008). Many quantitative studies investigate the implementation

and potential barriers of GPP (Testa et al. (2012), Testa et al. (2014), see Cheng et al. (2018) for a more detailed review). Studies on the economic impacts of GPP are only a handful. Simcoe and Toffel (2014) show empirical evidence that GPP can enhance the diffusion of environmental technologies by affecting the private sector demand. Rietbergen and Blok (2013) use the case of the Netherlands to show that GPP reduced the CO_2 -intensity of the supply chains of the public sector. Lundberg et al. (2015) find that GPP does not significantly influence the decision of firms to participate in a tender nor the overall number of bids submitted. However, the increased complexity of some GPP contracts is associated with a higher drop-out rate of bids at the qualification stage where bids are evaluated whether they meet all binding requirements.

Second, this paper relates to the literature which analyses procurement as demand-side innovation policy. There are some early and some more recent empirical studies investigating the link between public procurement and innovation (see Appelt and Galindo-Rueda (2016) and Mowery and Rosenberg (1979) for reviews), often comparing public procurement to other innovation policy tools. Empirical studies often face the difficulty of data availability – either on the side of the procurement or on the link between firm-level data and procurement, why often innovation survey are used. Aschhoff and Sofka (2009) for example made use of the 2003 German innovation survey. Comparing the effect of procurement to R&D subsidies and university research, they found that both public procurement and the public provision of R&D infrastructure in universities had a positive effect on firms’ innovations. Slavtchev and Wiederhold (2016) find causal evidence of increasing technological content on R&D activities in high-tech sectors in the US. Czarnitzki et al. (2018) use the German CIS data and show a significant positive effect of innovative procurement on the sales share of new products of firms who won a procurement contract.

Third, this paper also relates to the literature on the drivers of environmental innovations. GPP seems a highly under-researched piece in this literature. While studies investigated the effect of technology-push factors such as R&D grants and tax credits (Dechezleprêtre et al., 2016), demonstration plant funding (Nemet et al., 2018), regulatory push factors such as environmental regulations (Dechezleprêtre et al., 2015), as well as demand-pull factors like standards (Montero, 2002; Holland et al, 2009) and the pricing of externalities (Borghesi et al., 2015; Calel and Dechezleprêtre, 2016), an analysis of GPP as driver of environmental innovations is still missing. A notable contribution in this field is Ghisetti (2017) who provides first empirical evidence of the effect of innovative procurement on environmental innovations using Innobarometer data from the European Union. Horbach et al. (2012) analyse a range of potential drivers and show that i.a. customer requirements are an important driver of environmental innovations for firms, supporting the case for procurement as driver of environmental innovations.

The paper is structured as follows. Section 2 provides a rationale for GPP in the innovation context. Section 3 describes the data and methodology used for the empirical analysis. Section 4 presents the results, followed by section 5 providing some robustness checks. Section 6 concludes.

2. Framework

The framework for this paper is grounded on the innovation model developed by Crepon et al. (1998) as well as the taxonomy of the innovation and procurement policy space by Edler and Georghiou (2007). To analyse the research question of this paper, whether green public procurement works as demand-pull factor for innovations, the framework explained in this section is used to develop three hypotheses, which will be tested empirically later on in this paper.

Public procurement as demand-side innovation policy only recently attracted more attention – even though first empirical studies were conducted already in the early 1980s (see Mowery and Rosenberg (1979) for a review). As Edler and Georghiou (2007) review in their seminal paper, public procurement was mostly neglected in conceptual research⁴ as well as on the policy agenda until the early 2000s when the European Union picked it up again.

There are three main rationale, according to Edler and Georghiou (2007), to implement public procurement as demand-side innovation policy tool, even if the effect on innovation through public procurement will only be indirect. While there are policies, such as R&D grants, which are solely targeted at increasing innovations and which rather directly impact the innovation process, there are still good reasons to consider public procurement as useful demand-side innovation policy. First, the large share of public demand might create lead markets. Second, public procurement might be able to overcome existing market failures which lead to an under-supply of innovations. Third, public procurement might be used as innovation policy to achieve other normative policy objectives than innovation goals. The transition towards a low-carbon economy could be such a policy objective, which might be achieved faster through procurement-enhanced innovations than without procurement.

Looking at the innovation process within firms, a demand-pull effect of procurement might work through a direct channel affecting innovation output. In the innovation cycle framework developed by Crepon et al. (1998), firms' innovations are a function of their innovation budget, the size of the firm, sectoral effects, technological push and demand-pull effects. These

⁴A notable exception and interesting read is Geroski (1990). Using a historic case study approach, he identifies conditions under which procurement as innovation policy might be effective and when it might not be.

demand-pull effects might work as direct effect on innovation output and/or as indirect effect through the firms' innovation input, e.g. R&D budget, on innovations. From their multistage innovation model, Crepon et al. (1998) conclude that the direct effect of demand-pull factors is by far larger than the indirect effect: Using a reduced form estimation, they proxy demand-pull factors with a categorical survey variable and find that the magnitude of the indirect effect on innovative sales as innovation output variable is five times the direct effect of demand-pull factors. Keeping this evidence in mind, the analysis of this paper focuses on the direct effect of the demand-pull factors only.

Green public procurement implemented as environmental selection criteria might be especially suitable for triggering innovations through a demand-pull effect. Certainly, so-called innovation procurement, which explicitly involves innovative components in the procurement object with subsequent acquisition of successful products, is the most obvious type of procurement to trigger innovation. However, when awarding a tender through selection of the most economically advantageous tender (MEAT) instead of the lowest price criterion, additional criteria are specified for awarding the tender – which leave room for innovations to the firm. These selection criteria might be related to quality, delivery time or – in the case of GPP – to environmental aspects. These environmental aspects are often defined in broad terms, such as ‘energy efficiency’, ‘CO₂-reduction’, ‘lowest life-cycle cost’. The broadness of the criteria allows firms to be creative in the way of achieving the criteria and might thus spur innovation even if this is not an explicit innovation procurement.⁵ Therefore the following hypothesis is tested:

H1: Winning a green public procurement contract works as direct demand-pull effect in triggering general innovations.

