// NO.23-002 | 01/2023

DISCUSSION PAPER

// OLGA CHIAPPINELLI, LEONARDO M. GIUFFRIDA, AND GIANCARLO SPAGNOLO

Public Procurement as an Innovation Policy: Where Do We Stand?

Public procurement as an innovation policy: Where do we stand?*

Olga Chiappinelli Leonardo M. Giuffrida Giancarlo Spagnolo

January 25, 2023

Abstract

Economics and innovation scholars have long recognized the potential of public procurement to trigger innovation. To what extent has this potential been realized so far? What can be done to improve the performance of PPI in this regard? This paper addresses these issues by providing a literature survey of research on public procurement of innovation (PPI). After categorizing PPI instruments, the paper discusses existing interdisciplinary knowledge to answer four broad questions: i) Does PPI spur innovation? ii) How should PPI be designed to best spur innovation? iii) What are the main barriers to implement PPI? iv) What is the role of PPI in the innovation policy mix? The paper concludes with a discussion of future research needs and policy insights in light of current global challenges.

JEL codes: H23, H57, O30, O31, O32, O35, O36, O38.

Keywords: innovation; public procurement; public policy; R&D; green purchases.

1 Introduction

Market economies tend to underprovide innovation mainly because private firms face financial frictions and do not internalize the social benefits of their innovative efforts. As a result, innovators underinvest in research and development (R&D), primarily early-stage (Nelson 1959; Arrow 1962; Loury 1979; Reinganum 1985). Considering the crucial role that innovation plays in fostering productivity, competitiveness, and, ultimately, economic growth (Romer 1990; Grossman and Helpman 1991; Aghion and Howitt 1997; Moretti et al. 2019), public intervention is needed to address such market failure and strengthen firms' incentives to innovate (Arrow 1962). In addition, in order to ensure

*Olga Chiappinelli: University of Barcelona; email: olga.chiappinelli@ub.edu. Leonardo M. Giuffrida: ZEW Mannheim, MaCCI, and CESifo; email: leonardo.giuffrida@zew.de. Giancarlo Spagnolo: University of Rome Tor Vergata, EIEF, and CEPR; email: spagnologianca@gmail.com. We acknowledge financial support from the Italian Ministry of Education Grant no. 2017Y5PJ43 001 PRIN 2017. The authors would like to thank Bastian Krieger and Vera Zipperer for their helpful comments and suggestions. The usual disclaimers apply.

intellectual property rights and promote supply-side policies such as R&D tax credits and direct subsidies for private R&D initiatives (Nemet 2009; Costantini et al. 2015), governments can exploit their extensive purchasing power and procurement decisions to directly promote new ventures and spur innovation.

By demanding innovation to satisfy public needs, public procurement can create lead markets for innovative goods and services at a scale that makes the R&D investments worthwhile for the suppliers. In addition, acting as an early user of the innovation, the government can assume the risks associated with deploying new and unproven technologies.[1] The lessons that thus accrue to innovators can not only de-risk investment ex-ante but also help to accelerate the market diffusion of innovation ex-post. Innovation scholars have long recognized the potential for innovation to be encouraged by demand-side measures in general and public procurement of innovation (henceforth PPI) in particular (see, e.g., Edquist and Hommen 1999, Edler and Georghiou 2007, Edquist and Zabala-Iturriagagoitia 2012, Lember et al. 2014, Edquist et al. 2015, Uyarra 2016, Edler 2016). Furthermore, policymakers are also increasingly acknowledging PPI as a crucial innovation policy tool.

To what extent has this potential been realized? What is the evidence for PPI as an effective trigger of innovation, and what can be done to improve its performance in this regard? In short: where do we stand on public procurement as an innovation policy? This paper aims to answer these questions by providing an updated survey of the literature on PPI research. Conducting such a survey would appear relevant and timely given the multiple and interlocking challenges currently facing the global community—including climate change, war, and pandemics— and the resulting need to protect the environment as well as secure the supply of vital commodities. These challenges highlight the need for government intervention in innovation, and make "mission-oriented" public procurement (Geroski 1990; Maurer and Scotchmer 2004; Scotchmer 2004) arguably more relevant than ever before (Mazzucato 2011).

The review focuses on four overarching questions. First, what is the evidence for PPI as a trigger of innovation, and under what circumstance is it effective? Second, what can be done to improve its performance? Third, what are the main barriers to implementation? Fourth, what is the role of PPI in the innovation policy mix—i.e., when is procurement "more effective" than other instruments in triggering innovation, and why?

Our work aims to fill some of the gaps left by existing surveys. First, recent surveys on the economics of innovation and innovation policies largely ignore the role of public procurement. Bloom et al. (2019) and Bryan and Williams (2021) discuss evidence on instruments such as tax incentives, intellectual property rights, competition and labor market policies, and research grants. However, they only consider (in a tangential manner) procurement programs that are similar to grants (such as the US Small Business Innovation Research Program). The only two surveys we are aware of on the economics

[1] Moving innovations from market readiness to full commercial scale can be particularly challenging due to a combination of technical and market risks, and lack of funding—sometime referred to as the "valley of death" (see, e.g., Nemet et al. 2018).

of PPI are Iossa et al. (2018) and Cabral et al. (2006); however, these studies are limited in scope and have different aims. Primarily based on lessons from contract theory, Iossa et al. (2018) focuses on a particular design question—namely, whether the R&D and commercialization phases of PPI should be bundled or not—to assess PPI instruments adopted within the European Union (EU). Cabral et al. (2006) consider additional issues—e.g., on the design of research contests and standards—relying on lessons from contest and innovation theory to provide practical recommendations on PPI implementation. Neither of the two surveys provides a discussion of the empirical literature on the performance of PPI as a trigger for innovation—i.e., to what extent the potential of PPI, as highlighted by the innovation policy literature, has actually been realized. Third, while there are several surveys on PPI from an innovation research perspective (e.g., the works by Elder, Edquist, Kattel, and co-authors mentioned above), a comprehensive study that combines insights from innovation and economics is currently missing.

We aim to take a step toward filling these gaps by providing an updated review of economics and innovation papers that consider PPI performance as well as measures to improve it. We consider a broad overview of contributions related to direct effectiveness, contest design, and the role of public buyers and PPI in the policy mix. We also extend the coverage of PPI instruments chronologically (to include some novel instruments, such as contracts for difference and advance purchases as well as geographically (to include instruments outside the EU, e.g., in the US). Finally, we discuss these lessons while considering current global challenges, including climate change and pandemics.

