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The effectiveness of public procurement in stimulating innovation outputs: empirical evidence from European firms

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Abstract

Over the last decade a number of public procurement directives at national and European Union level have sought to enhance the effectiveness of public procurement in stimulating firm-level innovation. Yet there is an absence of empirical evidence relating to the impact of public procurement on innovation. In this paper, we address this gap by evaluating the effectiveness of public procurement on a range of innovation output indicators. Using the Community Innovation Survey 2012 dataset, we empirically estimate direct and indirect treatment effects of public procurement in different country groups (Innovation Leaders, Innovation Followers and Moderate Innovators). We find no systemic direct effects on innovation outputs across country groups. However, for indirect effects, our results indicate strong universal effects on non-technological innovations. Our empirical evidence provides some policy implications, in particular relating to "innovation-friendly" public procurement.

1. Introduction

This study uses data from the Community Innovation Survey (CIS) 2012 covering ten European countries to estimate two types of public procurement effects on various innovation outputs: direct effects arising from public procurement that required innovation; and indirect effects associated with public procurement that did not require innovation.

The literature distinguishes two types of procurement: public technology procurement; and regular or normal procurement (Edquist and Zabala-Iturriagagoitia, 2012; Uyarra and Flanagan, 2010; Uyarra, 2016). Public technology procurement occurs when a public-sector organisation purchases products or services that demand innovation by a supplier, such as R&D activities (Aschhoff and Sofka, 2009; Edquist and Hommen, 2000; Guerzoni and Raiteri, 2015; Uyarra and Flanagan, 2010). Scholars have recently introduced other terms to denote public technology procurement, such as "procurement for innovation" or "innovative procurement", to extend this concept beyond R&D (Edler and Georghiou, 2007; Edquist et al., 2015; Edquist and Zabala-Iturriagagoitia, 2012; Uyarra and Flanagan, 2010; Uyarra, 2016). Accordingly, Edquist et al. (2015, pp. 6-7) offer the following definition: 'Public Procurement for Innovation (PPI) occurs when a public organization places an order for the fulfilment of certain functions (that are not met at the moment of the order or call) within a reasonable period of time through a new or improved product.'

In contrast, regular or normal procurement refers to the purchase of ready-made products where contracts do not *require* any additional R&D or even broader innovative activities. Yet firms' innovation activities may be affected by public procurement even if that is not an explicit goal of public bodies. That is, although innovation may not be a direct result of procurement, it can occur indirectly or as a by-product (Guerzoni and Raiteri, 2015; Uyarra and Flanagan, 2010; Uyarra, 2016). Therefore, besides a direct intentional effect on innovation, public procurement can induce firms to innovate as a consequence of participation in a procurement tender, although its goal is not innovation itself.

Until recently, the main policy instruments for promoting innovation were supply-side instruments, such as R&D subsidies, R&D tax credits, the protection of Intellectual Property Rights (IPRs) and support for collaborative innovation activities (Edler et al., 2012; Edquist et al., 2015). However, recently public procurement as a policy instrument to promote innovation has appeared high on policy agendas across the EU (Edler et al., 2012; Edquist and Zabala-Iturriagagoitia, 2012; Uyarra and Flanagan, 2010). The proportion of public procurement in GDP is estimated to be approximately 12.8 per cent in the OECD countries (Loader, 2015; OECD, 2013) and between 15 and 20 per cent across the 28 EU member states (Amann and Essig, 2015; EU COM, 2012; Edquist, 2015; Stake, 2016). The findings of the European Public Sector Innovation Scoreboard 2013 show that, since 2009, 24 per cent of companies in the EU27 have sold innovations to the public sector through public procurement (European Commission, 2013).

The importance of public procurement of innovation is reflected in the Lead Market Initiative (European Commission, 2007), for which public procurement is considered to be a critical policy instrument (Davis and Brady, 2015; Uyarra and Flanagan, 2010).[1] This growing emphasis on public procurement as a means of promoting innovation calls for a quantitative evaluation of its effectiveness, especially since current evidence is based on case studies with little quantitative content (Aschhoff and Sofka, 2009; Guerzoni and Raiteri, 2015). This study addresses the lack of quantitative guidance on the innovation effects of public procurement. In so doing, it addresses a policy area with enormous potential.

[1]A lead market is a market with particular characteristics favourable to the introduction of a certain innovation (Edler et al., 2012).

According to Edquist (2015, p.34), if regular procurement were to be transformed into innovation-friendly procurement then this could be a much more powerful innovation policy instrument than R&D subsidies; yet, concluding on the situation in Sweden, 'almost nothing is done to promote innovations in public procurement'. Given that Sweden is the Innovation leader country according to the European Innovation Scoreboard as well as its history of innovation policy activism, we may assume that the situation in other European countries is similar.

Whilst scarce, previous empirical evidence (Guerzoni and Raiteri, 2015; Aschhoff and Sofka, 2009) indicates that public procurement of innovation is effective in promoting firms' innovation inputs and market success. However, still absent is empirical evidence on the impact of public procurement on innovation outputs. In this regard, a contribution of this study is to estimate procurement effects on different measures of innovation output as well as on the market success of innovation. We employ a range of innovation output indicators, both technological (product and process) and non-technological (organisational and marketing) innovations. We also utilize innovative sales as a measure of the commercial success of innovation. Besides these innovation outputs, our study provides among the first empirical evidence on the effectiveness of public procurement in stimulating radical, as well as incremental, innovations.

This study also contributes by analysing different country groups depending on the level of their innovation performance. Each year, Eurostat publishes the European Innovation Scoreboard, an annual report on innovation activities of European countries. Based on their innovation performance, countries are divided into four categories: Leaders, Followers, Moderate innovators and Modest innovators. Herein we estimate the treatment effects of public procurement separately for Leaders, Followers and Moderate innovators country groups, while Modest innovators country group is excluded from the analysis because of a small number of treated firms, results in poor matching quality estimation.