Green public procurement allows governments to internalise the environmental externalities of production and consumption as well as to solve market failures regarding environmental innovations. Similar to the case of general procurement being used as innovation policy to overcome market failures⁶ (Edler and Georghiou, 2007), green public procurement can be used as environmental policy to overcome the problem of environmental externalities as it can help taking into account environmental externalities from the production and consumption process. Moreover, green public procurement

⁵The broadness of environmental terms used in the selection criteria makes this selection criteria more likely to spur innovation than e.g. requirements on delivery time.

⁶Such market failures might be asymmetric information between the user and the producer of innovations where procurement can help facilitating this interaction (Edler and Georghiou, 2007), or it might be spill-overs of R&D where procurement can help to reduce the resulting under-supply of innovations

can help overcome market failures arising around environmental innovations: While environmental innovations are anticipated to have a double pay-off in terms of limiting environmental damage and increasing innovations at the same time⁷, they also have a double externality problem (Katsoulacos and Xepapadeas, 1996; Rennings, 2000). Next to the usual externality of innovations in the research phase in terms of knowledge spill-overs, environmental innovations also face externalities in the diffusion stage where the innovating firm does not reap the benefits of environmental innovations (i.e. the reduced environmental harm which is a public good) but incurs the costs. This leads to an under-provision of environmental innovations. GPP might thus be a suitable policy tool to overcome these market failures for environmental innovations.⁸ These environmental innovations could lie on the consumption side where the environmental performance of using a product is increased or they might lie on the production side where environmental impacts of the production process are reduced. Therefore the following hypothesis is tested:

H2: Winning a green public procurement contract increases the probability of producing ‘environmental’ product innovations (consumption side) as well as ‘environmental’ process innovations (production side).

Green public procurement is considered a so-called strategic procurement (European Commission, 2017b). Edler and Georghiou (2007) define strategic procurement as procurement which encourages “the demand for certain technologies, products or services [...] to stimulate the market” (p. 953). This implies that strategic procurement is often targeted at specific sectors (Edler and Georghiou, 2007). In the case of green public procurement, these sectors might for example be sectors where the government could buy readily available environmentally friendly products or they might be sectors which do not perform well in terms of environmental measures such as CO_2 performance and might thus still need to innovate. The government might target these sectors with different ways of GPP implementation. While for sectors with readily available products, a specification in the technical requirements might work as technology diffusion, using GPP in the selection criteria of contracts might be a more suitable way of targeting sectors which

⁷See Porter and Linde (1995) and moreover Jaffe et al. (2002) for a critical and detailed discussion

⁸Another relevant point in overcoming market failures in the special case of green public procurement is that by buying new environmentally friendly products and services, the government can demonstrate the functioning of the novel products as well as drawing public attention to them. Especially in the case of environmentally friendly products, this seems important as these products are often met with scepticism. Unfortunately, an analysis of this factor lies outside of the scope of this paper.

lag behind. While the selection specification of GPP thus provides incentives for better environmental performance, the effectiveness of this demand-pull effect might considerably differ across industries. Not only might it be absent in some but it might differ in magnitude across sectors. Therefore the following hypothesis is tested:

H3: The demand-pull effect of green public procurement on general innovations differs across sectors.

3. Empirical analysis

3.1. Data

The analysis in this paper uses a novel firm-level dataset for Germany which combines information on awarded green public procurement contracts with information on firm characteristics, especially firms' innovation activities. The datasets were matched at the firm-level, based on fuzzy string matching on the firms' name and address information.⁹ The combined dataset is an unbalanced panel dataset, spanning the time period 2006 to 2016, covering 5374 individual firms of which 46% innovated at some point during the observation period. Table 1 shows descriptive statistics for the underlying dataset.

Table 1: Descriptive statistics

Variable	Mean	Std. dev.	Min	Max
<i>Dependent variables</i>				
Product innovations ¹	0.286	0.452	0	1
Process innovations ¹	0.224	0.417	0	1
Env. product innovation ¹	0.315	0.465	0	1
Env. process innovation ¹	0.494	0.500	0	1
<i>Variable of interest</i>				
GPP ¹	0.005	0.07	0	1
<i>Control variables</i>				
Innovation intensity (Mio. EUR per employee)	0.003	0.011	0	0.345
Number of employees	354.3	6,748	1	402,700
High-skilled employees (%)	20.12	24.65	0	100
Export intensity	0.137	0.241	0	1
Costs per employee (Mio. EUR)	0.158	1.131	0.001	89.81
Public R&D support ¹	0.186	0.389	0	1
Business group ¹	0.264	0.441	0	1
Foreign business group ¹	0.129	0.335	0	1
East Germany ¹	0.376	0.484	0	1

Note: ¹denotes dummy variables. The data is cleaned for implausible values such as an export intensity above one or a share of high-skilled employees above 100.

⁹The matched results underwent a manual scrutiny check to exclude false positive matches.

The public procurement data was taken from the Tenders Electronic Daily (TED) database of the European Commission (TED, 2019). This database contains information about all public procurement notices and awards published in the European Union above certain thresholds.¹⁰ The data is collected by the European Commission and directly taken out of the standard procurement forms provided by the European Commission which are filled by the public authorities. Next to the date of the procurement award, the name of the contracting authority, and the name of the winning firm, the database also contains information about the selection criteria for awarding the procurement awards. For the analysis in this paper, only the contracts which were won by German firms were considered. These were 319,862 procurement contracts in total from 2006 to 2016.