The rest of the paper is organized as follows. Section 2 proposes a working definition of PPI and categorizes its instruments. Section 3 reviews the literature on existing evidence of PPI performance. Section 4 reviews the literature on the optimal design of PPI, while Section 5 discusses the barriers to implementation with a particular focus on the role of public buyer capabilities. Section 6 discusses the role of PPI in the broader policy mix for innovation. Section 7 concludes with a summary of takeaways from the literature as well as a discussion of open research questions and policy implications for current global challenges.

2 Background: what is PPI?

Innovation policies can be broadly classified into supply-side (or "technology-push") and demand-side (or "demand-pull"). On the one hand, supply-side policies seek to trigger innovation by providing ex-ante financial support for R&D investment, thereby reducing the cost of the *input* of innovation. Prominent examples of supply-side instruments are government-sponsored R&D grants, tax credits for companies to invest in R&D, basic-research funding to higher-education institutes, and training programs. On the other hand, demand-side policies aim to foster innovation by creating demand and markets for the *output* of innovation, thereby increasing the payoffs for successful innovations. Key examples of demand-side instruments are intellectual property rights, tax credits for new-technology consumers, technology mandates, regulatory standards, taxes on competing technologies, and, notably, PPI.[2] This section provides a working definition of PPI and its phases as well as a categorization and brief characterization of its instruments.

2.1 Definitions

PPI Following Edquist and Hommen (2000), we define PPI as the process by which "[...] a public agency purchases, or places an order for a product—service, good, or system—that does not yet exist, but which could probably be developed within a reasonable period of time as a result of additional or new innovative work by the organization(s) willing to produce, supply and sell the products being purchased". Notice that while sharing some similarities with government-sponsored R&D grants, PPI typically displays a higher degree of conditionality of the funding, in the sense that the government maintains decision rights on which projects to finance, thereby guiding technological development and limiting the spectrum of innovative activities pursued by suppliers (see, e.g., De Chiara and Iossa 2019).

Innovation Phases and R&D Stages An innovation-oriented process can be subdivided into two consecutive phases: R&D and commercialization. The former phase includes activities to introduce new products and services: an innovative solution is explored, and a prototype is tested. Following the definition of the US Federal Acquisition Regulation (FAR) §35.001, the R&D phase contains the following stages:

1. *Basic Research*: includes all scientific endeavors and experiments aimed at expanding the body of knowledge. Its goal is to set the ground for subsequent applied research.

2. *Applied Research*: includes efforts directed toward solving specific problems that emerged during basic research before the implementation of a development project.

3. *Development*: includes all advanced, engineering, or operational efforts directed at developing concepts and/or prototypes before the eventual commercialization phase.

The commercialization phase encompasses all the steps required to introduce to the market prototypes and successful deliverables from the R&D phase.

2.2 PPI Instruments

Various procurement instruments are available for procuring R&D services or innovative solutions. Unlike standard procurement, where the only relevant activity is production, in innovative procurement, the production phase (i.e., commercialization) is preceded by an R&D phase. Therefore, while PPI instruments may be categorized in several ways,

[2] We refer the reader to Costantini et al. (2015) and Nemet (2009) for further discussion and categorization of innovation instruments into push and pull policies.

one method that is particularly useful for the purpose of this paper is to subdivide instruments in terms of whether they cover just one phase—R&D or commercialization—or both. In the former case, the two phases of the innovation process are *unbundled*, while in the latter case, they are *bundled*. Iossa et al. (2018) provide this type of categorization for the PPI instruments adopted in the EU. In what follows, we extend this categorization to include PPI instruments from other contexts, particularly from the US, and also incorporate PPI instruments that were recently introduced. Below is a brief characterization of each instrument.

2.2.1 Instruments with unbundled R&D and commercialization phases

We start with unbundled instruments that only cover the R&D phase.

Pre-Commercial Procurement (PCP) PCP is an EU instrument for procuring R&D in situations in which an agency's need cannot be readily satisfied by existing market solutions. It is characterized by a competitive step-wise R&D contest, where multiple suppliers develop in parallel alternative solutions, compete, and are shortlisted sequentially on economic and technical grounds along the R&D process stages. In contrast to R&D procurement (see below), where single sourcing is the norm, PCP envisages multiple sourcing, meaning at least two suppliers should reach the final step and be awarded a PCP contract to maintain competitive pressure until the end of the R&D process and thus avoid *lock-in* (i.e., customer dependence on one vendor) in the subsequent commercialization phase. An additional characteristic of PCP is that risks and benefits are shared between the procurer and contractor(s). See Edquist and Zabala-Iturriagagoitia (2015) and Iossa et al. (2018) for more details.

R&D procurement (RDP) RDP is the leading category of unbundled PPI instruments adopted in the US for federal acquisitions. Like other PPI instruments, most RDP contracts are directed toward objectives when the work or methods cannot be precisely described in advance. Unlike other PPI tools, it envisages a different contest and contract for each R&D stage of a procurement process. In other words, the output of RDP is a contract between one buyer and one seller to conduct R&D on a specific innovation at a specific stage. Moreover, unlike other PPI instruments but like the other federal procurement contracts, the contract-pricing type is defined ex ante.[3] Similar to a RDP, a cooperative agreement is a category of grant that involves a higher degree of decision-making authority on the part of the federal agency (FAR §35.003) relative to

[3]Two types of contracts commonly used in the US are fixed-price and cost-plus contracts. In fixed-price contracts, the buyer offers the seller a predetermined price to complete the project. In a cost-plus contract, no price is set, but the contractor is reimbursed for the cost plus a markup. Because of the sizeable ex-ante project uncertainty, the more flexible cost-plus contracts are generally preferred for the procurement of R&D. Approximately 80 percent of R&D contracts over $1 million awarded yearly by federal agencies are cost-plus contracts (source: `usaspending.gov`). In between are the various incentive contracts in which the contractor's responsibility for the performance costs and the profit or fee incentives offered are tailored to the uncertainties involved in contract implementation.

standard grants, where typically the agency retains virtually no decision rights. This paper treats cooperative agreements as a hybrid instrument between grants and PPI. See Bruce et al. (2019), de Rassenfosse et al. (2019), and Decarolis et al. (2021) for more details on RDP and cooperative agreements.

Moving to the next PPI category, the following unbundled instruments only cover the commercialization phase.