2. Literature review

2.1. Public procurement as demand-side innovation policy

Although there is no commonly accepted definition of demand-side innovation policies, OECD (2011) adopts the definition proposed by Edler and Georghiou (2007, p. 952):

> … demand-side innovation policies are defined as all public measures to induce innovations and/or speed up diffusion of innovations through increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand.

Examples of demand-side innovation policies include: rebates for consumers of new technologies; technology mandates; innovation-specific regulations standards; and technology-oriented public procurement (OECD, 2011).

Instruments in support of innovation are divided into two categories – technology push and demand (market) pull. The first generation of innovation models were linear, technology-push models focused on supply side innovation policies. The second generation shifted the focus to the demand side of the innovation process (Nemet, 2009). Demand-side public measures were designed after the formalization of the third-generation interactive or coupling innovation models, which brought together the technology-push and the demand-pull arguments and emphasised the role in the innovation process played by demand (Edquist and Hommen, 2000).

Several qualitative and quantitative studies in the 1970s and 80s pointed out that public demand for innovation is an effective policy tool, perhaps even more so than R&D subsidies (Geroski, 1990). Although demand-side policy measures have been used in parallel with traditional supply-side measures in a few strategic sectors, such as construction, health care and transport (Edler and Georghiou, 2007), their wider diffusion was absent until recent years. Renewed interest from policy-makers at both national and EU levels during the last decade is a consequence of the realization that supply-side measures alone are not sufficient to promote innovation and enhance competitiveness and that, instead, supply-side and demand-side policy measures are complementary (Edler and Georghiou, 2007; OECD, 2011; Pickernell et al., 2011; Uyarra et al., 2014).[2] Consistent with this trend, Edler and Georghiou (2007) recognized the importance of public procurement in innovation policy, which is echoed in OECD (2011, p.11): '… public procurement is at the heart of demand-side innovation policy initiatives.' Consequently, the United Kingdom, Germany, the Netherlands,

[2] OECD (2014) identifies three potential reasons as to why demand-side measures in innovation policy have attracted renewed interest from policy makers. First, demand-side innovation policy might stimulate innovation to meet societal needs. Second, demand-side measures might be more cost effective than the traditional supply-side measures. Finally, the renewed interest might be motivated by the rather disappointing effects of the supply-side measures (or they were insufficient alone to foster innovation; Pickernell et al., 2011).

Finland and Spain have put in place legislation and programmes for integrating innovation into public procurement.

2.2. Public procurement and innovation

Because the CIS2012 questionnaire distinguishes between innovation that was required in public procurement tendering and innovation that was not required, but still firms engaged in it, we are able to explore the *direct* and *indirect* effects of public procurement on innovation.

The *direct* effects of public procurement are associated with the following theoretical considerations. The procurement effect on market size and expected demand gives rise to an “incentive effect” on both product and process innovations (Schmookler, 1962; Fontana and Guerzoni, 2008). Consistent with this, Uyarra (2016) argues that public procurement for products with insufficient private demand may induce firms to invest in R&D. In particular, public procurement can help firms to recover the sunk costs of large and sometime risky investments in innovation (OECD, 2011).

Edler and Georghiou (2007) identify asymmetric information as one of the main sources of market failures, and poor interaction between potential suppliers and users of innovative products as the main source of systemic failures, while Georghiou et al. (2014) argue that both of these can be overcome by public procurement. Similarly, Uyarra et al. (2014) argue that public procurement reduces information and interaction barriers to innovation. Regarding the former, lack of information is characteristic at both ends of the value chain. Both private and public customers might not be aware of innovative goods and services that are available in the marketplace or that could be supplied if sufficient demand were to occur. On the other hand, innovating firms might not have timely information about future trends in demand, which would enable them to meet that demand with new products and services. Accordingly, both Myers and Marquis (1969) and Fontana and Guerzoni (2008) argue that the provision of relevant information and knowledge about market needs and users’ requirements reduces the effects of uncertainty on innovation.

Poor interaction between suppliers and customers occurs, for instance, when dispersed demand hampers suppliers in identifying customers’ needs and from timely offering of new products to meet these needs (Edler and Georghiou, 2007). Consequently, any improved interaction between suppliers and users via public procurement mitigates systemic failures

(Uyarra et al., 2014). By purchasing innovative goods and service, governments as lead users can signal the usefulness of new products and services to the market and private users and thus facilitate the diffusion of innovation (OECD, 2011; Uyarra and Flanagan, 2010).

Besides direct effects, public procurement can induce firms to innovation, although innovation is not required in a tendering documentation. We term these *indirect* effects. Evidence on the effects of public procurement of innovation is scarce and mostly based on case studies, such as in OECD (2011). According to Uyarra (2016, p.362):

> Case studies tend to focus on those instances where innovation has allegedly been an explicit focus of the procurement project, however one could argue that most instances of innovation resulting from public procurement have occurred as a by-product of public procurement activities.

According to Cabral et al. (2006), public procurement can enlarge the market for new goods up to a critical level that will provide incentives for firms to invest in innovation. Moreover, domestic procurement may enhance the productivity and, hence, the market power of domestic producers and/or give them a first mover advantage in international markets. If such firms are in industries that give rise to learning effects and productivity 'spillovers' then this may induce product and process innovation (i.e., such innovation arises indirectly) (Cabral et al., 2006; Uyarra and Flanagan, 2010).

The concept of innovation-friendly public procurement has recently gained relevance among policy makers at national and EU levels as well as among scholars. Following Edquist et al. (2015, p.7), 'innovation-friendly public procurement is regular procurement which is carried out in such a way that new and innovative solutions are not excluded or treated unfairly'. This definition implies that innovation-friendly public procurement will not necessarily result in innovation, but may facilitate it, for instance, by including innovation-related criteria in the tender specifications and in the assessment of tender documents (OECD, 2011; Edquist et al., 2015; Uyarra, 2016).