The data on innovation activities and firm characteristics is taken from the Mannheimer Innovation Panel (MIP) which is collected by the Leibniz Centre for European Economic Research (ZEW)¹¹ since 1993 and which builds the German part of the Community Innovation Survey (CIS) of the European Commission. In contrast to other CISs, the MIP is constructed as panel survey and gathered annually. Around 6000 firms answer the questionnaire each year, yielding a response rate around 20%. The ZEW conducts annual non-response surveys, which show that the share of innovators among the responding firms is lower than among the non-responding firms (Peters and Rammer, 2013). The results of the analysis in this paper should thus be understood as lower bound effects.

The MIP is constructed as representative sample of the German industrial and service sectors.¹² The main focus of the survey lies on gathering information about a variety of innovation activities of firms. Not only are R&D expenditures collected as measure of an innovation input, but also indicators on product as well as process innovations and the share of new product sales in overall sales as measure of innovation outputs. The MIP in general thus allows to analyse the whole innovation cycle, while other measures used in innovation research often only give information on either

¹⁰To ensure transparency and a competitive procurement process EU-wide, the European Commission defined thresholds in terms of the Euro value of procurement tenders above which call for tenders have to be published in the TED database. These thresholds vary over time, type of contract, and type of public authority. For example, as of 2017, supplies contracts by sub-central authorities above a value of 221.000 Euros were required to be published in TED (European Commission, 2017a). As it is considered good practice to publish public tenders in the TED, even tenders below the threshold are published in TED. For the analysis of this paper, it is however not necessary to constrain the analysis to above threshold contracts only, even if they may have a larger impact due to their sheer size, on innovation activities of firms.

¹¹The data was accessed within the premises of the ZEW's Research Data Centre.

¹²For more information on the German CIS and the survey methodology, see Peters and Rammer (2013).

inputs (e.g. R&D expenditure) or outputs (e.g. patents) to the innovation process.¹³ Next to detailed information about innovations at the firm-level, the dataset also contains information about firm performance such as e.g. turnover, exports, number of employees. Moreover, each year there is a focus theme around which additional questions are asked, for example about environmental innovations. Unfortunately, these questions are often not repeated in subsequent surveys. Therefore, the information about environmental innovations used later in this analysis, is limited to two survey waves (survey waves 2009 and 2015).

3.2. Estimation framework

The estimation approach used in this paper goes back to the innovation model developed by Crepon et al. (1998). This paper focuses on the so-called innovation equation which tries to explain the drivers of innovation outputs. However, departing from the multi-stage model from Crepon et al. (1998) which uses predicted innovation, this paper estimates the following single-stage reduced form equation based on recorded innovation outputs, using a random effects probit model:¹⁴

$$Y_{it} = \beta_1 GPP_{it} + \beta X_{it} + \gamma_s + \tau_t + u_i + \epsilon_{it} \quad (1)$$

where Y_{it} is a dummy indicating whether the firm produced innovations in the last three years, GPP_{it} is a dummy indicating whether the firm won a GPP contract or not, X_{it} are firm-level control variables, γ_s are industry dummies, τ_t are year dummies, u_i is a random firm-specific effect, and ϵ_{it} is the remaining error term.

Dependent variables

In order to answer the hypotheses laid out in section 2, equation 1 is estimated for four different dependent variables. All of these dependent variables are dummy variables which indicate whether the firm had process, product, environmental process, or environmental product innovations. Using these variables as innovation indicators follows other studies in this field which investigate the drivers of innovations (Griffith et al., 2006) or of environmental innovations (Borghesi et al., 2015). To investigate *H1*, two dummies are used as indicator of innovation outputs. Firms are asked in the

¹³Nonetheless, the usual caveats of survey data should be kept in mind – even if the MIP questionnaire contains several plausibility questions to reduce the risk of inconsistent answers. For a more detailed discussion on the use of different innovation measures, see Gault (2013).

¹⁴The panel structure of the data yields itself to using panel estimation methods. The assumption of the random effects probit is that the explanatory factors are uncorrelated with the individual heterogeneity. This assumption is strong and will be relaxed later by using a the Mundlak approach (Mundlak, 1978).

MIP questionnaire whether they had product innovations in the last three years and whether they had process innovations in the last three years.¹⁵ This differentiation allows to evaluate in more detail, where in the production process, the innovations took place. Using this variable instead of other output variables such as patents, allows to take into account all innovations, not only the patented or patentable ones, as well as it avoid accounting for patents which are never used in practice. To investigate *H2*, a dummy variable is taken from the MIP which indicates specifically environmental innovations. This dummy is again differentiated between environmental product and environmental process innovations. Environmental product innovations are defined as innovations which reduce environmental externalities arising from using the product, while environmental process innovations are defined as innovations which reduce environmental externalities during the production process on site. Given that the information about environmental innovations was only part of two survey waves (2008 and 2013), the estimations relying on environmental innovations as dependent variable are estimated using a pooled probit model.¹⁶

Variable of interest

The main explanatory variable of interest to this paper indicates whether firms won a GPP contract or not. Using actual award-level data for procurement instead of having to rely on proxies of procurement as other studies had to (e.g. information about the customers of firms as in Aschhoff and Sofka (2009)), provides a major advancement in the analysis of the economic effects of procurement as this data is much more specific. The information provided by the TED database on the selection criteria of the procurement awards was used to create this variable of interest. The GPP-dummy indicates whether a firm won a green public procurement contract or not. The selection criteria of each procurement tender are specified as free text in the original database. This information is searched for keywords which indicate environmental criteria, e.g. recyclable, energy efficient, sustainable etc., to code the dummy variable.¹⁷ Out of all 319.862 contracts won by German

¹⁵The definition of product and process innovations follows the definition in the Oslo Manual (OECD/Eurostat, 2005).

¹⁶Running a random effects probit model shows a rho-coefficient similar to zero which indicates that the panel-dimension of the data does not add much to the explanation of the underlying data generating process. Thus, the pooled probit estimation is preferred. Results of the random effects probit model are available from the author upon request.

