Discussion Paper No. 18-001

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Zentrum für Europäische Wirtschaftsforschung GmbH

Centre for European Economic Research

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January 2018

**Abstract**

The use of public procurement to promote private innovation activities has attracted increasing attention recently. Germany implemented a legal change in its procurement framework in 2009, which allowed government agencies to specify innovative aspects of procured products as selection criteria in tender calls. We analyze a representative sample of German firms to investigate whether this reform stimulated innovation in the business sector. Across a wide set of specifications—OLS, nearest-neighbor matching, IV regressions and difference-in-differences—we find a robust and significant effect of innovation-directed public procurement on turnover from new products and services. However, our results show that the effect is largely attributable to innovations of more incremental nature rather than market novelties.

**Keywords:** Public Procurement of Innovation, Public Procurement with Contracted Innovation, Technical Change, Research and Development, Econometric Policy Evaluation
**JEL Classification:** H57, O38

## 1 Introduction

Governments sponsor private research and development (R&D) activities in a number of ways and theoretical justifications for these public interventions are well understood in the literature (Arrow, 1962; Hall and Lerner, 2010). In addition to a functioning system of

[1] Dirk Czarnitzki gratefully acknowledges funding from the Research Foundation Flanders (FWO grant G077218N); Paul Hünermund gratefully acknowledges funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 645884. The authors are fully responsible for all views expressed in this paper. The authors thank the MIP team at the Center for European Research (ZEW), Mannheim, Germany, for data access to the Mannheim Innovation Panel. We also thank the audiences at following conferences and seminars: 7th Asia-Pacific Innovation Conference, Fukuoka; DRUID, New York; 15th IIOC, Boston; Atlanta Conference on Science and Innovation Policy; Annual Meeting of the Technology Transfer Society, Phoenix; EARIE, Maastricht; IIPF, Lake Tahoe; MEIDE, Moscow; IMT Lucca; Federal Australian Government, Canberra; State Government of Victoria, Melbourne.

intellectual property protection, R&D tax credits (Dechezleprêtre, Einiö, Martin, Nguyen, Van Reenen, 2016) and direct subsidies for private R&D projects (Einiö, 2014; Howell, 2017) are the most important policy instruments at the disposal of governments to date. In recent years, however, demand-side alternatives such as *public procurement of innovation* have attracted increasing attention by policy makers and academics alike (EFI 2013; OECD, 2017; Slavtchev and Wiederhold, 2016).

Governments spend large budgets in various product categories in order to provide their services to citizens. If a share of this public spending could be redirected towards more innovative products and services instead of already established alternatives, so the idea goes, the demand for innovative solutions in the economy would increase significantly (Edler and Georghiou, 2017). At the same time, private firms would have larger incentives to invest in R&D, especially in sectors where there is insufficient private demand (e.g, in green energy or transportation). The idea is particularly appealing to policy makers in times of continued budgetary pressure, as the additional demand for innovation and resulting incentives for R&D investment might be created with little to no extra money (OECD, 2016).[2]

In the past, however, the way in which public procurement contracts were awarded constituted a major obstacle for implementation. Procurement agencies tried to define as precisely as possible the products and services they were willing to buy in a call for tenders. At the same time, legal frameworks did not offer the possibility to explicitly specify innovative aspects or more broadly defined performance characteristics as selection criteria in tender calls. In other words, standard procurement tenders did not allow to describe products or services that were not yet invented or developed. Recognizing this problem, the European

[2] A closely related variant to public procurement of innovation is pre-commercial procurement (PCP), which refers to the direct purchase of R&D services by government agencies. PCP does not involve the transaction of a marketable product but instead is a form of contract research. Therefore, authors in the literature tend to characterize it as a supply-side measure (Edquist and Zabala-Iturriagagoitia, 2012). In the following we will focus our attention on public procurement of innovation as a demand-side instrument but will discuss the possibility of a combined use with PCP in Section 5.

Union (EU) passed revised public procurement directives in 2014 that aimed at facilitating the procurement of innovations. Under the new regulatory framework, innovative solutions and yet to be developed technologies can be an explicit part of the contractual arrangements of the procurement process (*Public Procurement with Contracted Innovation*, PPCI). This is permitted as long as the transparency of the process is guaranteed and fair rules of competition are not affected. The new directives favor functional specifications in tender calls, which reduce the risk of overly rigid tenders and provide more flexibility to suppliers to come up with innovative ways of meeting public needs. Furthermore, the revised framework encourages procurers to take life-cycle cost considerations into account rather than deciding solely on the basis of initial purchasing costs.

In this paper we exploit the fact that Germany was a forerunner in this policy development and adopted similar regulations already in 2009. Thus, although reforms were only recently adopted at the European level and data for evaluation still need to accumulate, we are able to infer the effectiveness of PPCI as a policy instrument for innovation from the German experience. To this end we analyze a sample of 3410 firms from the German part of the EU's Community Innovation Survey in the period of 2010 to 2012.[3] As a baseline we start with cross-sectional results from OLS regressions. To relax parametric assumptions, we also present nearest-neighbor matching results. Subsequently, in order to rule out endogeneity concerns as much as our data permit, we estimate IV regressions based on a procedure suggested by Lewbel (2012), which allows identification based on higher moments without the need for outside instruments. Eventually, augmenting our data with additional information from the Tender Electronics Daily (TED) database, provided by the European Commission, puts us into the position to employ panel fixed-effects models (i.e., generalized difference-in-

[3] Our data is at the firm-level. We have no information on other participants (and their bidding behavior) in procurement auctions that involve innovative products or services. Therefore, we do not contribute to a stream of literature that investigates optimal auction design (see for example, Lewis and Bajari, 2011; Decarolis, 2014; and Hyytinen, Lundberg and Toivanen, 2017). We regard the collection of more detailed data on innovation-related public procurement auctions as a fruitful avenue for future research.

differences). We find a positive and statistically significant effect of PPCI on firms' share of turnover from selling new products and services that is robust across all specifications. The marginal effect amounts to 8.7 percentage points according to our OLS baseline and remains at comparable levels in the other models too. Based on these estimates we calculate that PPCI increased turnover with new products and services in the German business sector in 2012 by EUR 13 billion, which represents 0.37% of GDP. However, our results reveal that the effect is primarily driven by increased turnover with products and services that are new to the firm, while we find the effect on market novelties to be insignificant.

Our paper is not the first to investigate the effectiveness of demand-side innovation policies empirically (see Appelt and Galindo-Rueda, 2016, for a detailed review). A seminal study by Lichtenberg (1988) establishes a positive relationship between competitively awarded procurement contracts[4] and company-sponsored R&D in a panel of 169 US firms in the period between 1979 and 1984. Draca (2013) finds a positive effect of defense-related procurement on firm's patenting activities and R&D expenditures in the US. In a sample of 1149 German firms between 2000 and 2002, Aschoff and Sofka (2009) document higher shares of turnover from market novelties in firms that introduced significantly improved products or processes due to demand from public authorities. Guerzoni and Raiteri (2015) investigate both supply-side and demand-side technology policies and find a robust positive impact of the latter on innovation spending in a sample of firms from 27 EU member states. Most recently, Slavtchev and Wiederhold (2016) show that public purchases of high-tech products can positively affect private R&D employment at the state-level in the US. None of these studies, however, consider whether public procurement frameworks actually permit to specify innovation-related components in tenders, which we regard as a necessary condition to develop the full potential of this policy instrument. Furthermore, we contribute to the

[4] In his analysis Lichtenberg differentiates between competitive public procurement contracts, which are auctioned off by a federal agency, and "follow-on" contracts that are awarded to once successful bidders on a non-competitive basis. He finds a positive impact on private R&D investment only for the former type.

literature by investigating the differential effect of public procurement on firms' success with radical versus more incremental innovations.

The remainder of the paper is organized as follows. Section 2 discusses the potential for public procurement as an innovation policy instrument and outlines recent changes of procurement frameworks in the EU. Section 3 describes our data and econometric approaches. Empirical results are presented in Section 4. Finally, Section 5 discusses the theoretical and policy implications of our study and Section 6 concludes.

# 2 Conceptual background

## 2.1 Potential of public procurement as policy instrument for innovation

The idea behind public procurement of innovation as a policy instrument can be motivated by the sheer size of government demand. In 2013, public procurement represented on average 12% of GDP and 29% of total government expenditures in OECD countries (Appelt and Galindo-Rueda, 2016). For Germany, in a study prepared on behalf of the federal government, the Wegweiser GmbH (2009) reports that public procurement volumes have been exceeding EUR 200 billion since the early 2000s. In 2006, the public procurement volume has reached almost EUR 250 billion. It is instructive to compare this volume with current levels of public R&D funding. In 2009 (2013), total R&D spending in Germany amounted to EUR 67 (80) billion according to the Federal Ministry for Education and Research.[5] These totals are split into shares expensed by the business sector, the federal government and the state governments in **Table 1**.