2.3. Empirical evidence

To date, only two studies – Aschhoff and Sofka (2009) and Guerzoni and Raiteri (2015) – report empirical findings on the effectiveness of public procurement in promoting innovation. Both studies utilize matching estimators. Aschhoff and Sofka (2009) find that public procurement increases German firms' market success, especially for smaller firms located in regions under economic stress. In turn, this may suggest that public procurement is particularly effective for firms with limited internal resources (Pickernell et al., 2011). Guerzoni and Raiteri (2015) investigate how interaction between public procurement of innovation, R&D tax credits and R&D subsidies affect innovation expenditure. The data utilized in their study is the Innobarometer data on "Strategic Trends in Innovation 2006-2008", which was conducted in 2007 in the 27 EU member states, plus Norway and Switzerland. Their results suggest that public procurement of innovation has a positive impact on innovation inputs when this policy tool is considered separately, as well as when analysed in combination with R&D subsidies and R&D tax credits.

3. Methodology

3.1. Data

We utilize the Community Innovation Survey 2012 covering ten accessable European countries' data (anonymised dataset obtained from Eurostat). Only firms with more than 10 employees are surveyed, although firms with less than 10 employees can also be included if treated separately. Although the firm size variable in the data contains the category "less than 50 employees", we defined this category as small firms, because it is not possible to distinguish between micro firms with less than 10 employees and small firms having between 10 and 50 employees. The sample of firms for each country is obtained using stratified sampling according to industry classification (NACE 2 digit industries, apart from NACE 74.2 and 74.3) and size classes according to the number of employees. The three size classes are considered: less than 50 employees (small firms), 50-249 employees (medium-sized firms) and more than 250 employees (large firms).[3] The regional component is also considered to ensure that the geographic distribution of sampled firms reflects that of the population.

Given a relatively small number of firms from individual countries, they were grouped into three categories based on the European Innovation Scoreboard (European Commission 2011)[4]:

[3] Following the new European Commission (2008) guidelines, micro-sized firms are defined as those with fewer than 10 employees, small firms with more than 10 and fewer than 50 employees and medium-sized firms with more than 50 and fewer than 250 employees.

[4] The European Innovation Scoreboard publishes the average innovation performance of EU member states based on a composite indicator, consisting of 24 individual indicators. Innovation performance of each Member State is then compared to the average innovation performance of 27 EU Member States. For the purpose of this

- *'Innovation leaders'*, countries whose innovation performance is well above the EU27 average. Our effective sample consists of 2,950 firms operating in Germany, the only country from this group represented in the dataset.
- *'Innovation followers'*, countries with performance close to the EU27 average (3,581 firms from Belgium, Slovenia and Estonia); and
- *'Moderate innovators'*, countries whose performance is below that of the EU27 average (5,830 firms from Portugal, Slovakia, Spain, Croatia, Norway, and Hungary).

We exclude from the analysis "*Modest innovators"* country group (countries whose performance is well below that of the EU27 average), because the only country in the dataset from this group is Lithuania and very few firms from the country have participated in public procurement of innovation. In addition, we excluded firms from Cyprus because of the lack of information on firm size, and from Romania and Czech Republic because there are no surveyed firms from these countries that participated in public procurement.

One of the features of the CIS data is that is has been anonymized to ensure that individual respondents cannot be identified. This prevents vertically linking the same enterprise through time to analyse dynamic effects of changes in innovation status and trade participation. Without time-series data on firm operations one can only rely on the cross-sectional dimension of the data and hence can only provide evidence on correlations between variables rather than analyse causality. Moreover, in addition to removing firm identifiers the anonymization process also ensures that industries with a small number of firms surveyed were not included in the sample. The requirement that for each country-industry-size class combination at least three firms exist, which ensures that for a large number of industries data is omitted.

Our analysis includes only firms that are innovators. Following Aschhoff and Sofka (2009), in order to mitigate a potential selection bias arising from a non-random selection of firms in the sample, we excluded non-innovating firms (defined in a broad sense, as firms that introduce neither technological nor non-technological innovations). The definition of innovation adopted in the survey is as follows. 'Innovation occurs when a company introduces a new or significantly improved good, service, process, marketing strategy or

study, we use the Innovation Scoreboard from 2011, as it refers to innovation performance in the years 2009/2010.

organizational method. The innovation can be developed by the company itself or has been originally developed by other companies or organizations.' This broad definition of innovation is in accordance with the *Oslo Manual* (OECD, 2005), thus encompassing both technological (product and process) innovations and non-technological (marketing and organisational) innovations.

For each country group, Table A1 in the Appendix shows the share of firms that included innovation in a public procurement contract because it was required as well as those that included innovation although it was not required. Out of the total number of innovative firms, concerning participation in public procurement which required innovation, 3.6 per cent of firms in *Innovation leaders* country group innovated because it was required in tender documentation, along with 2.9 per cent of firms in *Innovation followers* country group, and 8.1 per cent in *Moderate innovators* country group. Regarding innovative firms that participated in public procurement which did not require innovation, the shares are 2.6 per cent of firms from *Innovation leader*; 5.7 per cent of firms from *Innovation followers*; and 7 per cent of firms from *Moderate innovators* country group.

3.2. Empirical strategy

In evaluating public procurement, OECD (2014) notes that firms might self-select themselves into a public procurement tender, i.e. those firms that are more likely to innovate have higher propensity to apply for a tender. In addition, public agencies might adopt a "picking-the-winner" strategy, whereby firms might be selected on the basis of their observable innovation capabilities. Therefore, similar to the traditional supply-side measures, quantitative evaluation has to take into account the potential endogeneity of innovation procurement. To address the problem that procurement might be attracted by firms' innovation record, rather than procurement leading to innovation, we implement a matching methodology, which is the most commonly applied evaluation method in innovation studies (Cerulli, 2010). This approach entails two identifying assumptions. The first is the conditional independence assumption (CIA) or selection on observables, which posits that the outcome in the case of no treatment (Y_0) is independent of treatment assignment, conditional on covariates X (Imbens, 2004; Imbens and Wooldridge, 2009). That is,

$$Y_0 \amalg D | X \tag{1}$$

where X represents a vector of covariates and D is the treatment assignment.