Procurement of Innovative Solutions (PIS) PIS is an EU procurement process where the contracting authority acts as a lead buyer or early adopter for innovative products that are not yet available on a large-scale commercial basis. As PIS does not include the procurement of R&D services, the latter needs to have been already covered by some other instrument. In this light, PIS and PCP can be seen as complementary. For example, following a successful PCP that has led to the development of a suitable prototype for an innovative solution, the procurer may decide to run a PIS to procure the production of the solution on a large scale. Note that as the R&D and commercial phases are unbundled, the companies awarded with the PCP have no guarantee of also winning a follow-up contract in the PIS. This separation allows companies that have developed innovative solutions outside the PCP framework (e.g., thanks to R&D grants, equity funding, venture capital) to participate in PIS contests on a level playing field with the PCP solution developer. See Iossa et al. (2018) for more details.

Advance Purchases This instrument has been used to procure new vaccines. Through advance purchases (such as Advance Market Commitments or Advance Purchase Agreements), governments commit to buying a given volume of doses of effective vaccines at a fixed unit price for doses produced within a specified time frame. By doing so, the buyer finances part of the upfront costs for vaccine R&D and manufacturing—thereby partially de-risking the investments. In exchange, it gets a binding commitment from the companies to build the manufacturing capacity and produce the vaccine before market authorization. This set of instruments aims to ensure that a specific volume of doses can be delivered as soon as the vaccine is authorized. See Snyder et al. (2020) for more details.

Contracts for Difference While Contracts for Difference are not necessarily an explicit form of PPI, they can trigger innovation by hedging investors against risk. These contracts have recently been employed to reduce the regulatory uncertainty that has been a considerable barrier to investment in low-carbon technologies. For example, Carbon Contracts for Difference are being introduced in various EU countries to "buy" non-emitted CO2 emissions in industrial sectors.[4] These contracts, involving a public agency and a company investing in low-carbon industrial technology, are based on an agreed strike price for emission reductions relative to the sector benchmark to guarantee

[4]These contracts are already in place in the Netherlands and about to be introduced in Germany. The introduction of EU-wide Carbon Contracts for Difference is also under discussion.

investors a fixed revenue per ton of non-emitted CO2.[5] Carbon Contracts for Difference can therefore limit uncertainty regarding future carbon price levels, thereby facilitating investment in technologies for industrial decarbonization (see, e.g., Richstein and Neuhoff 2022). Similarly, publicly auctioned renewable Contracts for Difference or publicly backed Power Purchase Agreements are being used in various countries, including the United Kingdom and Spain, to purchase production of electricity from renewable sources. They are conceived to reduce regulatory uncertainties in electricity markets with high supply and price volatility. Therefore, they allow project developers to secure low-cost financing, thus reducing power generation costs and accelerating investments in renewables such as wind and solar (Neuhoff et al. 2018; Fabra et al. 2020).

2.2.2 Instruments with bundled R&D and commercialization phases

Other PPI instruments are bundled as they envisage a single procurement process covering both the R&D and commercialization phases.

Innovation Partnership (IP) IP is the main bundled PPI instrument in the EU. The rationale of the follow-on contract that is foreseen under this scheme is to incentivize suppliers to engage in an effort level that is valuable to the buyer throughout the sequential innovation phases. Similar to PCP, it is structured in competitive stages with the sequential shortlisting of suppliers. The final stage is no longer the development of the solution but the commercialization of the manufactured product or the provided service. The instrument leaves flexibility to the buyer concerning how risks and benefits are shared among parties and whether there should be single or multiple sourcing. See Iossa et al. (2018) for more details.

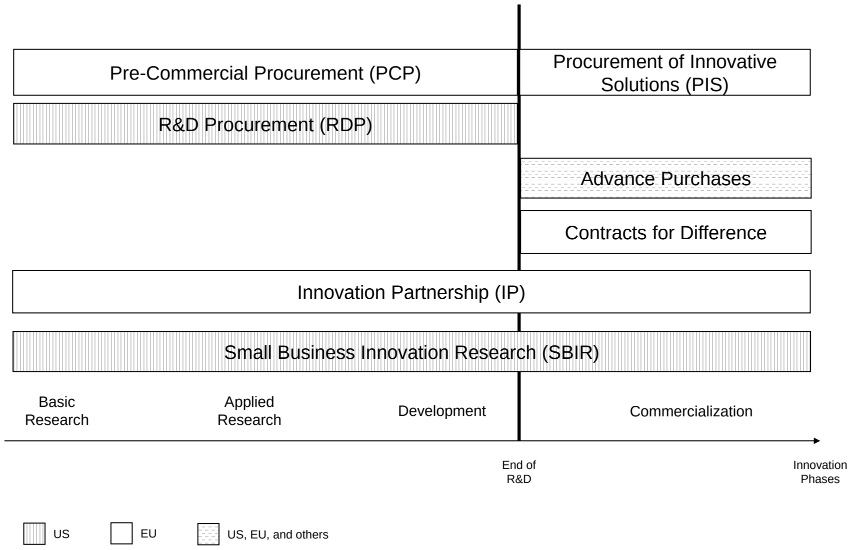
Small Business Innovation Research (SBIR) One prominent example of bundled PPI instruments in the US context is the SBIR program, a multistage contest designed to support innovative small businesses. It is among the world's largest and most influential government programs to spur innovation among small businesses, amounting to approximately $3 billion across 11 federal agencies in 2018 (Howell et al. 2021). Similar to the IP, the program is structured in a competitive step-wise contest with shortlisting.[6] See Bhattacharya (2021) for more details.[7]

[5] As long as the CO2 price (e.g., the EU Emission Trading System) is below the strike price, the difference between the strike price and the market price is reimbursed. Investors must return additional earnings if the CO2 price exceeds the strike price to avoid windfall profits.

[6] Another US federal program that aims to provide seed money to move small business scientific innovations from research to practice is the Small Business Technology Transfer (STTR). In this paper, we consider STTR contracts as SBIR contracts, as in the papers we survey. Indeed, the main difference between the two programs is mostly whether partnerships with a non-profit research institution are allowed (SBIR) or required (STTR).

[7] Other examples of bundled PPI instruments include the UK's Small Business Research Initiative and the European Commission's EIC Accelerator Pilot. Selviaridis (2020) provides a qualitative study of the former instrument based on interviews with local practitioners. We are not aware of any academic investigation of the latter instrument.

Figure 1: PPI Instruments



Notes: PPI instruments are categorized depending on the bundled or unbundled nature of the innovation phases and the geography of their adoption.

Figure 1 provides a visual summary of our categorization of PPI instruments.