[5] These and the following numbers have been obtained from multiple editions of the report "Bundesbericht Forschung" published by the Federal Ministry for Education and Research.

**Table 1:** R&D spending in Germany 2009 and 2013

| | 2009 | 2013 |
|---|---|---|
| Total R&D spending (billion EUR) | 67 | 80 |
| Business sector | 42 | 54 |
| Federal government | 12 | 16 |
| State governments | 10 | 10 |

Source: "Bundesbericht Forschung" published by the Federal Ministry for Education and Research.

Roughly two thirds of total R&D spending occur in the business sector. The one third coming from the public sector can be further split into direct and indirect R&D grants, which are used to subsidize R&D projects in both firms and public research institutions, and into institutional funding for public research institutions as well as "other" types. Institutional and other funding amount to EUR 6.4 billion and R&D grants to EUR 5.6 billion in 2009. The latter amount can be further broken down according to the type of recipients, i.e. public research organizations and the business sector. In 2009, EUR 2.3 billion arrived in the business sector in form of direct and indirect R&D subsidies.

We can thus conclude that the overall public procurement volume of EUR 250 billion in 2006 was about one hundred times higher than the amount paid as R&D subsidies to the business sector in 2009. The factor hundred thereby illustrates the massive potential of public procurement to stimulate demand in policy-relevant product categories such as innovation and technology. Obviously, the lion's share of public procurement does not offer any possibilities for stimulating innovation as many procurement contracts will involve the purchase of standardized goods and services for everyday business. In order to estimate the innovation potential of public procurement, Wegweiser GmbH (2009) mapped procurement contracts into product categories. Based on a classification of "high-tech" products, the authors estimated that a share of about 10% of total public procurement, or EUR 25 billion, could potentially be used to stimulate innovation. This implies that the quantitative potential of public procurement of innovation is about ten times larger than the amount of public R&D subsidies distributed to the business sector.

## 2.2 Revision of public procurement law in the EU

In the EU, the potential of using demand-side innovation policies in order to enhance the competitiveness of European industries, improve the provision of public services, and tackle grand societal challenges has been long recognized (European Commission, 2003). Commitment 17 of the EU's *Innovation Union Flagship Initiative* was concerned with improving the well-functioning of public procurement markets for innovation across Europe (European Commission, 2015). In particular, the initiative aimed at overcoming the fragmentation of procurement activities by harmonizing framework conditions that allow for cross-border tenders. Moreover, the participation of small and medium-sized enterprises should be promoted and specific public procurement budgets were set aside in the EU'S *Framework Programmes for Research and Innovation* (Horizon 2020).[6]

Most importantly, however, the European Commission proposed the revised public procurement directives 2014/24/EU[7] and 2014/25/EU[8], which were adopted by the European Parliament and Council in 2014 and had to be translated into national laws by 2016 (European Commission, 2015).[9] Within the new legal framework public procurers are explicitly encouraged to prepare calls for tenders that include functional and performance-based specifications in order to promote innovation (2014/24/EU, par. 74). Furthermore, the possibility to consider innovative aspects and life-cycle costs of proposed solutions has been put on a proper legal basis. Appropriate award criteria are supposed to guarantee that innovative products and services have a better chance of getting selected in procurement

[6] See: https://ec.europa.eu/programmes/horizon2020/ (accessed 30 November 2017).

[7] See: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0024&from=EN (accessed 30 November 2017).

[8] See: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0025&from=EN (accessed 30 November 2017).

[9] Interestingly, a majority of EU Member States missed the deadline of April 2016 for implementation of directives 2014/24/EU and 2014/25/EU. As a consequence, the European Commission launched formal infringement procedures against the delinquent countries. See http://europa.eu/rapid/press-release_IP-17-1846_en.htm (accessed 30 November 2017).

auctions. The adoption of these rules constituted a major milestone in removing obstacles for the use of public procurement as an effective policy tool for innovation.

Procurement procedures adhere to the principles of transparency, non-discrimination, and cost-effectiveness (Valovirta, 2015; Vonortas, 2015). In practice, however, this meant that public agencies issued calls for tenders that were very narrowly specified in order to guarantee said transparency in the award process. Moreover, cost-effectiveness was often defined solely on the basis of initial costs at the time of purchase; i.e., the lowest bid won in a procurement auction (Edler and Georghiou, 2007).

Compared to overly narrow descriptions of requested products and services, functional specifications allow suppliers to come up with innovative solutions that are best suited for solving a given problem at hand (Aschoff and Sofka, 2009; Edquist, Vonortas, and Zabala-Iturriagagoitia, 2015). Likewise, because firms need to recoup their R&D costs, innovative products are often initially more expensive than conventional alternatives (Edquist and Zabala-Iturriagagoitia, 2012). Thus, broader definitions of cost-effectiveness, i.e., taking into account life-cycle costs, in which innovative products prove to be superior, are necessary in order to make them competitive in bidding rounds (European Commission, 2015). Specifying broader performance-related award criteria and requiring innovations as integral components of public procurement tenders additionally reduces the investment risk for suppliers associated with the development of innovative products and services (van Meerveld, Nauta, and Whyles, 2015).

**Table 2:** Examples for public procurement calls for tenders

| |
|---|
| **Example 1:** traditional specification<br>"The government agency invites tenders for the delivery and installation of 280 street lights; each equipped with 70 watts sodium vapor lamps."<br><br>**Example 2:** functional specification, including innovative aspects<br>"The government agency seeks to illuminate 18 residential streets with an illumination level of three lux over a period of 11.2 hours (on average) per day. The light sources need to have a minimum life expectancy of 100,000 service hours and their energy consumption should be 85% percent below the currently employed system." |

*Notes:* examples adapted from Eßig, Schaupp, Jungclaus, and Kurz (2014)

**Table 2** contrasts a traditional tender specification, which leaves little room for innovative solutions, with a specification that is in accordance with directives 2014/24/EU and 2014/25/EU. The latter specifies procurement needs in terms of functional requirements, takes life-cycle cost considerations into account, and defines innovative aspects (here with respect to energy consumption compared to the current technology in place) as award criteria. As such, it creates the necessary preconditions for suppliers to be successful with innovative solutions at the tender-stage. In the following, in order to emphasize the importance of said contractual arrangements in innovation procurement, we will use the term *Public Procurement with Contracted Innovation* (PPCI) for procurement contracts that specify innovation-related activities in accordance with the new regulatory rules.

Interestingly, Germany was a forerunner in revising its public procurement framework and already adopted similar rules in a *Procurement Law Amendment Act* in 2009 (Falck and Wiederhold, 2013). The act unequivocally clarified the legal basis for taking innovative aspects into account and defining selection criteria with respect to life-cycle costs and broader performance measures of procured products. Germany is thus an ideal laboratory to empirically study the effect of policy changes that have only recently been put forward in the EU. Although evidence for the impact of reforms at the European level will still take years to accumulate, our analysis is able to make predictions about their likely effects by drawing lessons from the German experience.

## 2.3 Scope of public procurement as innovation policy instrument

Although the potential for demand-side innovation policies is large in scale, we argue that it is still limited in scope. Because public procurement of innovation only recently attracted attention as a strategic policy instrument, existing skill sets of procurement agencies are not yet well aligned and established organizational cultures only adapt slowly to the new requirements (Yeow and Edler, 2012). In particular, relevant market knowledge about the range of possible innovative solutions to a given problem and their potential suppliers can be missing. Moreover, technical knowledge to properly assess the value and viability of cutting-edge technologies is rare (Georghiou, Edler, Uyarra, and Yeow, 2014). Consequently, innovation activities conducted as part of procurement contracts are unlikely to be of radically new nature. Instead, government agencies will resort to solutions that have already proven to be applicable in other closely related contexts. Primarily, such incremental innovations and adaptations of already existing products entail a much lower development risk and are less prone to failure. Also, as these technologies are already better understood than radically new approaches, they are easier to control and describe (Edler, Rolfstam, Tsipouri and Uyarra, 2015).

In general, risk aversion among public procurers constitutes a main bottleneck. This might be the result of a reluctance to change that is inherent in administrative institutions (Edler et al., 2015). Even more decisive, however, is a skewed incentive structure in the public sector. Procurers are directly accountable for failures in the procurement process and can face personal career consequences in case of obstructions. At the same time, a much broader group of stakeholders reaps the benefits of innovative products and services that are procured (Yeow and Edler, 2012). Adequate risk management within public organizations, which could mitigate the problem, is largely absent (Edler et al., 2015). As these obstacles remain unaddressed by recent policy reforms at the European level, we expect a potentially positive effect of PPCI to be limited to more incremental innovation efforts.