¹⁷The language of the procurement tender documents is often equivalent to the language of the country where the procuring authority is based. However, to ensure that also GPP contracts are detected which were won by German firms but called for by non-German authorities, the keyword search was not only conducted in German but also in the languages of the biggest European economies, namely in English, French, Spanish, and Italian.

firms in 2006-2016, only 2.19% were classified as GPP. In addition to the simple dummy, a cumulative measure of having won a GPP contract is calculated as cumulative sum of the original GPP dummy variable.¹⁸ This cumulative variable is used to analyse whether there is a longer lasting relationship between winning a GPP contract and innovation.

Control variables

A range of firm-level control variables, X_{it} , are included in the analysis. The initial innovation model from Crepon et al. (1998), including innovation intensity (R&D expenditure over employees), firm size (log of number of employees, lagged), sector dummies¹⁹ is supplemented with established controls used in similar research (e.g. Czarnitzki et al. (2018), Borghesi et al. (2015), Aschhoff and Sofka (2009), Griffith et al. (2006)), namely human capital (share of high-skilled employees, lagged), export intensity (total exports over total turnover, lagged), a dummy for receiving public R&D support in the last three years, production costs per employee (lagged), a dummy for belonging to a business group, a dummy for belonging to a foreign business group and a dummy for being located in east Germany. In the estimation on the environmental innovations, an additional ETS-dummy is included as control variable, indicating whether the sector is subject to the European Emission Trading Scheme or not.²⁰

4. Results

Hypothesis 1

The results of analysing hypothesis 1 show mixed supportive evidence for innovations (see Table 2). While winning a GPP contract increases the probability of having product innovations, no significant relation is found on the probability of having process innovations (Table 2). Looking at the cumulative GPP measure described above, which potentially is able to track longer term impacts of GPP on innovations, shows still a significant but smaller coefficient than in the previous estimation for product innovations.²¹ While these aggregate results suggest a positive demand-pull effect of GPP on new products, there seems no effect on new production processes as a result of winning GPP contracts.

¹⁸Each time a firm won a GPP contract, the cumulative measure increases by one.

¹⁹Sector dummies are based on the 21 main categories of NACE Rev. 2 classification. See Appendix 7.1 Table 5 for more details.

²⁰Nace2-sectors covered until 2013 under the Emission Trading Scheme include paper and paper products (sector 17), coke and refinery (sector 19), ceramics and cement (sector 23), metallurgy (sectors 24 and 25). After 2013, chemicals (sector 20) is added.

²¹Note that coefficients are displayed, not marginal effects.

The control variables are mostly significant and have the expected signs.²² Innovation intensity, firm size and public R&D support significantly increase the probability of having product and process innovations. Additionally, for product innovations, human capital, the export intensity, the production costs per employee contributes to a higher probability of innovation. Belonging to a business group is statistically relevant for the likelihood of process innovations while being located in the east of Germany is associated with a lower probability of process innovations.

The results also show that a random effects probit estimation is preferred to a pooled probit estimation, as the panel structure is statistically important to explain the underlying data generation process (see rho and Chi-squared statistic in Table 2). The underlying assumption that the regressors are uncorrelated with any unobserved heterogeneity will be relaxed later on in the robustness checks.

Hypothesis 2

Testing hypothesis 2 yields neither a clear rejection nor an acceptance of the hypothesis that winning a GPP contract is associated with an increased probability of having environmental innovations. The results in Table 3 show no significant correlations of winning a GPP contract and the probability of environmental product or process innovations, nor does a cumulative measure of GPP has statistical significance. Keeping in mind that these estimations are to be understood as lower bound of any possible effect, a clear conclusion that there is no relationship between GPP and environmental innovations is not possible. In contrast to the estimation of hypothesis 1, this estimation is conducted using a pooled probit model for the two survey waves which include information about environmental innovations. Additional estimations of a panel probit model showed that the panel factor (rho) is not significant.²³ This is as expected considering that there are only two years of data available for this estimation.

The ETS dummy, additionally included in the analysis of environmental innovations, is significantly negatively related to the probability of having environmental product innovations, while it is significantly positively related to the probability of having environmental process innovations. The negative effect on the probability of environmental product innovations might be a crowding-out effect of investments into process innovations: While firms regulated under the EU ETS are reliable for their own emissions on their

²²The Akaike information criterion (AIC) and the Bayesian information criterion (BIC) were evaluated to test whether the inclusion of additional control variables actually contributes to the explanatory power of the estimation model instead of over identifying it. The specification shown in Table 2 showed the lowest values of AIC and BIC. Results of different specifications of control variables are available upon request.

²³Results available upon request.

Table 2: Hypothesis 1 – Estimation results (random effects probit)

	Product innovations		Process innovations	
	I	II	I	II
GPP ¹	0.918** (0.025)		0.123 (0.755)	
GPP (cum.)		0.538** (0.013)		0.0802 (0.677)
Innovation intensity (t-1)	27.73** (0.013)	27.78** (0.013)	5.918** (0.048)	5.923** (0.048)
Firm size (t-1)	0.134*** (0.000)	0.132*** (0.000)	0.229*** (0.000)	0.228*** (0.000)
High-skilled employees (%) (t-1)	0.00693*** (0.000)	0.00692*** (0.000)	0.000108 (0.943)	0.000104 (0.944)
Export intensity (t-1)	1.361*** (0.000)	1.352*** (0.000)	0.112 (0.418)	0.111 (0.420)
Public R&D support ¹	2.864*** (0.000)	2.866*** (0.000)	1.919*** (0.000)	1.919*** (0.000)
Costs p.c. (t-1)	0.00803*** (0.000)	0.00802*** (0.000)	0.0554 (0.169)	0.0552 (0.170)
Business group ¹	0.0547 (0.592)	0.0581 (0.569)	0.226*** (0.008)	0.227*** (0.007)
Foreign business group ¹	0.117 (0.378)	0.116 (0.380)	-0.132 (0.207)	-0.132 (0.207)
East Germany ¹	-0.0527 (0.481)	-0.0570 (0.447)	-0.128** (0.047)	-0.129** (0.045)
Constant	-3.230*** (0.000)	-3.215*** (0.000)	-4.489*** (0.000)	-4.486*** (0.000)
Observations	8651	8651	8637	8637
Pseudo R-squared	0.055	0.055	0.041	0.041
rho	0.660	0.660	0.560	0.560
Chi-squared (comparison test)	334.7	334.9	272.3	272.3