3 Does PPI Spur Innovation?

Publicly funded R&D other than PPI has been shown to have positive spillovers on the economy (Fleming et al. 2019), thus mitigating concerns related to the crowding-out effects that may result from government support for innovation. Recent causal evidence on R&D grants (Santoleri et al. 2022) and R&D tax credits (Dechezleprêtre et al. 2016) furnish robust empirical evidence that government technology-push policies can encourage innovative private-sector investment.[8] Promoting private innovation activities directly or indirectly is also the ultimate goal of PPI interventions.

This section focuses on how PPI impacts the innovative performance of firms. Specifically, we examine to what extent public procurement contracts encourage firm innovation. A firm-level focus is relevant, as innovation outputs are merely an intermediate step toward the ultimate objectives of better company performance, as measured in terms of job creation (Link and Scott 2012) or productivity growth (Haskel and Wallis 2013; Moretti et al. 2019). Moreover, some studies suggest that public funding of innovation

[8]There is a rich body of research on the effect of public supply-side instruments on private-sector innovation. For instance, Azoulay et al. (2019) study the effect of US National Institute of Health grants on publications and patenting; Bronzini and Iachini (2014) focus on the effect of R&D subsidies on capital investment by Italian firms.

differs from private sources in how it impacts the behavior of recipient firms (Clarysse et al. 2009; Gök and Edler 2012). In the following, we report empirical findings from Europe and US on the direct effect of PPI as an innovation policy tool at the micro level, and we dedicate a separate subsection to green innovation. We also include a summary of the sparse theory and evidence on spillover effects. Evidence on the impact of PPI in combination and/or comparison with other policy instruments is discussed in Section 6.

3.1 Evidence from Europe

The EU has recognized the importance of procurement as a tool for promoting innovation since the early 2000s (Wilkinson et al. 2005). In 2014 the EU passed revised procurement directives aimed at facilitating the acquisition of innovations via different PPI tools. In contrast with the traditional call for tenders, which left little room for innovative solutions, the newly introduced approach specified procurement needs in terms of functional requirements, took life-cycle cost considerations into account while assessing cost-effectiveness, and defined factors related to innovation as award criteria. In this way, it created the necessary preconditions for suppliers to be successful with innovative solutions at the tender stage.[9]

Germany was a forerunner in implementing the revised framework in 2009, allowing government agencies to specify innovative aspects of procured products as selection criteria in calls for tender. Using Germany as a laboratory, Czarnitzki et al. (2020) combine survey and contract data to study the introduction of this reform on firm innovative performance. To our knowledge, the paper is the first to evaluate PPI reform. The authors find a robust (yet small) effect of PPI awards on firm innovation performance. Standard procurement tenders, by contrast, show no detectable relationship with innovation success.

Based on survey data from Eastern European countries, Stojčić et al. (2020) shows that PPI positively affects innovation and output, and the highest additionality is achieved when firms receive both PPI contracts and other sources of financial support. A major takeaway from this paper is that PPI may be especially valuable for firm innovation outcomes in catching-up economies.[10] In both Czarnitzki et al. (2020) and Stojčić et al. (2020), the induced innovations are found to be more of an incremental nature rather than radical, thus indicating that PPI is more effective in stimulating technology diffusion rather than breakthrough innovation.

Recently, Castelnovo et al. (2023) combine 15 years of PPI contract data from the Italian Space Agency with records of patent applications from contract recipients. The authors identify a positive impact of PPI contracts on the innovation activity of companies in the upstream space industry. Importantly, this work highlights a long-term effect of the innovation boost, which persists for several years after contract award.

[9] See 2014/24/EU, par. 74.

[10] Also, effectiveness might not be limited to democratic contexts. Recently, Beraja et al. (2021) find causal evidence that PPI stimulates firm innovation in China. Contracted firms developing AI-based facial recognition technology subsequently innovated more both for the government and commercial markets.

3.2 Evidence from the US

In the US, PPI instruments (e.g., RDP and SBIR) account for about one-third of the $130 billion annual federal R&D budget (de Rassenfosse et al. 2019)—with the remainder distributed among grants and in-house research (Bruce and de Figueiredo 2020). US federal procurement has been critical to developing some of the most influential technologies of the the 20th and 21st centuries, including personal computers, the internet, and GPS systems (Scotchmer 2004; Ruttan 2006; Cabral et al. 2006). Also, Cozzi and Impullitti (2008) point out that the US government's shift in procurement decisions in favor of high-tech sectors was one of the critical determinants of the wave of innovation that swept the US economy in the 1980s and 1990s.

The research that pertains to the US focuses almost exclusively on the SBIR program.[11] The earliest studies focus on the long-term effects of SBIR on small business performance (Lerner 2000; Wallsten 2000). The first assessment of innovation outcomes dates back to Howell (2017). The author, focusing on the SBIR contests from the Department of Energy, shows that an SBIR award approximately doubles the probability of a firm receiving subsequent venture capital and has large, positive impacts on patenting and revenue.[12] These effects are stronger for more financially constrained firms. The certification level—i.e., the extent to which the selection takes into account information about firm quality—does not explain the effect of the award. Instead, the awards are beneficial because they reduce technology uncertainty.

More recently, Howell et al. (2021) examined the implementation of the SBIR program by the Department of Defense (DoD), which places significant emphasis on acquiring specific technologies. The SBIR is inherently suitable for defense procurement, which typically involves contracting for both R&D and delivery (Rogerson 1989). The DoD often considers multiple prototypes before narrowing down the competition and selecting a supplier for delivery (Anton and Yao 1989; Lyon 2006). Specifically, Howell et al. (2021) study the reform of the SBIR adopted by the US Air Force, which invited firms to propose innovative potentially useful technologies with a bottom-up approach. Such "Open Program" was run simultaneously with the traditional top-down approach in RDP (i.e., the "Conventional Program"), allowing for a meaningful comparison. The success of the Open Program is attributed to its bottom-up character: Firms were given a chance to present technological opportunities not previously known to the Air Force. The paper documents that firms benefited from winning an Open award in terms of venture capital funding and patenting, while no such benefits resulted from the Conventional program, which was instead found to foster incumbency and lock-in effects. Consistent with Howell (2017), the effect on venture capital is driven by entrants, both in the sense of young firms and those without previous SBIR awards.

[11] A recent exception is Clemens and Rogers (2020), who analyze patents linked to wartime public procurement of prosthetic devices. The authors conclude that the payment models significantly shaped the incentives faced by contractors, including the choice to innovate on quality and cost.

[12] Patents are often used as an indicator of invention rate, which in turn is a crucial precursor to innovation, in particular commercial innovation (Roberts 1988).