For the reasons just stated, we also compare the effect of public procurement with direct R&D grants in a robustness check of our empirical study. This is conceptually an interesting comparison as it clarifies possible limitations of demand-side innovation policies. It is practically impossible for procurers in government agencies to be aware of all feasible approaches to innovation and viable (but not yet existing) technologies that potential inventors might think of. Bottom-up policies, where firms develop and submit R&D projects by themselves, might therefore have an advantage with respect to promoting more novel solutions. By contrast, procurement projects may always remain limited in their scientific and technological scope because of the top-down character of public procurement as an innovation policy instrument.

# 3 Data and Methods

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**+++ Insert Table 3, Table 4, and Table 5 about here +++**

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For our empirical analysis we collect a sample of 3410 German firms from the Community Innovation Survey[10] (CIS)—the official survey of innovation activities by private enterprises in the European Union. The German part of the CIS is called *Mannheim Innovation Panel* (MIP) and is conducted annually since 1993 by the Centre for European Economic Research (ZEW) in Mannheim, Germany. The 2013 wave of the MIP includes items on firms' public procurement contracts and—relevant for our research question—on public procurement with contracted innovation. We make use of a dummy variable which is equal to one if firms were

[10] See: http://ec.europa.eu/eurostat/web/microdata/community-innovation-survey (accessed 30 November 2017).

awarded one or more public procurement contracts in the period between 2010 and 2012. This is the case for almost 20% of firms in our sample. A second dummy variable records whether firms conducted any innovation activities that were part of a public procurement contract awarded to them (PPCI), which applies to 15.3% of the firms with a public procurement contract. In the total population the share of firms that benefitted from PPCI is thus equal to about 3% (**Table 3** presents summary statistics for the variables in our data). **Table 5** reveals that the lion's share of PPCI occurs in IT and telecommunications, electronics, and technical engineering.[11]

## 3.1 Dependent variables

Public procurement of innovation involves the sale of goods and services. Consequently, we use the share of total turnover a firm made in 2012 with new or significantly improved products and services that were introduced in a three-year period before, between 2010 and 2012, as dependent variable. Furthermore, we differentiate between turnover from selling products and services that were new to the market (market novelties), with no similar products already available before, and those that were new to the respective firm or significant improvements of existing products (firm novelties). On average, 8.7% of total turnover were attributable to new products, 2% to market novelties, and 6.7% to firm novelties. Split sample descriptive statistics of our dependent variables are given in **Table 4**. It is noteworthy, that firms with public procurement contracts, but without PPCI, have very similar average shares of turnover with innovative products as the population; whereas firms with PPCI show considerably higher shares.

[11] Our sample does not include any firm operating in the sector C25.4 ("Manufacture of weapons and ammunition") according to the NACE classification (Rev. 2). In an additional web search we found only five (out of 103) firms with PPCI contracts that possibly have ties to the military. We thus conclude that the vast majority of observations in our sample represent procurement for civilian rather than defense purposes.

## 3.2 Control variables

**Table 3** describes and presents descriptive statistics of a set of control variables that we employ throughout our estimations. We control for firm size measured as the number of employees. On the one hand, smaller firms may naturally have a higher share of sales with new products, as an innovation may have relatively more weight in a total product or service portfolio when compared to larger, more diversified firms. On the other hand, larger firms may innovate more routinely. Furthermore, we control for the share of high-skilled personnel, i.e., employees with a university degree, as a highly skilled workforce might be positively associated with a firm's innovativeness. The innovation intensity itself, measured as innovation expenditures divided by sales (in %), is also included as control, for the same reason as high-skilled employment. The more resources a firm devotes to innovation, the more sales with new products or services it is expected to achieve, independently of any public procurement contracts. In order to control for the affinity to innovation in a longer historical context, we also include a firms' knowledge stock, measured as the patent stock generated by the perpetual inventory method. To control for factor inputs, we include a firm's cost per capita, i.e., the sum of wages, materials and energy per employee, in our estimations. Furthermore, we include a firm's share of sales from exporting because competition on international markets may induce firms to innovate at higher rates to stay competitive. We also control for ownership structure by including a dummy indicating whether a firm is associated with a group and whether the parent company is located outside of Germany. Finally, we include a dummy for firms located in Eastern Germany, and a set of industry dummies based on a 2-digit NACE classification (Rev. 2)[12] given in **Table 5**. To avoid simultaneity bias, time-variant control variables are lagged whenever possible.

[12] NACE is comparable to the SIC classification in the US. See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE) (accessed 30 November 2017).

### 3.3 Methods

We test the effect of PPCI on our three dependent variables in a variety of different specifications. As a baseline we present OLS estimations. Subsequently we report results of a nearest-neighbor matching to rule out an influence of parametric functional form assumptions. Matching estimators are widely applied in the treatment effects literature (Smith and Todd, 2005) and innovation policy evaluation literature (Zúñiga-Vicente, Alonso-Borrego, Forcadell, Galán, 2012; Guerzoni and Raiteri, 2015). Moreover, because the award of public procurement contracts is possibly endogenous, we estimate instrumental variable regressions using generated instruments as introduced by Lewbel (2012, 2016). Lewbel shows that in the absence of an exclusion restriction (i.e., no traditional instrumental variables are available) parameters of a triangular or fully recursive system can still be identified if errors are heteroskedastic, which is plausible in many applied settings, and by placing appropriate restrictions on the correlation between regressors and the product of error terms. Instruments can then be constructed from the variables in the data set without the need for outside instruments. Lewbel (2012) demonstrates that the imposed identifying restrictions are fulfilled in many standard econometric settings, such as in the presence of an unobserved single factor or classic measurement error. However, since identification is based on higher moments, estimates should be less robust compared to standard instrumental variable approaches. Furthermore, in the case of a binary endogenous regressor the method relies on strong distributional assumptions (Lewbel, 2016). For this reason we present a final robustness check in which we make use of the longitudinal character of the German CIS to estimate a difference-in-differences specification. Details on this approach are deferred to Section 4.4.

# 4 Estimation Results

## 4.1 Cross-sectional OLS regressions

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**+++ Insert Table 6 about here +++**
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presents our baseline OLS results. If we only control for industry affiliation we find positive and statistically significant (at the 1%-level) effects of PPCI on all three of our outcome variables (column 1, 3, and 6). At the same time, there is no significant effect of standard public procurement without contracted innovation on the share of turnover from selling new products and services, market novelties, or firm novelties.[13]

Once we control for other possibly confounding influences, the estimated effects of PPCI become substantially smaller. Nevertheless, coefficients remain positive and statistically significant in the regressions with turnover from new products ($p < 0.001$) and firm novelties ($p = 0.001$) as dependent variables. Point estimates are also economically significant. PPCI increases the share of firms' turnover with new products and services in general by about 8.7 percentage points and turnover with firm novelties by almost 7 percentage points. By contrast, as hypothesized in Section 2.3, we find no statistically significant effect on market novelties ($p = 0.224$).

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Coefficients of control variables have expected signs. In particular, the innovation intensity of a firm and the share of high-skilled employees are positively related to turnover with innovations. Also, a higher share of turnover from exports is positively associated with

[13] Note that, since PPCI is zero if public procurement is absent, both variables together can be interpreted as an interaction term where the product term would be collinear with PPCI and therefore drops out of the regressions.

innovative sales. Firms located in Eastern Germany have a higher share of turnover with new products and services. This effect, however, is restricted to firm novelties, which points to the catch-up process that is still taking place in the ex-communist part of Germany.

**Table 7** shows that our OLS results remain unchanged if we control for other types of public support measures for R&D, i.e., whether a firm received an R&D grant between 2010 and 2012. Interestingly, unlike PPCI, R&D grants are positively associated with both turnover from market novelties and firm novelties (see Section 5 for a further discussion of this finding).

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**+++ Insert Table 8 about here +++**
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## 4.2 Cross-sectional analysis using matching techniques

We perform a nearest-neighbor matching using Mahalanobis distances (**Table 8**) in order to confirm that these results are not driven by parametric model assumptions. In a first step, we find matched pairs within the sample of firms with a public procurement contract that are similar in terms of the covariates used in **Table 6**.

Subsequently, we perform the same matching with the added restriction that matched pairs need to be equal (exact matching) with regard to whether they received a public R&D grant. After the matching we generally find a good covariate balance with only insignificant differences remaining in the control variables between treatment and control group.[14]

Although estimated standard errors become larger, results of the nearest-neighbor matching are close to our baseline OLS estimates. There is a significant average treatment

[14] Tests on covariate differences are shown in the supplemental material to this paper. Note that we do not report results of the popular propensity score matching in detail. Frölich, Huber and Wiesenfarth (2017) perform simulation studies using different matching estimators and conclude that direct matching estimators have preferable finite sample properties. We point out, however, that propensity score matching leads to similar results in our case. We also performed a 5-nearest-neighbor matching and found results to be robust (see the supplemental material to this paper).

effect on the treated of PPCI on the share of turnover with new products and services (p = 0.033). The treatment effect on firm novelties is still significant at the 10%-level (p = 0.059). As before, we find no significant effect of PPCI on turnover with market novelties. The same holds if we require an exact matching on R&D grant. Here the estimated treatment effect on firms' turnover with firm novelties is again significant at the 5%-level (p = 0.038). Note that this procedure does not allow to assess whether R&D grants themselves have positive effects on the dependent variable (as in the OLS regressions performed above). This would require a fully-fledged heterogeneous treatment effects analysis as done in, e.g., Czarnitzki, Ebersberger, Fier, (2007), for R&D grants and R&D co-operation as treatments, or Czarnitzki and Lopes-Bento (2014) for R&D grants from the European Commission versus national subsidies. Such an analysis is beyond the scope of this paper as we are mainly interested in the effect of PPCI and its robustness if direct R&D grants are taken into account.