The second assumption is associated with the overlap or common support condition, where the estimated propensity scores take values between zero and one (see Equation 2) (Heckman and Vytilacil, 2007). The overlap condition implies that both treated and non-treated firms have a positive probability (P) of receiving a treatment (D=1) or not receiving a treatment (D=0).

$$0 < P(D = 1|X) < 1 \qquad (2)$$

The treatment of interest is the Average Treatment Effect on the Treated (ATT), which indicates the difference in outcomes of the treated firms with and without treatment and can be written as:

$$ATT = E[Y_1|D = 1] - E[Y_0|D = 1] \qquad (3)$$

The first term on the right-hand side of Eq. (3), $E[Y_1|D = 1]$, is the expected outcome for firms conditional on their participation in public procurement, while the second term $E[Y_0|D = 1]$ is the expected outcome had treated firms not participated. This second term refers to a counterfactual outcome that is not observed but estimated.

Concerning the choice of covariates X, the literature suggests that all observed variables that simultaneously affect treatment assignment and the outcome should be included. After the selection of matching variables, the next step in the matching protocol is the estimation of the propensity score model using either probit or logit models as they usually yield similar results (Caliendo and Kopeinig, 2008).

Next, we select the matching algorithm. We utilize the Inverse Probability Weighing Regression Adjustment (IPWRA) estimator. The main advantage of the IPWRA estimator is its double robust property. If either the propensity score model (the outcome model) or the treatment model is correctly specified, then this estimator will yield treatment effects with a lower bias than will other estimators that are not characterized by the double robustness property. Busso et al. (2014) conducted Monte Carlo simulations on finite samples to compare matching and reweighting estimators – which include the IPWRA – in the estimation of ATTs. Their findings support our use of the IPWRA: first, we use normalised reweighting, which exhibits overt bias of the same magnitude as pair matching but much smaller variance; second, their findings suggest that normalised reweighting outperforms matching estimators when overlap is good, which is the case in our study (see Figures A.1, A.2 and A.3 in the Appendix).

The estimator consists of three steps: first, the propensity score model – the treatment model – is estimated. Second, the inverse of the estimated propensity scores (probabilities of receiving a certain level of treatment) are used as weights in the regression analysis. Third, the ATT is computed as the difference in the weighted averages of the predicted outcomes (for technical details see Wooldridge, 2010). This three-step approach provides consistent estimates given the underlying assumption of the independence of the treatment from the predicted outcomes once covariates are modelled in steps 1 and 2. We report valid standard errors (of the Huber/White/sandwich variety) which take into account that the estimates are computed in a three-step approach (Emsley et al. 2008).

3.3. Model specification

The two treatment variables are binary indicators equal to 1 if firms participated in public procurement in which innovation was required, and equal to 1 if firms participated in public procurement and innovated although innovation was not a requirement stipulated in a tender documentation (see Table A1. for descriptive statistics). The outcome variables are binary indicators for the introduction of technological (product and process) innovations (product innovation is divided into goods and services) and non-technological (organisational and marketing) innovations. Following Aschoff and Sofka (2009), innovative sales as a measure of the commercial success of innovation is also used as an outcome variable. Finally, we include two innovation output indicators measuring the level of innovativeness. First, the variable *Radical innovation* is equal to 1 if a firm introduced innovations that are either new to the world or new to Europe (zero otherwise). Second, the variable *Incremental innovation* is the percentage of turnover from product innovations that are new to the firm.

To account for firm and market characteristics, we include the following matching covariates in the models. We specify a binary indicator for firms that belong to an enterprise *group* (Czarnitzki and Hottenrott, 2011; Czarnitzki and Lopes-Bento, 2014). To account for firms' financial performance, we included a continuous variable *Turnover* measuring firms' turnover in 2012 (in natural logarithm). Also, we control for firms' cooperative behaviour by including the variable *Cooperation*, which is a binary indicator equal to 1 if a firm cooperated for innovation in the surveyed period (and zero otherwise).[5] The models include dummy variables for firm sizes: *Small firms* equal to 1 for firms with less than 50 employees (the base category); *Medium-sized firms* equal to 1 for firms with more than 50 and less than 250 employees; and *Large firms* equal to 1 for firms with more than 250 employees.

As a measure of firms' absorptive capacity (Cohen and Levinthal, 1990), we model two variables: *Internal R&D* which is equal to 1 if a firm engaged in internal R&D activities (and zero otherwise); and *External R&D*, equal to 1 if a firm invested in external R&D activities (and zero otherwise). In addition to firms' R&D activities, we include a number of variables measuring other innovation activities: *Acquisition of knowledge*; *Acquisition of machinery*; *Training for innovation*; and *Market introduction of innovation*. Regarding training for innovation, education and training enhance competencies and provide a foundation for employees and firms to engage in innovation. When changes are introduced, employees and firms need to solve new problems by developing new skills and competencies (Caloghirou et al., 2004).

The importance of external knowledge sources is particularly emphasized through the concept of open innovation (Chesbrough, 2003). By accessing external knowledge sources to foster the introduction of new products and services, firms can experience cost and time savings (Chesbrough, 2003), shorter time to market (Huizingh, 2011) and can create synergies in available internal and external resources and in developing new approaches to market (Dahlander and Gann, 2010). We control for internal knowledge sources (*Internal knowledge sources*) and a number of external sources: from customers, suppliers, competitors and consultants (*Market knowledge sources*); from universities, research institutes, conferences, trade fairs and exhibitions (*Institutional knowledge sources*); and from scientific journals, trade/technical publications, professional and industry associations (*Other knowledge sources*). We also control for the lack of demand as an obstacle to meeting a firm's goals, because the function of public procurement is to satisfy demand (variable *Obstacle-lack of demand*).