3.3 Green procurement and green innovation

The empirical literature highlights demand as one of the main drivers of environmental innovations (e.g., Horbach et al. 2012; Kesidou and Demirel 2012; Veugelers 2012; Ghisetti 2017; Costantini et al. 2015, 2017). A set of studies focus specifically on green public procurement (GPP) as a strong stimulus for the development of new eco-innovations. In particular, Ghisetti (2017) studies the role of PPI in driving the adoption and diffusion of sustainable manufacturing technologies. Based on firm-level data in the 28 Member States of the EU plus Switzerland and the US, the study finds that winning GPP contracts increases a firm's probability of introducing more environmentally friendly products, thus furnishing a first evidence that PPI plays a crucial role in the uptake of innovative environmental technologies. Orsatti et al. (2020) provide additional quantitative evidence of GPP on environmental innovation. They find a positive relationship between GPP spending and green patent activity at the US Commuting Zone level.

In more recent work, Krieger and Zipperer (2022) provide the first empirical micro-evidence of the effect of GPP on firm performance in producing environmental innovations. Unlike Ghisetti (2017), they do not assume but rather explicitly test the hypothesis that GPP creates a demand pull for eco-innovations. Combining firm-level survey and procurement data and employing cross-sectional difference-in-difference methods, the authors investigate the effect of winning GPP contracts on firms' probability of introducing novel and more environmentally friendly products, processes, and innovations. They find a positive effect, driven by small firms, and a nonsignificant effect for larger firms, thus indicating that GPP triggers a demand-pull effect for small firms only. This finding is consistent with the idea that firms generally subject to greater financial constraints are more likely to respond to innovation policies (Dechezleprêtre et al. 2016; Santoleri et al. 2022).

A theoretical framework on GPP and innovation is formalized by Rainville (2021). The paper focuses on the relevance of standards in green tenders and the differential impact of standard versus innovative procurement on the creation of incremental innovations, radical innovations, and their diffusion. The model predicts the relevance of GPP as a policy lever to achieve a decarbonized growth path and validate the previous findings of Testa et al. (2011), who provide an empirical analysis of the construction sector across various EU countries. The authors find that the effectiveness of GPP policies is strongly related to investment in technological innovation and that stringent environmental regulations produce meaningful incentives to innovate.

3.4 Spillovers

We conclude this section with a discussion of the recent yet sparse literature on PPI spillover effects. Understanding the impact of PPI spillovers is relevant because, if PPI has an effect on technologically close peer firms, this could imply significant underinvestment in R&D.[13] This literature reports cross-country and, notably, within-country spillovers. Evidence on cross-country spillover is limited to Moretti et al. (2019), who find positive international spillovers from US government RDP spending: increases in government-funded R&D in a particular industry and country raise private R&D in the same industry in other countries.

Evidence on within-country spillovers is relatively more abundant, pointing overall to positive effects (i.e., crowding-in), and is backed by theoretical predictions. Slavtchev and Wiederhold (2016) present a theoretical model formalizing that a shift in the composition of public purchases toward high-tech products translates into higher economy-wide returns to innovation, leading to an increase in the aggregate level of private R&D. They also present empirical results disclosing robustly that an increase in the technological content of US government procurement induces additional private R&D in the economy. The technological intensity of public procurement is constructed as the share of federal procurement in high-tech industries performed in a given state over total federal procurement in the same state, considering only non-R&D procurement contracts awarded to private-sector firms. Moretti et al. (2019) reports that government-funded R&D targeted to industry results in significant increases in private sector R&D in that industry. No innovation effect from domestic push policies abroad is detected, yet substantive innovation spillovers from domestic pull policies exist. Supranationally coordinated demand-pull policies are required to address the spillovers. Lastly, Veugelers (2012) use survey data on Belgian firm motives for introducing clean innovations. Policy interventions are shown to induce the adoption and development of new clean technologies by firms. Furthermore, such interventions are more impactful when they are part of a broader policy mix and designed to be time-consistent, such that firms have a reliable basis for planning.

4 How Should PPI Be Designed to Best Spur Innovation?

The previous section reviewed the empirical, mostly micro, evidence on the degree to which PPI successfully encourages innovation, surveying existing PPI approaches and their positive spillovers. This section, by contrast, has a normative purpose. In summarizing the relevant state of the art, we aim to shed light on *how* PPI practices should be designed in order to improve the performance of PPI as an innovation lever. We discuss various design dimensions and the trade-offs they entail. We conclude the section with a specific focus on the design of new-vaccines procurement.

4.1 The complexity of PPI design

There are several layers of complexity that PPI adds to standard procurement and that need to be considered in the interest of efficient policy design. First, in contrast to standard procurement, where the only relevant activity is production, and sole regulatory

[13] For instance, in the context of R&D grants, sectoral spillovers are channeled in the form of higher rates of entry into entrepreneurship (Santoleri et al. 2022).

focus is cost efficiency and rent extraction, in innovative procurement, an R&D phase precedes the production phase (i.e., commercialization). Therefore, the procurement process should also aim at creating incentives for the company to exert innovative effort, and this objective may, to some extent, conflict with the goal of efficiency. Second, the difficulty associated with observing and verifying innovation efforts gives rise to information asymmetries between buyer and seller in PPI, adding to the standard informational asymmetries related to production costs. Third, the fact that the innovation might have value for the buyer only—posing a risk that the seller may be (partially) expropriated of the surplus it generates through R&D—creates a "hold-up problem", which further influences the provision of innovative efforts. Combined with uncertainties inherent to innovation, these issues shape PPI as a multi-faceted incentive problem. This complexity requires contracts and procedures to be designed in a manner that provides suppliers with the right incentives to meet the objectives of innovation performance and efficiency. Several design dimensions are relevant in this context. Accordingly, in what follows we review the (mostly theoretical) literature analyzing these different aspects of PPI design.

Bundling versus unbundling The incentives of innovation suppliers can be affected by the bundled (or unbundled) format of the design (see Section 2.2). The investigation of this problem started in the context of military and defense procurement, where bundling is recurrent. Rogerson (1989) finds that since innovation quality is difficult to describe or measure objectively, regulatory instruments should be designed to create incentives for successful innovation in the form of positive profits on the production contract.[14] These results provide a rationale for why defense procurement is typically bundled with sole-source production.[15] In follow-up work, Rogerson (1994) further argues that designing contracts on a multi-year basis can not only improve the provision of innovative effort by addressing the hold-up problem but also boost incentives for cost efficiency because it expands the regulatory lag, therefore increasing the incentive for firms to reduce costs.