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**+++ Insert Table 9 about here +++**

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In **Table 9** we report our instrumental variable (IV) regression results accounting for the possible endogeneity of public procurement and PPCI. Following Lewbel (2012, 2016) we exploit heteroscedasticity in the first stage residuals of a two stage least squares regression, and construct a vector of instruments $(X - \bar{X})\hat{\varepsilon}_2$, where $X$ corresponds to the exogenous variables in the model and $\hat{\varepsilon}_2$ to the first-stage residuals. Note that heteroscedasticity arises naturally in a setting with binary endogenous regressors. Point estimates for the coefficients of interest increase moderately compared to the OLS. They are again significant at the 5%-level in the regression of turnover with new products and services ($p < 0.001$) and with firm novelties ($p = 0.002$). At the same time, the coefficient of PPCI remains insignificant in the regression on market novelties ($p = 0.114$), which is in line with the results we established so far. First-stage F statistics are sufficiently large such that we do not need to worry about weak identification. Overidentifying restrictions tests do not reject the null for any of the estimated models in **Table 9**.

### 4.3 Further robustness tests using cross-sectional data

In unreported estimations (reported in the supplemental material to this paper) we find similar results for all our cross-sectional specifications (OLS and IV) if we restrict the sample to only include firms that were awarded a public procurement contracts between 2010 and 2012.

### 4.4 Robustness check using panel data

In Germany, unlike in other European countries (Peters and Rammer, 2013), the Community Innovation Survey is conducted annually and not only every second year as in most other countries and the sampling is designed as a panel, i.e. to the largest possible extent the same firms are traced over time. Note, however, that although an effort is made to survey firms repeatedly, not all firms respond in each year. We are able to retrieve longitudinal information for 1310 firms from the 2013 sample that responded at least in one other wave. This results in an unbalanced panel covering the years 2006 to 2008 and 2010 to 2015, with a minimum of two, and a maximum of nine observations per firm ($2 \leq T \leq 9$).[15] In total, the panel contains 5619 firm-year observations.

Unfortunately, items on public procurement contracts of firms are not part of the standard CIS questionnaire and were only included in the 2013 wave. We therefore resort to the Tender Electronics Daily (TED[16]) database provided by the European Commission, which lists detailed information about procurement contracts awarded within the European Economic Area. We construct the dummy *Public Procurement (TED)*, equal to one if a firm won a procurement contract in a given year. However, this comes with a caveat. In general, it

[15] We exclude information from 2009, as the public procurement policy change occurred in this year.
[16] TED csv dataset (2006-2015), Tenders Electronic Daily, supplement to the Official Journal of the European Union. DG Internal Market, Industry, Entrepreneurship, and SMEs, European Commission, Brussels. Available at https://open-data.europa.eu/en/data/dataset/ted-csv. Version 2.1. Accessed on 30 November 2017.

is only mandatory to publish procurement tenders in TED that exceed a certain threshold in value.[17] Although publishing tenders with below-threshold values is "considered good practice" and encouraged,[18] some procurement contracts of smaller scale might not be captured. This limitation of the TED data has to be kept in mind for the interpretation of results. The treatment variable PPCI is again constructed from the 2013 wave of the German CIS. PPCI is set to one in all years after 2009 if a firm won a respective contract between 2010 and 2012, and remains zero otherwise. Ultimately, this allows us to make use of fixed-effects models that control for time-invariant unobserved heterogeneity. This specification is a generalization of the difference-in-differences estimator for $T \geq 2$.

As the within variation of our dependent variables measured in shares is low, we take the absolute values of turnover from new products and services, market novelties, and firm novelties. We estimate Poisson fixed-effects regressions (Hausman, Hall, and Griliches, 1984), which model the conditional mean of the data as $E(y_{it}|x_{i1}, \ldots, x_{iT,}c_i) = c_i \exp(x_{it}, \beta)$, with $c_i$ being an unobserved firm-specific effect. This specification is similar to using $\log(y)$ as dependent variable (Wooldridge, 2002, p. 648), without the added complication of logarithms being undefined at zero. Both of these features are relevant in our case as the distributions of firm turnover are substantially skewed and firms may report zero sales with new products. In addition, the Poisson fixed-effects estimator has desirable robustness properties (Wooldridge, 1999).

**------------------------------------------------**
**+++ Insert Table 10 about here +++**
**------------------------------------------------**

[17] Directive 2014/24/EU specifies the following thresholds: (a) EUR 5186000 for public works contracts; (b) EUR 134000 for public supply and service contracts awarded by central government authorities and design contests organized by such authorities; (c) EUR 207 000 for public supply and service contracts awarded by sub-central contracting authorities and design contests organized by such authorities; (d) EUR 750 000 for public service contracts for social and other specific services. These thresholds are regularly adjusted for inflation.

[18] See: http://data.europa.eu/euodp/repository/ec/dg-grow/mapps/TED(csv)_data_information.pdf. For an analysis of below-threshold publication rates in TED see: http://ec.europa.eu/DocsRoom/documents/15421/attachments/1/translations/en/renditions/native (both accessed 30 November 2017).

**Table 10** reports panel descriptive statistics separately for firms with PPCI contracts (treated) and for those without (untreated); respectively before the policy change (before 2009) and after (after 2009). On average, turnover with new products decreases from EUR 4.43 million for untreated firms before 2009 to EUR 3.95 million after 2009. By contrast, sales figures increase for treated firms from EUR 5.05 million on average to EUR 6.12 million. Consistent with our cross-sectional results, the increase for treated firms is driven by innovative products that are new to the firm only. Turnover from market novelties decreases both for treated and untreated firms.

**-------------------------------------------**
**+++ Insert Table 11 about here +++**
**-------------------------------------------**

This pattern, which is already visible in the descriptive statistics, is confirmed by our estimation results in **Table 11**. PPCI has a significantly positive effect on turnover from new products and services, and firm novelties. Having won a PPCI contract (between 2010 and 2012) on average increases firms' yearly innovation turnover (after 2009) by $100 \cdot (\exp(0.422) - 1) = 52.5\%$. The effect on market novelties remains insignificant. Interestingly, the introduction of control variables in the estimation does not affect results by much; in contrast to our cross-sectional estimations where incorporating controls resulted in substantially smaller coefficients. This can be explained by the fixed effect already picking up a substantial part of the confounding heterogeneity otherwise captured by controls.

To make sure that the dependent variables of treated and untreated firms exhibit a common trend before 2009 we conduct a pseudo-treatment test by interacting the treatment indicator with time dummies in the pre-2009 sample. Reassuringly, we found no statistically significant interactions. Detailed results are reported in the supplemental material to this paper.

## 4.5 Population-level impact

In this paragraph we conduct a "back of the envelope" calculation in order to get an idea about the impact of PPCI at the population level. According to Aschoff et al. (2014) the sample that was collected in the 2013 wave of the German CIS represents a population of 276,600 firms. It covers all industries listed in **Table 5**, including mining, manufacturing, energy and water supply, and service sectors such as wholesale trade, engineering, management consulting, and various other business and ICT-related services (Peters and Rammer, 2013). The vast majority of business R&D is expected to occur in these sectors.

The share of firms with PPCI, extrapolated to the population level, amounts to 1.76% (Aschoff et al., 2014). Thus, 4,868 (1.76% · 276,600) firms in Germany won a PPCI contract between 2010 and 2012. According to our OLS results in column 2 of **Table 6** these firms enjoyed an 8.666 percentage points higher share of total turnover with new products and services in 2012. Given that the average firm with PPCI in our sample reported EUR 30.83 million in sales, we find that EUR 2.67 million of this turnover was attributable to PPCI. Multiplied by 4,868 firms this leads to a total impact of EUR 13 billion, which represents 0.37% of German GDP in 2012.

We find a very similar effect if we base the calculation on our difference-in-differences results. The coefficient of 0.422 we obtain in the Poisson model in **Table 11** translates into a marginal effect of 52.5%. Multiplied by the average pre-treatment turnover with new products for treated firms, equal to EUR 5.05 million (**Table 10**), and further multiplied by 4,868 firms, we arrive at a population-level impact of EUR 12.9 billion.