Note: p-values in parentheses * p<0.1, ** p<0.05, *** p<0.01. Robust std. errors used. Industry and year dummies not shown. ¹denotes dummy variables.

production site, they are not reliable for environmental externalities which arise through the use of their products. It is thus reasonable for a firm to invest into environmental process innovations to reduce their externality costs. However, this might reduce investments into the development of new products and thus lead to a crowding-out effect on environmental product innovations. The positive correlation with the probability of environmental process innovations is also in line with previous literature (see Borghesi et al. (2015) for a more in-depth study of the effects of the EU ETS on environmental innovations).

The other control variables show slightly different results compared to the estimations on overall innovations before. The innovation intensity is not found to be a significant contributor for the probability of having environmental innovations (in line with previous research, e.g. Borghesi et al. (2015)). Firm size and public R&D support is positively significant as be-

Table 3: Hypothesis 2 – Estimation results (pooled probit)

	Env. product innovations		Env. process innovations	
	I	II	I	II
GPP ¹	0.118 (0.764)		0.295 (0.445)	
GPP (cum.)		0.133 (0.554)		0.182 (0.361)
Innovation intensity (t-1)	2.053 (0.627)	2.076 (0.627)	0.864 (0.568)	0.870 (0.566)
Firm size (t-1)	0.0842*** (0.000)	0.0832*** (0.000)	0.116*** (0.000)	0.115*** (0.000)
High-skilled employees (%) (t-1)	0.0000765 (0.963)	0.0000575 (0.973)	-0.00313** (0.047)	-0.00314** (0.045)
Export intensity (t-1)	-0.0457 (0.767)	-0.0449 (0.770)	-0.0420 (0.817)	-0.0411 (0.820)
Public R&D support ¹	0.761*** (0.000)	0.762*** (0.000)	0.838*** (0.000)	0.838*** (0.000)
Costs p.c. (t-1)	0.0131 (0.878)	0.0130 (0.879)	-0.0503 (0.356)	-0.0500 (0.359)
Business group ¹	-0.000409 (0.991)	0.000211 (0.996)	0.0602 (0.170)	0.0615 (0.161)
Foreign business group ¹	0.0470 (0.642)	0.0477 (0.641)	0.0328 (0.686)	0.0325 (0.690)
East Germany ¹	-0.0615 (0.562)	-0.0619 (0.561)	-0.0747 (0.309)	-0.0754 (0.302)
ETS ¹	-0.110*** (0.000)	-0.109*** (0.000)	0.0295*** (0.000)	0.0299*** (0.000)
Constant	-1.437*** (0.000)	-1.432*** (0.000)	0.270*** (0.000)	0.271*** (0.000)
Observations	2525	2525	2555	2555
Pseudo R-squared	0.080	0.080	0.102	0.102

Note: p-values in parentheses * p<0.1, ** p<0.05, *** p<0.01. Std. errors are clustered at industry-level. Industry dummies not shown. ¹denotes dummy variables.

fore. The human capital variable is negatively related to environmental process innovations, and the export intensity, costs per capita, belonging to a (foreign) business group, and the location in East Germany are not significantly related to the probability of environmental product or process innovations.

Hypothesis 3

To evaluate hypothesis 3, whether the demand-pull effect might be larger in different sectors, equation 1 is estimated with a pooled probit model for several sectors separately.²⁴ As GPP contracts are used in varying intensi-

²⁴A pooled probit model is used here as an estimation of a random effects probit model only confirms the significance of the panel structure for one of the sectors (manufacturing sector). For the sake of comparability, a pooled probit estimation is shown for all sectors. The random effects probit results for sector 3 confirm the results of the pooled estimation. Detailed results are available upon request.

ties in different sectors, the results are only shown for sectors where GPP contracts were identified at all. These sectors are: manufacturing; electricity, gas, steam and air conditioning supply; water supply, sewerage, waste management and remediation activities; professional, scientific and technical activities; administrative and support service activities.

The results shown in Table 4 indicate a positive relationship between winning a GPP contract and the probability of product innovations for the water supply and waste industry. The electricity and gas sector shows an increase in the probability of process innovations when a GPP contract is won. Using the cumulative measure of GPP, the effect in the water supply and waste industry is confirmed again. Additionally, the manufacturing industry shows a positive effect on the probability of product innovations from a cumulative measure of GPP. The cumulative measure of GPP shows a negative relation with the probability of process innovations in the water and sewerage sector.

The results show that the correlation between winning a GPP contract and the probability of product or process innovations differs across sectors. While the water and sewerage sector sees a correlation between GPP and product innovations, there seems to be a slight crowding-out effect for investments into process innovations. The electricity sector on the other hand sees a positive correlation between winning a GPP contract and process innovations. This might indicate that the product in this sector is a perfect substitute in terms of the usage - but that firms are able to differentiate themselves in terms of the production process used to generate electricity (e.g. conventional versus renewable energy). The positive association of the cumulative GPP measure and the probability of product innovations in the manufacturing sector might indicate a slow but sustained effect of GPP.