Che et al. (2021) provide an overarching analysis of the appropriateness of the bundled-versus-unbundled setup problem. The authors show that, in case of exclusive development (i.e., when the innovation is valuable only to the buyer), if research efforts are (at least in part) unverifiable and implementation costs are contractors' private information, a public buyer should commit to accord preferential treatment to the proposer of a highly innovative solution. Such preferential treatment takes the form of a follow-on contract for the implementation of the proposed solution (e.g., supply of commercial products) that bundles with the previous stage, provided that it is sufficiently valuable for the public buyer. To fulfill its incentive purpose, the value of the follow-on

[14]Another issue studied by this early literature is the trade-off between quantity and quality in defense procurement, motivated by the observation that often in defense procurement decisions there is a tendency to purchase an excessive number of high-quality weapons (see, e.g., Rogerson 1995, Feinerman and Lipow 2001). McKean (1964) was the first to document the defense's apparent bias toward "too much quality" in a long series of examples.

[15]For example, in the approach of the US DoD, while competition among different designs in the R&D phase is allowed—and two design approaches through to the development stage are funded—the production is sourced from a single firm.

contract should increase with the value of the proposed solution for the buyer.

Therefore, the logic behind bundled approaches is in accordance with economic principles on the optimal procurement mechanism to incentivize innovation. However, the practical implementation of a bundled approach may not abide by these principles, resulting in inefficiencies. The most promiment risk is an excessively high follow-on contract value for incentive purposes, given innovations that are not sufficiently valuable for the buyer or already available in the market, or without proper competition amongst potential suppliers. While the risk of distortions to competition may also arise under unbundled procedures, the peculiarity of the bundling, which lies in the possibility of awarding a follow-on contract to the supplier of R&D services, exposes this procedure to the greatest risk. This can occur as the amount of uncertainty at the tendering stage regarding production—and the accompanying amount of discretion in selecting contractors—may impede the establishment of a price that could be considered a 'market price' (Arrowsmith 2010). As a result, the contracting authority may be paying too much for the commercialized product, service, or works, and there may be a market foreclosure of entrants that are unable to sell to the contracting authority but that are locked into the follow-on contract.

Acknowledging these issues, Iossa et al. (2018) concludes that the benefit of bundling is more likely to outweigh its costs when i) there are significant economies of scope between the two phases to be realized; ii) the innovation is public-sector specific, i.e., highly valuable for the public buyer but without significant demand from the private sector; iii) there is no significant risk of market foreclosure and supplier lock-in; iv) there are strong institutional incentives within the procurer organization—so that low-value projects are not continued; v) project value is observable and measurable ex-post (i.e., informational asymmetries are low).

Decision rights allocation Another mechanism that can be harnessed to trigger innovative efforts from suppliers is to allocate decision rights between the buyer and seller. Contract theory predicts that in the case of non-contractible quality or effort, a higher degree of involvement for the government (or higher degree of public retention of decision rights) performs better, but this requires government personnel to have adequate expertise and incentives (Hart et al. 1997; Williamson 1999). Bruce et al. (2019) find evidence supporting these predictions applied to the procurement of innovation: cooperative agreements are more likely to perform better in terms of innovative output relative to standard grants. This applies more to early-stage projects—where uncertainty is higher—than to later-stage projects and when government personnel has adequate expertise.

Award criteria Economic literature suggests that for triggering innovation from suppliers, the procurer should base the requirements and award criteria on functionalities that the contractor must provide, allowing for flexibility in the technology used to implement them (see, e.g., Cabral et al. 2006, Edquist and Zabala-Iturriagagoitia 2020). Fabra et al. (2020) formally analyze this question, investigating whether the procurement auction should be technology-specific or, rather, technology-neutral, given the objective of procuring low-carbon technologies (e.g., renewable energy systems or electricity-based steel production) at the lowest possible cost. They find that the optimal mechanism is not "one size fits all", but they solve the cost-efficiency/rent-extraction trade-off: whenever cost-minimization is more important—e.g., when cost uncertainty is high—technology neutrality should be favored, as allowing intra-technology competition in the same auction permits quantities to adjust to cost-shocks but at the cost of leaving high rents with the more efficient producers. On the other hand, technology specificity, which reduces the rents at the cost of efficiency losses, should be preferred when rent extraction is the main concern—e.g., when technologies are very asymmetric. The choice also depends on the degree of substitutability across technologies, as this can distort the technology allocation under technology neutrality but not under technology specificity. Therefore, a low degree of substitutability further favors the technology-specific approach.

Award procedure The design choice also involves the award procedure format—e.g., whether the contract should be awarded via an auction or via negotiation. An important consideration that drives this choice is the extent and nature of information asymmetries between the contracting parties. Bajari and Tadelis (2001) were the first in the procurement literature to predict that buyers of complex projects may have difficulty specifying all possible contingencies ex ante (i.e., at the contract award stage), which can lead to costly ex-post adaptations at the contract execution stage. Subsequent empirical evidence has corroborated these results. Auctions have been shown to perform best for the award of standardized and well-defined products when the priority is to trigger price competition. On the other hand, negotiations are superior for technically, legally, and financially complex projects for which the ex-ante description is potentially incomplete, and, as a result, the priority is to reduce the risk of costly ex-post renegotiations (Bajari et al. 2008, 2014). This reasoning could therefore apply to the procurement of complex decarbonization technologies, for example, via Carbon Contracts for Difference, where the object of the contract is to reduce emissions through innovative (and therefore non-standard) low-carbon technologies, and there is ex-ante uncertainty on the ex-post performance of the new technology.

Competition design Because of the competitive nature of many of its instruments, a central feature of PPI is the design of the competition itself. Usually, multiple potential suppliers conduct costly research to develop innovative products, and the procurer offers one of these firms a delivery contract as a prize. Factors such as the value of the procurement contract, the number of contestants (at each R&D phase), and their characteristics (i.e., the value of their innovation and their cost efficiency) determine the level and structure of competition, which in turn influences incentives to exert effort.