Under the assumption that procurement expenditures in the German public sector did not increase substantially between 2010 and 2012, the sizeable estimate of PPCI's additionality suggests a success of the policy. By changing their demand behavior and redirecting existing budgets towards more innovative products and services, public authorities were able to improve the market conditions for innovations significantly. This interpretation is supported by OECD statistics, which indicate that the share of general government procurement as a percentage of GDP in Germany remained stable between 2010 and 2012 (with a mean of 14.9 and standard deviation of 0.15).[19]

Ultimately, however, we would like to judge the success of the policy based on whether it creates additional demand for innovations on top of public expenditures. Only in this case, public procurement would play a catalytic role and pave the way for subsequent market success with customers from the private sector (Edler and Georghiou, 2007). Unfortunately, we do not know the aggregate level of PPCI in terms of value. Micro-level data sources such as TED do not categorize procurement contracts accordingly. In Section 2.1 the potential of public procurement of innovation in Germany was estimated to be EUR 25 billion per year. Currently, however, this still seems to be a gross overestimation of the actual budgets spent. It thus remains unclear whether the EUR 13 billion additional turnover in 2012 that we find contain any catalytic component.

## 5 Discussion

We have presented evidence for a positive effect of PPCI on firms' innovation output across several econometric specifications. Although, taken individually, these specifications might not be able to eliminate all endogeneity concerns, together they point to a very consistent picture. Our baseline specification relies on a cross-section of firms in the period immediately after the 2009 revision of public procurement regulations in Germany. We find a large and robust effect of PPCI. At the same time, the effect of standard public procurement *without* contracted innovations remains insignificant throughout. From our results we conclude that policy reforms laying the legal foundations for PPCI—such as Germany's amendment act, or, more recently, directives 2014/24/EU and 2014/25/EU at the European level—are beneficial for stimulating innovation activities in the economy. We find further evidence confirming this

[19] See https://stats.oecd.org/Index.aspx?DataSetCode=GOV_2015 (accessed 30 November 2017).

interpretation in matching and IV estimations, as well as in panel fixed-effects specifications, after augmenting our data with additional information from the TED database.

In light of the considerable impact of PPCI—EUR 13 billion additional turnover with new products and services in 2012 alone, without a noticeable upswing in public procurement expenditures—the share of PPCI, being equal to 1.76% in the population, is still low. Although it is plausible that the average impact of the policy might decrease once it will be expanded to a larger group of firms, there seems to be room for achieving an even larger impact at the macro level. To this end, PPCI's advantages need to be publicized more widely in the public sector and procurement agencies need to be equipped with the necessary skills to apply the new strategic instrument. Whether PPCI also has a catalytic effect, in that it creates additional private demand for innovations, remains a question for future research. Currently, we are unable to compare its additionality to the level of public expenditures on PPCI, as the latter is unknown. In addition, we would require more detailed data on the amount and value of PPCI contracts that individual firms win. Augmenting the TED database with a classification into types of innovation procurement would be helpful in this regard.

A key finding of our study is that PPCI raises turnover with products and services that are new to the firm but not new to the market. These types of more incremental innovations are more easily understood and pose a smaller risk to procurers than radically new approaches. Hence, public procurement of innovation is mainly suitable for inducing the diffusion of technologies and upgrading of already existing product portfolios. This result is consistent with our finding that R&D grants are positively associated with both turnover from market novelties and firm novelties. Grants and subsidies, unlike public procurement, have more of a bottom-up character, as firms are able to request funding for research projects they develop by themselves. In that way, problems posed by information asymmetries are mitigated. Consequently, our results point to the importance of a policy mix that combines top-down instruments, such as public procurement, with bottom-up approaches, such as R&D subsidies.

Nevertheless, by improving public risk management and strengthening the commitment to innovation procurement at the superordinate political level, incentives for procurers to consider more radical innovations could be increased. One possible way would be to more frequently combine PPCI with pre-commercial procurement (PCP) upstream. PCP refers to the purchase of direct R&D services from private firms by the government (Edquist and Zabala-Iturriagagoitia, 2012). It is particularly useful in situations where commercial solutions to address public needs do not yet exist. Consulting several possible suppliers simultaneously and following, for instance, a staged process to gradually select the most suitable approach can thereby improve the risk management capabilities of public authorities. Subsequently, radically new solutions, which have proven their viability in the PCP process, could be disseminated more widely with the help of PPCI.

Finally, we would like to stress that our results are also informative for countries outside of the EU. According to a survey in 2015, existing legal and regulatory frameworks constitute a main obstacle for the implementation of public procurement of innovation in OECD countries because they do not provide sufficient clarity about the lawfulness of innovation-related aspects as selection criteria (OECD, 2017). In the United States, for example, individual federal agencies enjoy a much larger discretionary power in their procurement procedures. This results in “best practice” examples, such as the Department of Defense, which possesses ample experience with technology procurement (Mowery, 2010). However, a general focus on public procurement of innovation as a strategic policy tool remains still limited. Outside of defense and national security, regulatory frameworks that provide appropriate guidance to procurement offices are missing (Vonortas, 2015). Because of legal uncertainty and a resulting fear of litigation, procurers tend to overspecify the to-be-procured products and services in tender calls. As argued in Section 2.2, this is detrimental to the success of innovative solutions. Therefore, the US might benefit from reconsidering their discretionary approach to public procurement of innovation and adopting a more comprehensive set of rules comparable to those implemented in the EU.

# 6 Conclusion

In this paper we presented empirical evidence for the effectiveness of *Public Procurement with Contracted Innovation* (PPCI) as a policy instrument to stimulate private innovation activities. Germany's experience with the instrument after its introduction in 2009 documents a positive effect of PPCI on firms' turnover with innovative products and services. We find robust empirical results across a wide set of specifications, including cross-sectional OLS and nearest-neighbor matching, as well as IV and difference-in-difference estimators, implemented as panel fixed-effect regressions. The impact of PPCI seems limited, however, to products and services that are merely new to the firm. Because of insufficient incentives to opt for radically new solutions and the lack of an appropriate risk management in the public sector, procurers limit the scope of PPCI to innovations of more incremental character that bear a lower development risk.

Our analysis reveals that standard public procurement without contracted innovation has no effect on turnover with innovative products and services. We therefore conclude that Germany's efforts to reform its public procurement framework, and put the implementation of PPCI on a solid legal basis, were successful. At the European level, we expect a comparable impact of the revised public procurement directives 2014/24/EU and 2014/25/EU, once they are adopted universally at the national level. Our results inform the academic literature about the—previously ignored—importance of contractual specifications in innovation procurement. Likewise, our paper might motivate other countries outside of the EU to adopt similar regulatory frameworks that explicitly allow for PPCI.

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# Tables

**Table 3:** Descriptive statistics

| | Description | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Dependent Variables: | | | | | |
| Turnover New Products (%) | Share of turnover with new products and services in 2012 (in %) | 8.723 | 18.731 | 0 | 100 |
| Turnover Market Novelties (%) | Share of turnover with new products and services that were market novelties in 2012 (in %) | 2.022 | 8.336 | 0 | 100 |
| Turnover Firm Novelties (%) | Share of turnover with new products and services that were not market novelties in 2012 (in %) | 6.701 | 15.916 | 0 | 100 |
| Treatment Variables: | | | | | |
| Public Procurement | Public procurement contract awarded between 2010 to 2012 | 0.198 | | 0 | 1 |
| Public Procurement with Contracted Innovation (PPCI) | Innovation activities were part of a procurement contract awarded between 2010 to 2012 | 0.030 | | 0 | 1 |
| Control Variables: | | | | | |
| Innovation Intensity | Innovation expenditures over sales in 2012 (in %) | 4.144 | 11.808 | 0 | 100 |
| Firm Size | Number of employees in 2011 | 101.991 | 730.533 | 1 | 33556 |
| High-skilled Employees | Share of employees holding a university degree in 2011 (in %) | 20.026 | 26.196 | 0 | 100 |
| Knowledge Stock | Discounted stock of patent applications at EPO in 2011 (since 2001, 15% discount factor) | 0.370 | 4.217 | 0 | 146.1 |
| Cost Per Capita | Expenditures for wages, materials, energy and other inputs per employee (in million EUR) in 2011 | 0.103 | 0.156 | 0 | 2.491 |
| Export Share | Export sales over total sales in 2012 (in %) | 11.736 | 21.989 | 0 | 100 |
| Group | Firm is part of a group | 0.217 | | 0 | 1 |
| Foreign Group | Firm is part of a group with headquarter outside of Germany | 0.049 | | 0 | 1 |
| East German | Firm is located in Eastern Germany | 0.387 | | 0 | 1 |
| R&D Grant | Firm received a public R&D grant between 2010 and 2012 | 0.1666 | | 0 | 1 |