Finally, to control for industry effects, we created seven industry dummies by grouping sectors based on their technology intensity using NACE Rev.2 classification: high technology sectors; medium high technology sectors; medium low technology sectors; low technology sectors; knowledge-intensive services (KIS); less knowledge-intensive services

[5] We do not control for firms' exporting firms, because almost all firms in the sample are exporters (99.2 per cent).

(LKIS) (the base category) and other sectors (for the list of industries in each category see Table A1 in the Appendix).

4. Results and discussion

Before proceeding with the interpretation of our results, we check for the overlap condition. The plots depicted in Figures A.1 and A.2 (in the Appendix) show that the overlap or the common support condition is satisfied in all reported models, given that the probabilities of receiving treatment (treatment=1) or not receiving treatment (treatment=0) are between zero and one (and not too close to the boundary values) (Cattaneo et al., 2013).

Table 1 reports results from one outcome variable, as an example; namely, from the logit model of product innovation in goods for estimating direct effects in *Innovation leaders* country group.[6] Table 1 also reports the treatment (selection) model estimated by the logit model, which is the same for all outcome variables. The treatment model shows the effects of covariates on the probabilities of receiving a treatment (i.e. a procurement contract that required innovation), while the outcome model estimates the impact of covariates on potential outcomes for treated (=1) and untreated (=0) firms. The coefficients in the models are not of interest in themselves, as the purpose of specifying the model is to facilitate the estimation of treatment effects (Cattaneo et al. 2013).

Table 1. Results from the logit model in *Innovation leaders* country group; treatment variable is public procurement in which innovation is required; outcome variable is product innovation in goods.

Independent variables	**Outcome model**		**Treatment model**
	Potential-outcome model for treatment =0	Potential -outcome model for treatment =1	
Turnover in 2012 (in natural logarithm)	-0.012	-0.292	0.038
	(0.069)	(0.336)	(0.074)
Group	0.291	-0.759	-0.344
	(0.194)	(0.937)	(0.247)
Cooperation	0.352*	0.407	0.401
	(0.182)	(1.248)	(0.245)
Internal R&D	0.894***	-0.147	0.809***
	(0.193)	(1.587)	(0.312)
External R&D	-0.175	0.354	0.001

[6] Results for the other models (with the other outcome variables) are not reported but are available on request.

	(0.198)	(1.521)	(0.237)
Acquisition of knowledge	-0.103	-1.218	0.233
	(0.178)	(1.115)	(0.226)
Acquisition of machinery	0.146	-1.778*	0.045
	(0.191)	(0.936)	(0.252)
Training	-0.231	1.054	0.501*
	(0.185)	(1.246)	(0.267)
Market introduction	1.261***	3.184***	0.220
	(0.170)	(1.044)	(0.241)
Medium firms	-0.358	2.933*	-0.823**
	(0.229)	(1.574)	(0.323)
Large firms	-0.430	1.815	-0.329
	(0.351)	(1.948)	(0.360)
Internal knowledge sources	0.573**	1.460	0.673
	(0.280)	(1.228)	(0.448)
Market knowledge sources	0.837*	-2.509	0.232
	(0.476)	(1.803)	(0.605)
Institutional knowledge sources	-0.133	2.834	1.253**
	(0.484)	(2.874)	(0.556)
Other knowledge sources	-0.373	1.759	-0.468
	(0.399)	(1.765)	(0.524)
Obstacle-lack of demand	-0.018	-0.294	-0.071
	(0.094)	(0.445)	(0.113)
High-tech sectors	2.553***	7.777***	0.704
	(0.358)	(1.809)	(0.567)
Medium high-tech sectors	2.842***	1.015	0.156
	(0.339)	(2.123)	(0.561)
Medium low-tech sectors	1.801***	0.710	-0.247
	(0.313)	(1.627)	(0.592)
Low-tech sectors	2.262***	8.076***	-0.609
	(0.325)	(2.175)	(0.681)
Knowledge intensive services	0.103	-3.164**	0.470
	(0.308)	(1.596)	(0.532)
Other sectors	-0.365	0.265	0.468
	(0.545)	(1.715)	(0.704)
Constant	-2.697**	3.809	-5.697***
	(1.070)	(4.950)	(1.273)
No of observations	2,950		

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table 2 shows the *direct* treatment effects (participation in public procurement that required innovation). With respect to *Innovation Leaders* country group, our results indicate significant effects on product innovation in goods and innovative sales as well as marginally significant effects (at the 10% significance level) on organizational and incremental innovation. Concerning *Innovation followers* country group, we found positive treatment effects on organizational innovation (at the 1% level) and marginally on marketing innovation (at the 10% level). For *Moderate innovators* country group, our results suggest that participating in public procurement that required innovation reduced the probability of introducing process innovation (at the 1% level) and marginally reduced the probability of radical and incremental innovation (at the 10% level).

Table 2. Estimated Average Treatment Effects on the Treated (ATT) using the IPWRA estimator. The treatment variable is public procurement that required innovation.

Outcome variables	Innovation leaders	Innovation followers	Moderate innovators
Product innovation in goods	0.123*** (0.039)	0.013 (0.046)	0.006 (0.021)
Product innovation in services	0.059 (0.046)	0.026 (0.046)	-0.034 (0.023)
Process innovation	0.037 (0.046)	0.059 (0.044)	-0.117*** (0.022)
Organizational innovation	0.071* (0.041)	0.172*** (0.041)	0.009 (0.021)
Marketing innovation	0.070 (0.044)	0.084* (0.045)	0.002 (0.022)
Innovative sales	0.046** (0.023)	-0.002 (0.029)	-0.012 (0.011)
Radical innovation	-0.002 (0.040)	0.018 (0.047)	-0.030* (0.016)
Incremental innovation	0.041* (0.022)	-0.035 (0.023)	-0.021** (0.009)

Notes: Abadie-Imbens (2009) standard errors in parentheses; ***p <0.01, **p<0.05; *p<0.1.