In an older study, Lichtenberg (1988) showed a positive relationship between competitively awarded public contracts and private R&D spending by winning firms. However, only recently has Bhattacharya (2021) provided a discussion of the trade-offs associated with the above factors. For example, a higher contract value can exacerbate a firm's incentive to displace competitors from subsequent stages (i.e., *business stealing* effect) because firms have a greater incentive to compete for the award, leading to the overprovision of innovative efforts. This can more than offset the underprovision of effort due to the holdup effect.[16] In addition, increasing the number of competitors in a contest is directly beneficial when R&D outcomes are highly uncertain at the cost of duplicated effort. The benefit of increasing competition in the presence of uncertainty can outweigh the cost of reducing incentives to unilaterally exert effort—due to a lower probability of winning. The author concludes that inviting more contestants in a setting with symmetric bidders (i.e., small companies, start-ups, entrants) can increase welfare at the margin. This result seems to diverge from other contest-theory studies, which argue that given the negative impact of larger participation on effort provision, it might be optimal to restrict entry, and extract surplus by charging contestants an entry fee (see, e.g., Taylor 1995, Fullerton and McAfee 1999, Che and Gale 2003). In the case of asymmetric contestants, handicapping the most efficient contestant and allowing for multiple prizes can boost contestants' performance (see Che and Gale 2003 and Cabral et al. 2006).

4.2 The optimal design of new-vaccines procurement

A strand of works studies the optimal design of new-vaccine procurement via Advance Purchase Agreements or Advance Market Commitments (see, e.g., Batabyal 2005; Berndt and Hurvitz 2005; Glennerster et al. 2006; Berndt et al. 2007; Turner 2016; Kremer et al. 2020). Within this strand of the literature, some studies specifically consider COVID-19 vaccines (Snyder et al. 2020; Ahuja et al. 2021; Kremer et al. 2022).

The main emphasis in this context is on the hold-up problem that arises because the buyers in ex-post negotiations can appropriate returns from the pharmaceutical firm's sunk investment in capacity. Kremer et al. (2022) formalize these issues and find that the optimal contract design varies sensibly depending on how far in the R&D process the new-vaccine production is. If the new vaccine is in the early stage of R&D, the priority is to spur investment in R&D rather than in capacity. In this case, a framework design that subsidizes initial purchases using a fixed fund is appropriate. On the other hand, if the vaccine is in the late stages of R&D, the priority is to spur investment in capacity. In this case, a supply commitment or a capacity-forcing agreement that limits the firm's discretion over capacity can create the right incentives.

A related issue is the risk for pharmaceutical companies to invest in capacity that eventually proves worthless, such that investments in large-scale capacity are postponed until the vaccine has been proved effective and gained market authorization. However, this delay might be very costly in cases in which vaccine deployment is socially urgent. For example, as the COVID crisis demonstrated, the pressure imposed at the outset of an epidemic or pandemic requires vaccines to be produced and distributed as soon as they

[16] Which effect predominates depends on the shape of the effort function, influencing the marginal cost of effort in earlier stages and the current level of incentives for firms. The author shows that the holdup effect empirically dominates in the SBIR contests for which providing competitors with higher incentives can marginally increase the social surplus—measured as the difference between the buyer's willingness to pay for the innovation and the total research and delivery costs.

are approved. Incentives are even lower in the case of diseases that disproportionally affect low-income countries (e.g., malaria, pneumonia), as potential customers might not have sufficient income to create a business case (see, e.g., Glennerster et al. 2006; Berndt et al. 2007).

Motivated by these considerations, Ahuja et al. (2021) assess contractual options to accelerate investments in capacity. With push contracts, the buyer reimburses the supplier's installation cost before testing and regulatory approval are complete, therefore taking all the risk. On the other hand, with procurement contracts, the buyer commits to purchasing vaccines on specified terms, but only if regulatory approval is successful, leaving the risk to suppliers. The authors conclude that when suppliers have private information on the probability of success, procurers should contract directly on capacity, relying primarily on demand-push funding. At the same time, a technology-pull component can be added to incentivize speed.[17] The rationale for this mechanism is that when firms have private information on the probability of success, pull contracts are expensive relative to push contracts, as inducing risky investments from a diverse set of firms requires offering all firms a price high enough to induce the marginal firm to invest. This leaves substantial rents for firms with a high probability of success.

5 What are the Main Barriers to PPI Implementation?

Numerous frictions may arise in PPI on the side of both suppliers and buyers, limiting the ability of suppliers to innovate and of buyers to benefit from innovative outcomes. For instance, Georghiou et al. (2014) present a comprehensive taxonomy of procurement instruments that have emerged in OECD countries in response to perceived shortcomings and then compares them to business perceptions based on a dedicated survey of 800 public sector suppliers in the United Kingdom. The survey finds that companies face barriers originating from the buyer's failure to consider the full procurement cycle and risk aversion. Therefore, excluding financial constraints, the main remaining barriers reported by suppliers relate directly or indirectly to the buyer side. Uyarra et al. (2014) corroborates these findings. Lack of interaction with procuring organizations, use of over-specified tenders as opposed to outcome-based specifications, insufficient skill on the part of procurers, lack of useful feedback and communication, and poor risk management during the procurement process are examples of the main barriers reported by suppliers. These frictions are perceived as even greater when the supplier is a small company or nonprofit organization.

Buyer capabilities *appear therefore* particularly important in this context. Empirical evidence on standard procurement in different sectors and contexts has shown that buyers have a significant impact on contract performance and can explain a relevant share of variation in outcomes (Best et al. 2017; Decarolis et al. 2020; Bucciol et al. 2020; Baltrunaite et al. 2021).[18] Since Edquist (2015), innovation scholars have highlighted

[17] The push payments should, however, cover less than the entire cost, giving firms "skin in the game" and deterring those with no realistic chance of success from accepting push funding.

[18] The role of buyer capabilities, motivation, and organizational incentives are often mentioned also as

the importance of public buyers clearly identifying their needs and specifying the functional requirements of the procured activity or good, in order to reap the full benefits of innovation. Indeed, when procuring innovation, public buyers play a more critical role in project success than in standard procurement.[19] Yet despite the importance of public buyers, until recently there has been little research on their role for innovation, in sharp contrast to other topics of study which have received much greater attention, including the effectiveness of public policies (e.g., subsidies, tax benefits) for private R&D (see, for example, Takalo et al. 2013).

Causal evidence on the relevance of the demand side for publicly funded R&D was first provided by Bruce et al. (2019) and Decarolis et al. (2021). The former study emphasizes that federally funded standard R&D grants in the US have worse innovation outcomes than cooperative agreements precisely *because* the buyer has greater discretion over cooperative agreements. The latter study provides the first quantification of the role of public buyers in RDP success. Specifically, the authors use variation in manager deaths across contracting agencies and time to estimate the probability that contracts deliver patented inventions. Manager deaths are found to have a strong, negative impact on project innovation outcomes, as measured in terms of patents plus their citations and claims. These results suggest that the death of managers leads to a disruption in specialized human capital that is difficult to replace.