**Table 4:** Split sample descriptive statistics

| | Public Procurement = 0 | | Public Procurement = 1 | | | |
|---|---|---|---|---|---|---|
| | | | PPCI = 0 | | PPCI = 1 | |
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Turnover New Products (%) | 8.119 | 18.302 | 8.410 | 17.742 | 26.496 | 25.602 |
| Turnover Market Novelties (%) | 1.840 | 8.089 | 1.984 | 8.186 | 7.058 | 12.927 |
| Turnover Firm Novelties (%) | 6.279 | 15.623 | 6.426 | 15.023 | 19.438 | 22.154 |

**Table 5:** Industry dummies

| Industries | NACE (Rev. 2.0) | % of all Firms | % of firms with PP | % of firms with PPCI |
|---|---|---|---|---|
| Food/Beverages/Tobacco | 10, 11, 12 | 4.90 | 1.48 | 0.97 |
| Textiles/Clothing | 13, 14, 15 | 3.64 | 1.48 | 0.97 |
| Wood/Paper | 16, 17 | 3.11 | 2.07 | 0.00 |
| Chemicals/Pharmaceuticals | 20, 21 | 3.17 | 2.37 | 4.85 |
| Rubber/Plastics | 22 | 2.61 | 0.59 | 0.97 |
| Glass/Ceramics/Concrete | 23 | 2.40 | 2.07 | 1.94 |
| Metals | 24, 25 | 7.48 | 5.48 | 3.88 |
| Electronics/Electrical | 26, 27 | 6.48 | 9.93 | 20.39 |
| Machinery/Equipment | 28, 33 | 7.01 | 7.26 | 4.85 |
| Vehicles | 29, 30 | 2.29 | 2.37 | 3.88 |
| Furniture/Other Manufacturing | 31, 32 | 3.55 | 4.44 | 1.94 |
| Energy/Mining/Oil | 5, 6, 7, 8, 9, 19, 35 | 3.17 | 3.41 | 0.97 |
| Water Supply/Waste/Recycling | 36, 37, 38, 39 | 4.57 | 5.63 | 0.97 |
| Wholesale Trade | 46 | 3.28 | 3.85 | 0.97 |
| Transportation/Postal Services | 49, 50, 51, 52, 53, 79 | 7.24 | 4.15 | 2.91 |
| Printing/Publishing/Media | 18, 58, 59, 60 | 3.96 | 3.70 | 2.91 |
| IT-Services/Telecommunications | 61, 62, 63 | 4.22 | 7.56 | 15.53 |
| Financial Intermediation | 64, 65, 66 | 2.35 | 0.74 | 0.00 |
| Consulting/Advertising | 69, 70, 73 | 5.45 | 3.56 | 6.80 |
| Technical Engineering/R&D | 71, 72 | 8.06 | 14.22 | 18.45 |
| Other Producer Services | 74, 78, 80, 81, 82 | 6.04 | 7.11 | 2.91 |
| Other | | 5.01 | 6.52 | 2.91 |

**Table 6:** OLS estimation results

| | Turn. New Products (%) | | Turn. Market Novelties (%) | | Turn. Firm Novelties (%) | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PPCI | 18.086*** | 8.666*** | 5.074*** | 1.708 | 13.011*** | 6.958*** |
| | (2.619) | (2.423) | (1.313) | (1.404) | (2.262) | (2.143) |
| Public Procurement | 0.291 | 0.037 | 0.144 | 0.086 | 0.148 | -0.049 |
| | (0.820) | (0.728) | (0.375) | (0.353) | (0.695) | (0.653) |
| Innovation Intensity | | 0.510*** | | 0.221*** | | 0.289*** |
| | | (0.058) | | (0.044) | | (0.046) |
| Firm Size | | -0.000 | | 0.000 | | -0.000 |
| | | (0.000) | | (0.000) | | (0.000) |
| High-skilled Employees | | 0.063*** | | 0.021** | | 0.042*** |
| | | (0.017) | | (0.009) | | (0.015) |
| Knowledge Stock | | -0.071 | | 0.004 | | -0.075 |
| | | (0.072) | | (0.037) | | (0.048) |
| Cost Per Capita | | -1.261 | | -0.887* | | -0.373 |
| | | (1.632) | | (0.524) | | (1.578) |
| Export Share | | 0.097*** | | 0.028*** | | 0.069*** |
| | | (0.018) | | (0.010) | | (0.017) |
| Group | | 1.647* | | 0.429 | | 1.218 |
| | | (0.845) | | (0.389) | | (0.769) |
| Foreign Group | | -3.097* | | -0.998 | | -2.099 |
| | | (1.774) | | (0.763) | | (1.641) |
| East German | | 1.290** | | -0.116 | | 1.406** |
| | | (0.598) | | (0.282) | | (0.548) |
| Constant | 8.119*** | 1.612* | 1.840*** | -0.003 | 6.279*** | 1.615* |
| | (0.350) | (0.867) | (0.155) | (0.249) | (0.299) | (0.833) |
| Adjusted $R^2$ | 0.028 | 0.250 | 0.011 | 0.154 | 0.019 | 0.153 |

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
N = 3410. Industry dummies included.

**Table 7:** OLS results controlling for R&D grants

| | Turn. New Products (%) (1) | Turn. Market Novelties (%) (2) | Turn. Firm Novelties (%) (3) |
|---|---|---|---|
| PPCI | 7.414*** | 1.318 | 6.096*** |
| | (2.450) | (1.439) | (2.139) |
| Public Procurement | 0.039 | 0.087 | -0.047 |
| | (0.723) | (0.350) | (0.654) |
| R&D Grant | 7.070*** | 2.204*** | 4.866*** |
| | (1.159) | (0.606) | (1.032) |
| Innovation Intensity | 0.447*** | 0.202*** | 0.245*** |
| | (0.059) | (0.045) | (0.047) |
| Firm Size | -0.000 | -0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| High-skilled Employees | 0.048*** | 0.017** | 0.031** |
| | (0.017) | (0.008) | (0.015) |
| Knowledge Stock | -0.067 | 0.005 | -0.072* |
| | (0.063) | (0.035) | (0.042) |
| Cost Per Capita | -0.867 | -0.764 | -0.102 |
| | (1.582) | (0.523) | (1.548) |
| Export Share | 0.082*** | 0.023** | 0.059*** |
| | (0.018) | (0.010) | (0.017) |
| Group | 1.607* | 0.416 | 1.191 |
| | (0.839) | (0.390) | (0.765) |
| Foreign Group | -2.588 | -0.839 | -1.749 |
| | (1.774) | (0.760) | (1.634) |
| East German | 1.044* | -0.193 | 1.237** |
| | (0.587) | (0.279) | (0.540) |
| Constant | 1.699** | 0.024 | 1.675** |
| | (0.866) | (0.252) | (0.831) |
| Adjusted $R^2$ | 0.265 | 0.161 | 0.162 |

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
N = 3410. Industry dummies included.

**Table 8:** Nearest-neighbor matching results

| | Turn. New Products (%) (1) | Turn. Market Novelties (%) (2) | Turn. Firm Novelties (%) (3) |
|---|---|---|---|
| PPCI | 7.710** | 1.697 | 6.013* |
| | (3.607) | (1.856) | (3.181) |
| PPCI (require exact matching of R&D Grant) | 8.496** | 1.835 | 6.661** |
| | (3.523) | (1.718) | (3.209) |

Standard errors according to Abadie and Imbens (2006, 2011) in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
N = 675. Control variables as in **Table 6**. Results denote average treatment effect on treated of PPCI in sample of firms with public procurement contracts.

**Table 9:** IV regression results using generated instruments as in Lewbel (2012)

| | Turn. New Products (%) | Turn. Market Novelties (%) | Turn. Firm Novelties (%) |
|---|---|---|---|
| | (1) | (2) | (3) |
| PPCI | 10.288*** | 2.606 | 7.682*** |
| | (2.760) | (1.650) | (2.446) |
| Public Procurement | -1.850 | -0.854 | -0.997 |
| | (1.498) | (0.785) | (1.259) |
| Innovation Intensity | 0.508*** | 0.220*** | 0.288*** |
| | (0.058) | (0.044) | (0.046) |
| Firm Size | -0.000 | 0.000 | -0.000 |
| | (0.000) | (0.000) | (0.000) |
| High-skilled Employees | 0.063*** | 0.021** | 0.042*** |
| | (0.017) | (0.009) | (0.015) |
| Knowledge Stock | -0.070 | 0.004 | -0.074 |
| | (0.073) | (0.037) | (0.048) |
| Cost Per Capita | -1.255 | -0.882* | -0.373 |
| | (1.619) | (0.518) | (1.569) |
| Export Share | 0.096*** | 0.027*** | 0.069*** |
| | (0.018) | (0.010) | (0.017) |
| Group | 1.609* | 0.410 | 1.199 |
| | (0.842) | (0.387) | (0.767) |
| Foreign Group | -3.197* | -1.046 | -2.150 |
| | (1.769) | (0.762) | (1.636) |
| East German | 1.384** | -0.069 | 1.453*** |
| | (0.598) | (0.281) | (0.550) |
| Constant | 1.702** | 0.042 | 1.660** |
| | (0.862) | (0.252) | (0.827) |
| Adjusted $R^2$ | 0.249 | 0.152 | 0.153 |
| Cragg-Donald F Statistic | 14.323 | 14.323 | 14.323 |
| Hansen's J Statistic | 70.753 | 64.561 | 63.341 |
| P-value Hansen's J | 0.121 | 0.258 | 0.294 |

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Instrumented: PPCI, Public Procurement
N = 3410. Industry dummies included.