5. Robustness checks

5.1. Unobserved heterogeneity

The random effects probit estimation relies on the assumption that the regressors are uncorrelated with the unobserved individual heterogeneity. This might be questionable in the case of this paper because there might be unobserved individual factors like managerial attitudes which are correlated with e.g. R&D spending. An alternative estimation technique, the Mundlak approach (Mundlak, 1978), allows for a correlation of explanatory variables and the individual heterogeneity by including individuals' mean value of time-varying variables. Results of this Mundlak estimation of Hypothesis 1 are shown in Appendix 7.2 Table 6 and partly confirm the results found earlier – depending on whether the mean value over time of the GPP variable is included (Table 6 columns .I) or not (Table 6 columns .II). As the results show a significant coefficient of the mean value of GPP, this indicates that the mean should be included – which renders the coefficient of the GPP

dummy variable insignificant in the case of product innovations. Slightly different is the case of the cumulative GPP measure where the time average is not statistically significant and thus maybe a sign of no correlation between the cumulative GPP measure and unobserved heterogeneity.

Table 4: Hypothesis 3 – Sector specific results

	Sector 3						Sector 4					
	Product innovations		Process innovations		Product innovations		Process innovations		Product innovations		Process innovations	
	I	II	I	II	I	II	I	II	I	II	I	II
GPP ¹	0		0.225		-0.152		0.935*					
	(.)		(0.663)		(0.801)		(0.087)					
GPP (cum.)		0.874**		0.312		0.0871		0.524				
		(0.039)		(0.243)		(0.819)		(0.140)				
Innovation intensity (t-1)	54.86***	54.61***	3.204	3.239	107.4	107.5	218.1	179.9				
	(0.004)	(0.004)	(0.451)	(0.446)	(0.661)	(0.658)	(0.175)	(0.282)				
Firm size (t-1)	0.123***	0.122***	0.176***	0.174***	0.227**	0.215*	0.00500	-0.00770				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.038)	(0.059)	(0.954)	(0.932)				
High-skilled employees (%) (t-1)	0.00604***	0.00608***	0.000612	0.000579	-0.0266*	-0.0285*	-0.0169	-0.0152				
	(0.005)	(0.004)	(0.703)	(0.717)	(0.080)	(0.063)	(0.256)	(0.294)				
Export intensity (t-1)	0.690***	0.687***	0.00593	0.00641			-9.847	-7.763				
	(0.000)	(0.000)	(0.955)	(0.951)			(0.139)	(0.214)				
Public R&D support ¹	1.688***	1.690***	1.277***	1.279***	2.273***	2.275***	2.544***	2.524***				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
Cost p.c. (t-1)	-0.488***	-0.486***	0.0123	0.0123	0.159	0.153	0.194	0.168				
	(0.009)	(0.008)	(0.885)	(0.884)	(0.306)	(0.336)	(0.142)	(0.189)				
Business group ¹	-0.0787	-0.0736	0.0987	0.102	-0.304	-0.288	-0.209	-0.189				
	(0.366)	(0.396)	(0.193)	(0.176)	(0.396)	(0.420)	(0.538)	(0.573)				
Foreign business group ¹	0.136	0.135	-0.0566	-0.0577	0.0592	0.0587	-0.00143	-0.00645				
	(0.186)	(0.190)	(0.511)	(0.503)	(0.905)	(0.905)	(0.998)	(0.990)				
East Germany ¹	-0.0209	-0.0254	-0.106**	-0.108**	-0.342	-0.331	-0.175	-0.237				
	(0.703)	(0.642)	(0.045)	(0.041)	(0.396)	(0.405)	(0.599)	(0.487)				
Constant	-2.147***	-2.142***	-2.209***	-2.200***	-3.104***	-3.031***	-2.324***	-2.265***				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
Observations	3973	3982	3979	3979	248	248	260	260				
Pseudo R-squared	0.386	0.388	0.219	0.219	0.406	0.406	0.340	0.337				

Note: p-values in parentheses * p<0.1, ** p<0.05, *** p<0.01. Robust std. errors used. Year dummies not shown. ¹denotes dummy variable. These sector numbering follows the NACE Rev. 2 categorisation and denotes: (3) manufacturing; (4) electricity, gas, steam and air conditioning supply; (5) water supply, sewerage, waste management and remediation activities; (13) professional, scientific and technical activities; (14) administrative and support service activities.

Table 4 (cont.): Hypothesis 3 – Sector specific results

	Sector 5				Sector 13				Sector 14			
	Product innovations		Process innovations		Process innovations		Process innovations		Process innovations		Process innovations	
	I	II	I	II	I	II	I	II	I	II	I	II
GPP ¹	1.045** (0.038)		0 (.)		1.047 (0.147)					0.357 (0.525)		
GPP (cum.)		0.757*** (0.001)		-0.418* (0.078)								0.131 (0.711)
Innovation intensity (t-1)	128.3*** (0.007)	127.5*** (0.008)	120.7*** (0.001)	120.4*** (0.001)	4.279* (0.071)					137.5 (0.300)		136.0 (0.307)
Firm size (t-1)	-0.0631 (0.318)	-0.0977 (0.115)	0.0505 (0.373)	0.0541 (0.343)	0.149*** (0.000)					-0.0529 (0.394)		-0.0519 (0.407)
High-skilled employees (%) (t-1)	-0.00932 (0.163)	-0.00966 (0.151)	-0.00268 (0.642)	-0.00259 (0.655)	0.000267 (0.870)					0.00827* (0.053)		0.00821* (0.056)
Export intensity (t-1)	1.358** (0.011)	1.198** (0.022)	1.075** (0.041)	1.145** (0.030)	0.290 (0.257)					0.422 (0.558)		0.429 (0.554)
Public R&D support ¹	1.205*** (0.000)	1.228*** (0.000)	2.126*** (0.000)	2.142*** (0.000)	1.148*** (0.000)					2.991*** (0.000)		2.995*** (0.000)
Costs p.c. (t-1)	0.269 (0.319)	0.262 (0.326)	-0.220 (0.577)	-0.219 (0.578)	-0.0793 (0.521)					-0.788 (0.291)		-0.812 (0.278)
Business group ¹	0.153 (0.472)	0.110 (0.613)	0.215 (0.252)	0.216 (0.250)	-0.0269 (0.872)					0.927*** (0.000)		0.937*** (0.000)
Foreign business group ¹	-0.419 (0.414)	-0.307 (0.544)	-0.0975 (0.769)	-0.117 (0.727)	-0.154 (0.504)					-0.650 (0.145)		-0.681 (0.127)
East Germany ¹	0.0577 (0.758)	0.0538 (0.776)	0.0130 (0.935)	0.00912 (0.954)	0.146 (0.139)					-0.423** (0.049)		-0.429** (0.045)
Constant	-2.001*** (0.000)	-1.872*** (0.000)	-3.222*** (0.000)	-3.246*** (0.000)	-2.139*** (0.000)					-2.151*** (0.000)		-2.620*** (0.000)
Observations	702	702	695	702	1149					426		426
Pseudo R-squared	0.255	0.272	0.328	0.328	0.199					0.340		0.339