Table 3 presents the estimated *indirect* treatment effects (participation in public procurement that did not require innovation). In *Innovation leaders* country group, our results suggest positive procurement effects on non-technological (organizational and marketing) innovation and on radical innovation. In *Innovation followers* country group, participation in public procurement that did not require innovation had positive effects on process innovation, non-technological (organizational and marketing) innovation and the commercial success of innovation (i.e. innovative sales). Finally, in *Moderate innovators* country group, we report strong effects on product innovation (both in goods and services), and on non-technological (organizational and marketing) innovation. The overall results for all three country groups indicate that public procurement that did not require innovation had uniformly strong effects on non-technological (organizational and marketing) innovation, while for other innovation output indicators, the estimated procurement effects are rather heterogenous.

Table 3. Estimated Average Treatment Effects on the Treated (ATT) using the IPWRA estimator. The treatment variable is public procurement that included innovation that was not required.

Outcome variables	Innovation leaders	Innovation followers	Moderate innovators
Product innovation in goods	0.032 (0.043)	0.006 (0.033)	0.070*** (0.024)
Product innovation in services	-0.032 (0.050)	0.022 (0.032)	0.114*** (0.024)
Process innovation	0.022 (0.052)	0.130*** (0.031)	0.005 (0.021)
Organizational innovation	0.130*** (0.046)	0.156*** (0.032)	0.073*** (0.021)
Marketing innovation	0.113** (0.046)	0.196*** (0.031)	0.092*** (0.022)
Innovative sales	0.010 (0.023)	0.054** (0.025)	0.013 (0.012)
Radical innovation	0.112** (0.045)	0.016 (0.032)	0.016 (0.019)
Incremental innovation	-0.015 (0.020)	0.007 (0.022)	0.008 (0.011)

Notes: Abadie-Imbens (2009) standard errors in parentheses; ***p <0.01, **p<0.05; *p<0.1.

Public procurement effects on innovation outputs suggest three main findings. First, the effects are heterogenous across different country groups and depending on the type of effects (direct or indirect). The only common pattern of procurement effects is reported for *indirect* effects with respect to non-technological innovations. Second, while we find no positive *direct* effects on innovation outputs in *Moderate innovators* country group, there is evidence that innovation occurs as a by-product (*indirect* effects) in the case of product innovation and non-technological innovations. Third, regarding the market success of innovation measured by innovative sales, direct effects are found in *Innovation leaders* country group, while indirect effects are estimated in *Innovation followers* country group. Therefore, public procurement has differentiated effects depending on a country's innovation performance and on whether public procurement requires innovation or not.

5. Conclusions and policy implications

Our study addresses the lack of quantitative evidence on the impact of public procurement on innovation outputs. As noted in our introduction, previous though scarce empirical evidence indicates that public procurement of innovation can be effective in promoting firms' innovation inputs and their market successes. We address the lacuna of empirical evidence on the impact of public procurement on innovation outputs, and estimate procurement effects on different measures of innovation output indicators, both technological (product and process) and non-technological (organisational and marketing), along with the indicative construct 'innovative sales'. Delimited in structure our study is at the forefront of emerging empirical evidence on the effectiveness of public procurement in stimulating radical and incremental output innovations.

We have followed the theoretical literature in distinguishing between the impact of public procurement for innovation as a *direct* effect (i.e. where innovation is required) and the impact of regular procurement on innovation as an *indirect* effect (i.e. where innovation is not required but may occur as a by-product). We used a matching approach to estimate procurement effects on different measures of innovation output as well as on the market success of innovation.

Consequently, with regard to *direct* effects, we find no systemic procurement effects across different country groups. Furthermore, for *Moderate innovators* country group, our results suggest no positive effects on innovation outputs. In contrast, empirical evidence for *indirect* effects indicate stronger effects across country groups and on a range of innovation output indicators. In particular, we find systematic indirect procurement effects on non-technological innovations. Overall, these findings point out that the incidence of indirect procurement effects is more prominent than that of direct effects. Consequently, the policy implication that can be derived from our empirical results is associated with the notion of a more "innovation-friendly" public procurement approach. Namely regular public procurement that encourages innovation may offer a significantly larger potential impact as an innovation policy instrument than either that earlier advanced with Public Procurement for Innovation (PPI) and Pre-Commercial Procurement (PCP) (Edquist, 2014; Edquist and Zabala-Iturriagagoitiaa, 2012).

Our study has limitations that can as well serve as suggestions for further research on assessing the effectiveness of public procurement in promoting innovation. First, data on the amount of a public procurement contracts are unavailable, which prevents us from investigating how the scale of public procurement affects firm innovation performance. Secondly, public procurement is likely to affect firms' innovation output in the medium and longer run (Edler et al., 2012). However, this impact cannot be explored in a cross-sectional setting. Longitudinal data would allow evaluators to assess the effectiveness of innovative public procurement over time (Flynn et al., 2015; Uyarra, 2016). Finally, a more fined-grained analysis at the individual country level could potentially enable the comparison of findings between countries.

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Appendix

Table A1. Variable description and summary statistics for each country group.