**Table 10:** Panel descriptive statistics

| | Before 2009 | | | | After 2009 | | | |
|---|---|---|---|---|---|---|---|---|
| | Untreated | | Treated | | Untreated | | Treated | |
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Dependent Variables: | | | | | | | | |
| Turnover New Products (mill. EUR) | 4.43 | 21.02 | 5.05 | 18.32 | 3.95 | 23.36 | 6.12 | 21.56 |
| Turnover Market Novelties (mill. EUR) | 1.04 | 9.38 | 2.44 | 11.06 | 0.94 | 9.42 | 1.63 | 9.20 |
| Turnover Firm Novelties (mill. EUR) | 3.43 | 17.42 | 2.61 | 7.98 | 2.83 | 18.37 | 4.66 | 16.63 |
| Control Variables: | | | | | | | | |
| Public Procurement (TED) | 0.02 | 0.14 | 0.06 | 0.25 | 0.02 | 0.14 | 0.06 | 0.23 |
| Innovation Intensity | 7.18 | 13.50 | 16.02 | 21.65 | 6.80 | 13.74 | 13.58 | 16.20 |
| Firm Size | 125.30 | 468.57 | 146.58 | 421.65 | 118.00 | 458.78 | 162.39 | 471.61 |
| High-skilled Employees | 22.32 | 25.35 | 38.23 | 29.78 | 25.69 | 27.13 | 44.99 | 31.19 |
| Cost Per Capita | 0.09 | 0.11 | 0.06 | 0.04 | 0.09 | 0.12 | 0.05 | 0.04 |
| Export Share | 18.85 | 24.72 | 23.03 | 25.77 | 19.92 | 26.25 | 24.07 | 27.24 |

N = 5619 firm-year observations covering the years 2006 to 2008 and 2010 to 2015

**Table 11:** Poisson fixed effects estimation results

| | Turn. New Products | | Turn. Market Novelties | | Turn. Firm Novelties | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PPCI | 0.496*** | 0.422** | 0.202 | 0.171 | 0.760*** | 0.763*** |
| | (0.123) | (0.201) | (0.266) | (0.293) | (0.168) | (0.251) |
| Public Procurement (TED) | -0.073 | -0.069 | 0.269 | 0.293 | -0.226 | -0.212 |
| | (0.177) | (0.179) | (0.366) | (0.369) | (0.261) | (0.260) |
| Innovation Intensity | | -0.002 | | -0.002 | | -0.005 |
| | | (0.008) | | (0.016) | | (0.009) |
| Firm Size | | 0.000 | | -0.000 | | 0.000 |
| | | (0.000) | | (0.000) | | (0.000) |
| High-skilled Employees | | -0.007** | | 0.004 | | -0.010** |
| | | (0.003) | | (0.006) | | (0.004) |
| Cost Per Capita | | 0.246 | | -0.838 | | 0.354* |
| | | (0.195) | | (1.126) | | (0.189) |
| Export Share | | -0.003 | | -0.016 | | 0.002 |
| | | (0.005) | | (0.011) | | (0.005) |
| Year: | | | | | | |
| 2007 | 0.029 | 0.015 | 0.078 | 0.128 | 0.026 | -0.006 |
| | (0.130) | (0.132) | (0.263) | (0.267) | (0.132) | (0.133) |
| 2008 | 0.341* | 0.351* | 0.662* | 0.713** | 0.236 | 0.240 |
| | (0.174) | (0.183) | (0.363) | (0.360) | (0.195) | (0.200) |
| 2010 | 0.007 | 0.021 | 0.374 | 0.421 | -0.095 | -0.161 |
| | (0.178) | (0.176) | (0.275) | (0.275) | (0.211) | (0.217) |
| 2011 | -0.125 | -0.131 | -0.035 | 0.048 | -0.224 | -0.249 |
| | (0.143) | (0.142) | (0.395) | (0.405) | (0.156) | (0.157) |
| 2012 | -0.095 | -0.075 | 0.298 | 0.407 | -0.215 | -0.204 |
| | (0.155) | (0.160) | (0.288) | (0.290) | (0.165) | (0.166) |
| 2013 | -0.253 | -0.280* | -0.535 | -0.502 | -0.190 | -0.210 |
| | (0.184) | (0.162) | (0.492) | (0.472) | (0.186) | (0.155) |
| 2014 | -0.175 | -0.165 | -0.307 | -0.220 | -0.114 | -0.117 |
| | (0.166) | (0.162) | (0.348) | (0.358) | (0.163) | (0.160) |
| 2015 | -0.322 | -0.222 | -0.573 | -0.607 | -0.322 | -0.196 |
| | (0.196) | (0.182) | (0.384) | (0.409) | (0.215) | (0.194) |
| N | 5619 | 5619 | 3057 | 3057 | 5242 | 5242 |

Cluster-robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

# Supplemental Material (intended for online publication)

**Table 12:** OLS results for sample of firms with procurement contracts

| | Turn. New Products (%) (1) | Turn. Market Novelties (%) (2) | Turn. Firm Novelties (%) (3) |
|---|---|---|---|
| PPCI | 8.754*** | 1.722 | 7.031*** |
| | (2.498) | (1.619) | (2.194) |
| Innovation Intensity | 0.453*** | 0.175* | 0.278*** |
| | (0.112) | (0.091) | (0.096) |
| Firm Size | 0.000 | -0.000 | 0.000 |
| | (0.001) | (0.000) | (0.000) |
| High-skilled Employees | 0.015 | 0.001 | 0.015 |
| | (0.033) | (0.015) | (0.033) |
| Knowledge Stock | -0.083 | 0.033 | -0.116* |
| | (0.120) | (0.071) | (0.068) |
| Cost Per Capita | -2.755 | -0.509 | -2.246 |
| | (4.183) | (1.714) | (3.518) |
| Export Share | 0.126*** | 0.069* | 0.058 |
| | (0.045) | (0.036) | (0.039) |
| Group | 2.983 | -0.130 | 3.114* |
| | (2.070) | (0.757) | (1.886) |
| Foreign Group | -11.182** | -1.273 | -9.909*** |
| | (4.450) | (2.314) | (3.617) |
| East German | 1.464 | 0.457 | 1.007 |
| | (1.350) | (0.697) | (1.223) |
| Constant | 0.598 | -0.183 | 0.781 |
| | (1.782) | (0.425) | (1.657) |
| Adjusted R2 | 0.322 | 0.159 | 0.203 |

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
N = 675. Industry dummies included.

**Table 13:** Covariate balance for nearest-neighbor matching in **Table 8** of the main paper

| Variable | Mean Treatment | Mean Control | Mean Difference | Std. Err. Difference | P-value Difference |
|---|---|---|---|---|---|
| Innovation Intensity | 0.670 | 0.350 | 0.320 | 0.202 | 0.115 |
| Firm Size | 0.245 | 0.003 | 0.241 | 0.251 | 0.338 |
| High-skilled Employees | 0.525 | 0.335 | 0.191 | 0.142 | 0.182 |
| Knowledge Stock | 0.362 | 0.028 | 0.334 | 0.253 | 0.187 |
| Cost Per Capita | -0.170 | -0.173 | 0.003 | 0.082 | 0.973 |
| Export Share | 0.437 | 0.399 | 0.038 | 0.179 | 0.833 |
| Group | 0.169 | 0.019 | 0.149 | 0.149 | 0.318 |
| Foreign Group | 0.169 | -0.003 | 0.172 | 0.168 | 0.309 |
| East German | -0.085 | -0.066 | -0.019 | 0.139 | 0.889 |
| Industry 1 | -0.042 | -0.042 | 0.000 | 0.114 | 1.000 |
| Industry 2 | -0.042 | -0.042 | 0.000 | 0.114 | 1.000 |
| Industry 3 | -0.145 | -0.145 | 0.000 | 0.000 | 1.000 |
| Industry 4 | 0.163 | 0.099 | 0.064 | 0.188 | 0.735 |
| Industry 5 | 0.049 | 0.049 | 0.000 | 0.179 | 1.000 |
| Industry 6 | -0.009 | -0.009 | 0.000 | 0.135 | 1.000 |
| Industry 7 | -0.070 | -0.070 | 0.000 | 0.119 | 1.000 |
| Industry 8 | 0.350 | 0.350 | 0.000 | 0.189 | 1.000 |
| Industry 9 | -0.093 | -0.018 | -0.075 | 0.126 | 0.554 |
| Industry 10 | 0.099 | 0.036 | 0.064 | 0.167 | 0.702 |
| Industry 11 | -0.121 | -0.121 | 0.000 | 0.094 | 1.000 |
| Industry 12 | -0.134 | -0.134 | 0.000 | 0.076 | 1.000 |
| Industry 13 | -0.202 | -0.202 | 0.000 | 0.060 | 1.000 |
| Industry 14 | -0.150 | -0.150 | 0.000 | 0.071 | 1.000 |
| Industry 15 | -0.062 | -0.062 | 0.000 | 0.118 | 1.000 |
| Industry 16 | -0.042 | -0.042 | 0.000 | 0.125 | 1.000 |
| Industry 17 | 0.302 | 0.302 | 0.000 | 0.192 | 1.000 |
| Industry 18 | -0.086 | -0.086 | 0.000 | 0.000 | 1.000 |
| Industry 19 | 0.175 | 0.175 | 0.000 | 0.190 | 1.000 |
| Industry 20 | 0.121 | 0.121 | 0.000 | 0.155 | 1.000 |
| Industry 21 | -0.163 | -0.163 | 0.000 | 0.092 | 1.000 |
| Industry 22 | -0.146 | -0.146 | 0.000 | 0.095 | 1.000 |