Note: p-values in parentheses * p<0.1, ** p<0.05, *** p<0.01. Robust std. errors used. Year dummies not shown. ¹denotes dummy variable. These sector numbering follows the NACE Rev. 2 categorisation and denotes: (3) manufacturing; (4) electricity, gas, steam and air conditioning supply; (5) water supply, sewerage, waste management and remediation activities; (13) professional, scientific and technical activities; (14) administrative and support service activities. Note that for sectors 13 and 14 only process innovations are shown as there were no observation pairs which received GPP and produced product innovations.

5.2. Intensity of GPP

As a robustness check, the cumulative GPP variable is also calculated as cumulative sum of all GPP contracts won – instead of simply accumulating the plain GPP variable.²⁵ Investigating Hypothesis 1 based on the cumulative sum of all GPP contracts won confirms the results found with the simple cumulative measure. This might indicate that there is no additional demand-pull effect on a single firm through winning multiple green contracts in one year but that the pull effect is already triggered through winning one contract.

6. Conclusion

The paper provides the first empirical analysis of green public procurement and the innovation activities of firms. The research question whether GPP can act as demand-side innovation policy is investigated using a novel firm-level dataset which combines procurement award-level data with firm-level economic and innovation data. By relying on actual procurement award data, the paper is able to identify a direct effect of winning a GPP contract instead of relying on proxy measures of procurement.

The results indicate indeed that the strategic use of green public procurement might be able to trigger new product innovations. These results however only hold for certain industries: a positive correlation between winning a GPP contract and the probability of general product innovations is found for the water supply and waste sector, while the electricity and gas sector shows a positive correlation for general process innovations. A slow but sustained demand-pull effect of GPP is identified in the manufacturing sector where a positive significant relation between a cumulative measure of GPP and general product innovations is found. Regarding the relationship between GPP and environmental innovations, no significant correlation is found. The absence of a statistically significant correlation does however not necessarily imply that there is no demand-pull effect as the statistical insignificance might be related to the larger share of non-innovators in the sample as well as to the limited number of survey waves asking about environmental innovations.

While GPP is a major priority on the policy agenda of multilateral organisations, the current implementation rate can be considered as a homeopathic dose. The United Nations anchored sustainable production and consumption in their framework of the Sustainable Development Goals as target under SDG 12 (target 12.7, see UNEP (2017)), the European Commission prioritises the uptake of green public procurement as one of its six

²⁵Example: If in one year, a firm wins two contracts, the cumulative sum increases by two.

priority areas in their 2017 procurement strategy (European Commission, 2017b). Analysing the data from the European Tenders Electronic shows however, that only 2.19% of the contracts won by German firms in 2006-2016 were procurement contracts which included environmental aspects in the selection criteria. This discrepancy between political ambition and actual implementation might be overcome by providing more training opportunities for procurement officers, developing handbooks for the implementation of GPP, enhanced joint procurement, and financial support from the general government to local authorities to cover their potential increased procurement costs due to the implementation of GPP (Chiappinelli and Zipperer, 2017).

The analysis in this paper should not be understood as exhaustive but only as the starting point for future research in this field. While this paper is not able to provide any causal evidence on the link between GPP and innovation, conducting such an analysis is a promising research path. Collecting more information on environmental innovations to conduct a robust analysis on environmental innovations is certainly an important future step. Moreover, as described above, this paper only looks at the direct pull effect of GPP. An analysis of the indirect pull effect of GPP through an effect on R&D efforts would add to the understanding of the channels of GPP. Furthermore, it is important to gain a better understanding of the type of innovations triggered by GPP, whether these are rather incremental innovations or whether GPP is able to trigger breakthrough technology development. Related to this question, investigating whether GPP has an actual effect on the creation of lead markets (e.g. for environmental products) seem a promising research area. Unrelated to the effect of GPP on innovation, it is also important to conduct more research on the effectiveness of GPP in terms of CO_2 reductions and other environmental measures.

7. Appendix

7.1. Sectors covered

Table 5: Sectors covered

Number	Sector	Freq.	Percent
1	Agriculture, forestry and fishing	7	0.08
2	Mining and quarrying	173	1.98
3	Manufacturing	4,001	45.89
4	Electricity, gas, steam and air conditioning supply	260	2.98
5	Water supply; sewerage, waste management and remediation activities	705	8.09
6	Construction	179	2.05
7	Wholesale and retail trade; repair of motor vehicles and motorcycles	451	5.17
8	Transportation and storage	583	6.69
9	Accommodation and food service activities	10	0.11
10	Information and communication	466	5.35
11	Financial and insurance activities	199	2.28
12	Real estate activities	74	0.85
13	Professional, scientific and technical activities	1,163	13.34
14	Administrative and support service activities	430	4.93
15	Public administration and defence; compulsory social security	0	0.00
16	Education	3	0.03
17	Human health and social work activities	3	0.03
18	Arts, entertainment and recreation	4	0.05
19	Other service activities	7	0.08
Total		8,718	100.00

Note: This sample covers the number of observations in the sectors in the MIP from 2006-2016. The nomenclature follows the NACE Rev. 2 and is retrieved from https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=NACE.REV2. None of the firms in section 15 (Public administration and defence; compulsory social security) have sufficient information to be included in our analysis. Section 20 (activities of households as employers; undifferentiated goods and services producing activities of households for own use) and section 21 (activities of extraterritorial organisations and bodies) are not covered by the MIP and therefore not included.