Variables	Variable description	Leaders Mean (standard deviation)	Followers Mean (standard deviation)	Moderate Mean (standard deviation)
Treatment variables				
Participation in public procurement which required innovation	DV=1 if a firm participated in public procurement that required innovation in the period 2010-2012; zero otherwise	0.036 (0.186)	0.029 (0.167)	0.081 (0.273)
Participation in public procurement which did not require innovation	DV=1 if a firm participated in public procurement that did not require innovation in the period 2010-2012; zero otherwise	0.026 (0.159)	0.057 (0.232)	0.070 (0.255)
Outcome variables				
Product innovation in goods	DV=1 if a firm introduced product innovation in goods in the period 2010-2012; zero otherwise	0.475 (0.499)	0.533 (0.499)	0.526 (0.499)
Product innovation in services	DV=1 if a firm introduced product innovation in services in the period 2010-2012; zero otherwise	0.255 (0.436)	0.276 (0.447)	0.367 (0.482)
Process innovation	DV=1 if a firm introduced process innovation in the period 2010-2012; zero otherwise	0.499 (0.500)	0.650 (0.477)	0.770 (0.421)
Organizational innovation	DV=1 if a firm introduced organizational innovation in the period 2010-2012; zero otherwise	0.636 (0.481)	0.455 (0.498)	0.614 (0.487)
Marketing innovation	DV=1 if a firm introduced marketing innovation in the period 2010-2012; zero otherwise	0.604 (0.489)	0.461 (0.499)	0.567 (0.496)
Radical innovation	DV=1 if a firm introduced radical innovation in the period 2010-2012 (first in Europe or first in world); zero otherwise	0.141 (0.348)	0.104 (0.305)	0.154 (0.361)
Incremental innovation	DV=1 if a firm introduced incremental innovation in the period 2010-2012 (new to the firm or new to the market); zero otherwise	0.100 (0.180)	0.238 (0.305)	0.122 (0.184)
Matching variables				
Turnover	Turnover in 2012 (in natural logarithm)	16.091 (2.065)	0.238 (0.305)	15.496 (1.921)
Group	DV=1 if a firm belongs to an enterprise group; zero otherwise	0.392	0.391	0.416

		(0.488)	(0.488)	(0.493)
Cooperation	DV=1 if a firm cooperated for innovation in the period 2010-2012; zero otherwise	0.344 (0.475)	0.326 (0.469)	0.347 (0.476)
Internal R&D	DV=1 if a firm invested in internal R&D in the period 2010-2012; zero otherwise	0.555 (0.497)	0.346 (0.476)	0.491 (0.500)
External R&D	DV=1 if a firm invested in external R&D in the period 2010-2012; zero otherwise	0.280 (0.449)	0.214 (0.410)	0.298 (0.457)
Acquisition of knowledge	DV=1 if a firm invested in knowledge acquisition in the period 2010-2012; zero otherwise	0.258 (0.438)	0.298 (0.457)	0.218 (0.413)
Acquisition of machinery	DV=1 if a firm invested in acquiring machinery in the period 2010-2012; zero otherwise	0.622 (0.485)	0.731 (0.443)	0.692 (0.462)
Training	DV=1 if a firm invested in training for innovative activities in the period 2010-2012; zero otherwise	0.563 (0.496)	0.432 (0.495)	0.551 (0.497)
Market introduction	DV=1 if a firm engaged in market introduction of innovation in the period 2010-2012; zero otherwise	0.398 (0.490)	0.356 (0.479)	0.359 (0.480)
Small firms (base category)	DV=1 if a firm has less than 50 employees; zero otherwise	0.477 (0.500)	0.536 (0.499)	0.460 (0.498)
Medium firms	DV=1 if a firm has more than 50 and less than 250 employees; zero otherwise	0.320 (0.467)	0.405 (0.491)	0.362 (0.481)
Large firms	DV=1 if a firm has more than 250 employees; zero otherwise	0.203 (0.402)	0.059 (0.237)	0.178 (0.382)
Internal knowledge sources	DV=1 if a firm uses internal knowledge sources (within the firm or enterprise group); zero otherwise	0.688 (0.395)	0.685 (0.342)	0.760 (0.322)
Market knowledge sources	DV=1 if a firm uses market knowledge sources (customers, suppliers, competitors and consultants); zero otherwise	0.398 (0.251)	0.468 (0.247)	0.493 (0.248)
Institutional knowledge sources	DV=1 if a firm uses institutional knowledge sources (universities, research institutes, conferences, trade fairs and exhibitions); zero otherwise	0.201 (0.209)	0.178 (0.257)	0.237 (0.293)
Other knowledge sources	DV=1 if a firm uses other knowledge sources (scientific journals, trade/technical publications, professional and industry associations); zero otherwise	0.362 (0.267)	0.367 (0.291)	0.403 (0.281)
Obstacle – lack of demand	Categorical variable =1 if lack of demand has low importance as an obstacle to meeting a firm's goals; =2 if lack of demand has medium importance; =3 if lack of demand has high importance; = 0 if lack of demand has no importance	1.592 (0.917)	1.737 (0.969)	1.952 (0.955)
High-tech sectors	DV=1 if a firm operates in NACE Rev.2 sectors: 21-Manufacture of basic	0.080	0.021	0.026