**Table 14:** Covariate balance for nearest-neighbor matching **Table 8** of the main paper when exact matching on R&D Grant is requested

| Variable | Mean Treatment | Mean Control | Mean Difference | Std. Err. Difference | P-value Difference |
|---|---|---|---|---|---|
| Innovation Intensity | 0.670 | 0.260 | 0.410 | 0.198 | 0.040 |
| Firm Size | 0.245 | -0.018 | 0.263 | 0.251 | 0.296 |
| High-skilled Employees | 0.525 | 0.392 | 0.134 | 0.145 | 0.359 |
| Knowledge Stock | 0.362 | -0.006 | 0.367 | 0.250 | 0.143 |
| Cost Per Capita | -0.170 | -0.139 | -0.031 | 0.084 | 0.709 |
| Export Share | 0.437 | 0.332 | 0.104 | 0.173 | 0.548 |
| Group | 0.169 | -0.006 | 0.174 | 0.148 | 0.240 |
| Foreign Group | 0.169 | 0.054 | 0.114 | 0.177 | 0.519 |
| East German | -0.085 | -0.046 | -0.039 | 0.139 | 0.780 |
| Industry 1 | -0.042 | -0.042 | 0.000 | 0.114 | 1.000 |
| Industry 2 | -0.042 | -0.042 | 0.000 | 0.114 | 1.000 |
| Industry 3 | -0.145 | -0.145 | 0.000 | 0.000 | 1.000 |
| Industry 4 | 0.163 | 0.099 | 0.064 | 0.188 | 0.735 |
| Industry 5 | 0.049 | 0.049 | 0.000 | 0.179 | 1.000 |
| Industry 6 | -0.009 | -0.009 | 0.000 | 0.135 | 1.000 |
| Industry 7 | -0.070 | -0.028 | -0.043 | 0.126 | 0.735 |
| Industry 8 | 0.350 | 0.350 | 0.000 | 0.189 | 1.000 |
| Industry 9 | -0.093 | -0.055 | -0.037 | 0.121 | 0.758 |
| Industry 10 | 0.099 | 0.036 | 0.064 | 0.167 | 0.702 |
| Industry 11 | -0.121 | -0.121 | 0.000 | 0.094 | 1.000 |
| Industry 12 | -0.134 | -0.134 | 0.000 | 0.076 | 1.000 |
| Industry 13 | -0.202 | -0.202 | 0.000 | 0.060 | 1.000 |
| Industry 14 | -0.150 | -0.150 | 0.000 | 0.071 | 1.000 |
| Industry 15 | -0.062 | -0.062 | 0.000 | 0.118 | 1.000 |
| Industry 16 | -0.042 | -0.042 | 0.000 | 0.125 | 1.000 |
| Industry 17 | 0.302 | 0.302 | 0.000 | 0.192 | 1.000 |
| Industry 18 | -0.086 | -0.086 | 0.000 | 0.000 | 1.000 |
| Industry 19 | 0.175 | 0.175 | 0.000 | 0.190 | 1.000 |
| Industry 20 | 0.121 | 0.121 | 0.000 | 0.155 | 1.000 |
| Industry 21 | -0.163 | -0.163 | 0.000 | 0.092 | 1.000 |
| Industry 22 | -0.146 | -0.146 | 0.000 | 0.095 | 1.000 |

**Table 15:** 5-nearest-neighbor matching results

| | Turn. New Products (%) (1) | Turn. Market Novelties (%) (2) | Turn. Firm Novelties (%) (3) |
|---|---|---|---|
| PPCI | 12.012*** | 3.038** | 8.973*** |
| | (2.595) | (1.421) | (2.386) |

Standard errors according to Abadie and Imbens (2006, 2011) in parentheses: * p < 0.1, ** p < 0.05, *** p < 0.01
Specification analogous to matching reported in the main paper (**Table 8**).

**Table 16:** IV regression results for sample of firms with procurement contracts

| | Turn. New Products (%) (1) | Turn. Market Novelties (%) (2) | Turn. Firm Novelties (%) (3) |
|---|---|---|---|
| PPCI | 8.719*** | 2.852 | 5.867** |
| | (2.997) | (2.318) | (2.597) |
| Innovation Intensity | 0.453*** | 0.169* | 0.284*** |
| | (0.111) | (0.093) | (0.095) |
| Firm Size | 0.000 | -0.000 | 0.000 |
| | (0.001) | (0.000) | (0.000) |
| High-skilled Employees | 0.015 | -0.001 | 0.017 |
| | (0.032) | (0.015) | (0.032) |
| Knowledge Stock | -0.083 | 0.026 | -0.109 |
| | (0.117) | (0.071) | (0.067) |
| Cost Per Capita | -2.762 | -0.278 | -2.483 |
| | (4.101) | (1.699) | (3.443) |
| Export Share | 0.126*** | 0.068* | 0.059 |
| | (0.044) | (0.036) | (0.038) |
| Group | 2.985 | -0.190 | 3.175* |
| | (2.019) | (0.738) | (1.834) |
| Foreign Group | -11.182** | -1.268 | -9.914*** |
| | (4.343) | (2.241) | (3.517) |
| East German | 1.463 | 0.494 | 0.969 |
| | (1.316) | (0.673) | (1.193) |
| Constant | 0.603 | -0.321 | 0.923 |
| | (1.747) | (0.465) | (1.589) |
| Adjusted $R^2$ | 0.322 | 0.157 | 0.202 |
| Cragg-Donald F Statistic | 35.783 | 35.783 | 35.783 |
| Hansen's J Statistic | 19.940 | 26.966 | 24.220 |
| P-value Hansen's J | 0.8948 | 0.5736 | 0.7180 |

Robust standard errors in parentheses: * p < 0.1, ** p < 0.05, *** p < 0.01
Instrumented: PPCI. N = 675. Industry dummies included.

**Table 17:** Pseudo-treatment test (pre-treatment period)

| | Turn. New Products<br>(1) | Turn. Market Novelties<br>(2) | Turn. Firm Novelties<br>(3) |
|---|---|---|---|
| Public Procurement (TED) | -0.789 | -0.955 | -0.770 |
| | (0.503) | (0.648) | (0.658) |
| Innovation Intensity | -0.008 | -0.005 | -0.016 |
| | (0.010) | (0.022) | (0.014) |
| Firm Size | 0.006*** | 0.006*** | 0.005** |
| | (0.001) | (0.001) | (0.002) |
| High-skilled Employees | -0.007 | 0.035* | -0.019 |
| | (0.013) | (0.021) | (0.016) |
| Cost Per Capita | 0.472 | 0.476 | 0.432 |
| | (0.450) | (1.813) | (0.454) |
| Export Share | 0.010 | -0.013 | 0.014 |
| | (0.009) | (0.023) | (0.011) |
| 2007 | -0.056 | 0.095 | -0.066 |
| | (0.130) | (0.233) | (0.154) |
| 2008 | 0.007 | -0.169 | 0.051 |
| | (0.164) | (0.289) | (0.174) |
| Treated × 2007 | 0.089 | 0.088 | 0.137 |
| | (0.422) | (0.398) | (0.566) |
| Treated × 2008 | -0.211 | -0.383 | -0.312 |
| | (0.462) | (0.383) | (0.638) |
| N | 747 | 399 | 671 |
| F test on joint significance of *Treated × (2007 and 2008)* (p-value) | 0.499 | 0.448 | 0.352 |

Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$