7.2. Mundlak approach

Table 6: Robustness check Hypothesis 1 – Mundlak approach

	Product innovations				Process innovations			
	I.I	I.II	II.I	II.II	I.I	I.II	II.I	II.II
GPP ¹	0.995** (0.018)	0.282 (0.587)			0.151 (0.705)	-0.202 (0.687)		
GPP (cum.)			0.623*** (0.004)	0.296 (0.441)			0.102 (0.606)	-0.183 (0.506)
Innovation intensity (t-1)	-0.649 (0.953)	-0.739 (0.946)	-0.747 (0.946)	-0.761 (0.945)	-0.264 (0.958)	-0.302 (0.952)	-0.277 (0.956)	-0.287 (0.954)
Firm size (t-1)	-0.0423 (0.721)	-0.0380 (0.748)	-0.0469 (0.693)	-0.0414 (0.727)	0.0342 (0.734)	0.0368 (0.714)	0.0339 (0.736)	0.0383 (0.704)
High-skilled employees (%) (t-1)	0.000317 (0.925)	0.000398 (0.906)	0.000367 (0.913)	0.000403 (0.905)	-0.00344 (0.258)	-0.00340 (0.263)	-0.00344 (0.257)	-0.00339 (0.264)
Export intensity (t-1)	0.717** (0.032)	0.693** (0.035)	0.682** (0.038)	0.683** (0.037)	-0.326 (0.237)	-0.330 (0.230)	-0.328 (0.234)	-0.328 (0.234)
Public R&D support ¹	1.950*** (0.000)	1.948*** (0.000)	1.950*** (0.000)	1.948*** (0.000)	1.480*** (0.000)	1.479*** (0.000)	1.480*** (0.000)	1.479*** (0.000)
Costs p.c. (t-1)	0.0713 (0.278)	0.0738 (0.272)	0.0738 (0.275)	0.0743 (0.272)	0.108** (0.024)	0.108** (0.024)	0.108** (0.024)	0.108** (0.024)
Business group ¹	0.0487 (0.646)	0.0478 (0.652)	0.0520 (0.624)	0.0497 (0.640)	0.224*** (0.009)	0.224*** (0.009)	0.225*** (0.009)	0.222*** (0.009)
Foreign business group ¹	0.105 (0.435)	0.103 (0.443)	0.105 (0.437)	0.104 (0.442)	-0.155 (0.144)	-0.156 (0.142)	-0.155 (0.144)	-0.156 (0.142)
East Germany ¹	-0.110 (0.162)	-0.113 (0.151)	-0.115 (0.145)	-0.115 (0.146)	-0.145** (0.028)	-0.147** (0.026)	-0.146** (0.027)	-0.146** (0.026)
Innovation intensity ²	33.91** (0.017)	34.23** (0.016)	34.12** (0.016)	34.25** (0.016)	6.044 (0.303)	6.154 (0.295)	6.069 (0.301)	6.146 (0.295)
Firm size ²	0.170 (0.171)	0.161 (0.195)	0.171 (0.170)	0.164 (0.188)	0.199* (0.055)	0.194* (0.062)	0.199* (0.056)	0.193* (0.064)
High-skilled employees ²	0.00716* (0.067)	0.00692* (0.077)	0.00706* (0.071)	0.00694* (0.076)	0.00372 (0.279)	0.00362 (0.293)	0.00372 (0.280)	0.00360 (0.296)
Export intensity ²	0.676* (0.091)	0.701* (0.077)	0.708* (0.074)	0.710* (0.073)	0.468 (0.139)	0.473 (0.134)	0.470 (0.137)	0.472 (0.135)
Public R&D support ²	1.386*** (0.000)	1.391*** (0.000)	1.394*** (0.000)	1.394*** (0.000)	0.623*** (0.000)	0.624*** (0.000)	0.623*** (0.000)	0.624*** (0.000)
Cost p.c. ²	-0.191 (0.333)	-0.198 (0.325)	-0.198 (0.328)	-0.200 (0.325)	-0.130* (0.085)	-0.132* (0.082)	-0.130* (0.085)	-0.132* (0.081)
GPP ²		1.825** (0.024)		1.325 (0.260)		0.852 (0.259)		1.141 (0.173)
Constant	-3.446*** (0.000)	-3.423*** (0.000)	-3.429*** (0.000)	-3.421*** (0.000)	-4.681*** (0.000)	-4.667*** (0.000)	-4.677*** (0.000)	-4.669*** (0.000)
Observations	8651	8651	8651	8651	8637	8637	8637	8637
Pseudo R-squared	0.055	0.055	0.055	0.055	0.041	0.041	0.041	0.041
AIC	5705.6	5704.0	5702.6	5703.6	6432.7	6433.6	6432.6	6433.4
BIC	5960.0	5965.4	5957.0	5965.0	6680.0	6687.9	6679.8	6687.7
rho	0.677	0.676	0.677	0.677	0.570	0.569	0.570	0.569
Chi-squared (comparison test)	326.7	326.0	327.0	326.3	274.9	274.3	274.9	274.1

Note: p-values in parentheses * p<0.1, ** p<0.05, *** p<0.01. Robust std. errors used. Year dummies not shown. ¹denotes dummy variable. ²denotes firm averages over time (Mundlak terms).

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