	pharmaceutical products and pharmaceutical preparations; or 26-Manufacture of computer, electronic and optical products; and zero otherwise	(0.271)	(0.144)	(0.159)
Medium high-tech sectors	DV=1 if a firm is in NACE Rev.2 sectors: 28-Manufacture of machinery and equipment n.e.c.; 29-Manufacture of motor vehicles, trailers and semi-trailers; or 30-Manufacture of other transport equipment; and zero otherwise	0.142 (0.348)	0.113 (0.317)	0.109 (0.311)
Medium low-tech sectors	DV=1 if a firm is in NACE Rev.2 sectors: 19-Manufacture of coke and refined petroleum products; 20-Manufacture of chemicals and chemical products; 27-Manufacture of electrical equipment; 22-Manufacture of rubber and plastic products; 23-Manufacture of other non-metallic mineral products; 24-Manufacture of basic metals; 25-Manufacture of fabricated metals products, excepts machinery and equipment; or 33-Repair and installation of machinery and equipment; and zero otherwise	0.198 (0.399)	0.200 (0.400)	0.204 (0.403)
Low tech sectors	DV=1 if a firm is in NACE Rev.2 sectors: 10-Manufacture of food products; 11-Manufacture of beverages; 12-Manufacture of tobacco products; 13-Manufacture of textile; 14-Manufacture of wearing apparel; 15-Manufacture of leather and related products; 16-Manufacture of wood and of products of wood; 17-Manufacture of paper and paper products; 18- Printing and reproduction of recorded media; 31-Manufacture of furniture; or 32-Other manufacturing; and zero otherwise	0.154 (0.361)	0.293 (0.455)	0.197 (0.398)
Knowledge-intensive services (KIS)	DV=1 if a firm is in NACE Rev.2 sectors: 50- Water transport; 51-Air transport; 58-Publishing activities; 59-Motion picture, video and television programme production, sound recording and music publish activities; 60- Programming and broadcasting activities; 61-Telecommunications; 62- Computer programming, consultancy and related activities; 63-Information service activities; 64- Financial service activities, except insurance and pension funding; 65- Insurance, reinsurance and pension funding, except compulsory social security; 66- Activities auxiliary to financial services and insurance activities; 69- Legal and accounting activities; 70- Activities of head offices, management consultancy activities; 71-Architectural and engineering activities, technical testing and analysis; 72-Scientific research and development; 73- Advertising and market research; 74-Other professional, scientific and technical activities; 75- Veterinary activities; 78- Employment activities; 80- Security and investigation activities; 85-Education; 86-Human health activities; 87-Residental care activities; 88-	0.271 (0.445)	0.177 (0.382)	0.213 (0.409)

	Social work activities without accommodation; 90- Creative, arts and entertainment activities; 91- Libraries, archives, museums and other cultural activities; 92- Gambling and betting activities; 93- Sports activities and amusement and recreation activities; and zero otherwise			
Less knowledge-intensive services (LKIS) (base category)	DV=1 if a firm is in NACE Rev.2 sectors: 45- Wholesale trade; 46- Retail trade; 47- Repair of motor vehicles and motorcycles; 49- Land transport and transport via pipelines; 52- Warehousing and support activities for transportation; 53- Postal and courier activities; 55-Accomodation; 56- Food and beverage service activities; 68- Real estate activities; 77- Rental and leasing activities; 79- Travel agency, tour operator reservation service and related activities; 81- Services to buildings and landscape activities; 82- Office administrative, office support and other business support activities; 94- Activities of membership organisation; 95- Repair of computers and personal and household goods; 96- Other personal service activities; and zero otherwise	0.093 (0.291)	0.156 (0.363)	0.179 (0.383)
Other sectors	DV=1 if a firm is in NACE Rev.2 sectors: 01-03: Agriculture, forestry and fishing; 05-09: Mining and quarrying; 35- Electricity, gas, steam and air conditioning supply; 36- Water collection, treatment and supply; 37-Sewerage; 38- Waste collection, treatment and disposal activities; materials recovery; 39- Remediation activities and other waste management services; 41- Construction of buildings; 42- Civil engineering; 43- Specialised construction activities; and zero otherwise	0.062 (0.241)	0.040 (0.196)	0.072 (0.259)

Table A1. Checking the common support condition for Model 1.

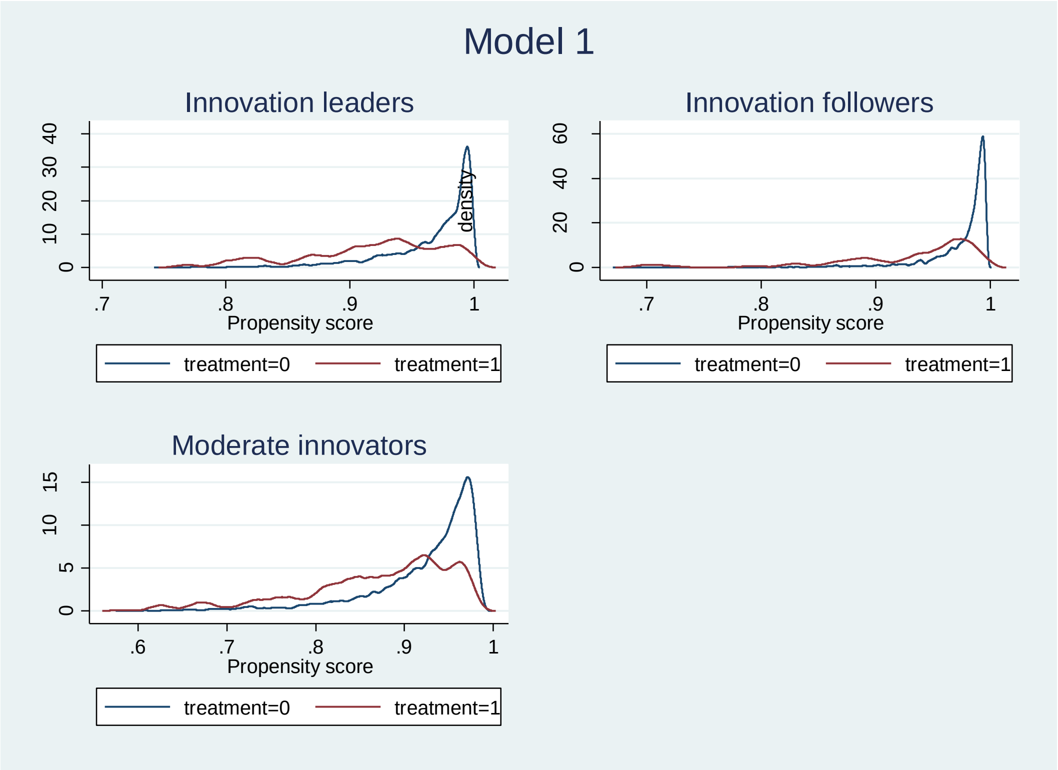

Table A2. Checking the common support condition for Model 2.