Decarolis et al. (2021) also discuss the possible mechanisms behind the buyer's role. Better work environments do not compensate for the sudden loss of specialized human capital through higher levels of perceived office cooperation, skills, or incentives. To further explore channels through which buyers may impact innovation, Giuffrida and Raiteri (2021) spotlight the most disaggregated decision-maker, which is the official responsible for the procurement process—who is commonly referred to as the contracting officer in the US. The authors focus specifically on (excessive) bureaucratic workload as a capacity bottleneck for officers in PPI units. By leveraging unexpected retirement postponements among contracting personnel, the authors show that when an officer's workload decreases, there is a sharp increase in patenting. They show that the officer workload is more disruptive at the margin when the time available to complete the transaction is less, leading to poorer guidance embedded in the contract. In fact, they show that suppliers that suffer from high buyer workloads are those that need the most guidance—that is, small and inexperienced firms. Consequently, the negative impact of bureaucratic workload is most relevant in cases in which the role of procurement personnel is central to the R&D process.

essential drivers for implementation of green public procurement, another form of complex procurement (see, e.g., Brammer and Walker 2011, Grandia 2015, Testa et al. 2016).

[19]Procurers' primary tasks are similar for innovation procurement and standard procurement: they conduct internal and market assessments to determine the government's needs and the status of the potential supply; they translate needs into functional requirements; they design complex tenders and award mechanisms; they select the most appropriate contractor; they manage contract execution, which ends months, if not years, after award. For PPI, however, these tasks are more complex, and inefficiencies in any of these steps can significantly degrade the innovation process.

6 What is the Role of PPI in the Innovation Policy Mix?

As anticipated in Section 2, PPI is only one of various policy instruments designed to trigger innovation. Therefore, it is relevant to ask how PPI performs relative to other instruments and how it might be combined with them to maximize incentives for innovation.

Mixing different innovation policies engenders the risk that firms may benefit simultaneously from several policy instruments, which may create a culture of dependence on the public sector and decrease the effectiveness of innovation policy expenditures. In addition, in case the combination of innovation policies implemented by different government agencies is not well coordinated, public intervention in market activities may result in the inefficient use of resources, and a policy failure may therefore occur (Link and Link 2009). A rich (primarily empirical) literature studies the determinants of innovation, highlighting the importance and role of demand-pull factors relative to and in combination with technology-push ones (see, for example, Horbach et al. 2012 and Veugelers 2012). This literature also emphasizes the importance of a balanced, comprehensive, and consistent policy mix (see, for example, Costantini et al. 2015 and Costantini et al. 2017). However, few studies explicitly address the role and relative performance of procurement as part of a broad policy framework to stimulate innovation.

To our knowledge, De Chiara and Iossa (2019) provide one of the few theoretical analyses of the relative performance of PPI versus R&D grants. In a setting where the preferences of the authority and the firm are misaligned—i.e., the most socially valuable projects are the least profitable—the authors find that both procurement and grants have the benefit of creating incentives for investment that would not have been carried out without public funds. However, there is a trade-off. While grants create a crowding-out effect—i.e., induce firms to substitute private funds with public funds to finance their preferred projects—which is socially inefficient when there is a cost for public funds, PPI creates a steering effect—i.e., induce firms to redirect their investment toward projects that are aligned with the preferences of the authority—even when it is socially inefficient to do so ("picking the wrong winner"). They conclude that procurement is preferable to grants when the projects preferred by the authority are highly socially valuable but of limited profitability (i.e., when the cost of "picking the wrong winner" is low) and when public funds are costly (i.e., when the benefit of limiting crowding out is high).

Cabral et al. (2006) conceptually assess the relative performance of PPI versus intellectual property. They argue that this issue boils down to comparing the distortion created by the two mechanisms. On the one hand, asymmetric information on the value of innovation makes it difficult to choose the correct level of the contract value. Therefore some innovations are overincentivized while others are underincentivized. On the other hand, a patent system creates the distortion associated with monopoly pricing. The authors conclude that procuring innovations through monetary prizes tends to be preferable to intellectual property when the innovation is easily describable in advance, the expected costs of monopoly prices are high, the occurrence of the innovation is verifiable, and there is little informational asymmetry on the value of the innovation.

Based on a survey of a broad sample of firms in Germany, Aschhoff and Sofka (2009) provide an empirical analysis to compare PPI explicitly to three other innovation policy instruments, namely co-public funding for private innovation projects, knowledge spillovers from publicly funded universities, and intervention through regulation (e.g., quality standards) that firms must comply with. They find that public procurement has a positive and significant effect on the innovative performance of firms—measured by the market success of their innovations—similar to knowledge spillovers from universities. On the other hand, neither regulation nor public funding for innovation projects seems to significantly impact market success. The trigger effect of procurement seems to be stronger for smaller firms in regional areas under economic stress—corroborating the evidence from Stojčić et al. (2020) on the stronger effect of PPI on firms located in catching-up economies—and in distributive and technological services.

Based on data from an EU-wide survey, Guerzoni and Raiteri (2015) provide an empirical assessment of PPI versus two supply-side policies, i.e., R&D subsidies and tax credits. The authors find that when the interactions between different policies in the assessment of the impact of individual policies are taken into account, then the effect of R&D subsidies is no longer significant and the effect of tax credits is much weaker than when not controlling for policy interactions. On the other hand, the positive effect of PPI persists, suggesting that PPI might dominate supply-side policies in a large, heterogeneous sample of innovative projects.

In a study on the manufacturing sector in the UK, Kesidou and Demirel (2012) confirm the importance of demand-side factors such as corporate social responsibility and customer requirements to initiate innovation but also suggest that other factors such as organizational capabilities and regulation are crucial to boost the level of R&D investment. They therefore recommend that demand-boosting GPP policies be complemented with appropriate environmental regulations and innovation platforms to support capacity building.

In their already mentioned literature review, Bloom et al. (2019) discuss a number of US innovation policy levers. They argue that among the different innovation funding programs, SBIR, together with other "mission-oriented" R&D policies that focus support on particular technologies or sectors—e.g., in defense and space—have been conducive to important innovations. Together with tax incentives for R&D, these programs and direct funding via government research grants seem the most effective in the short run. At the same time, policies aimed at increasing the supply of human capital focused on innovation are more effective in the long run (with earlier benefits in encouraging skilled immigration). Pro-competitive policies might have a modest effect but are advantageous in financial terms. Aside from a tangential discussion of SBIR, the paper makes no explicit reference to PPI instruments.

Stojčić et al. (2020) reveal the beneficial effects of both push and pull of policy instruments in Central and Eastern Europe. While firms receiving PPI contracts are more likely to innovate and achieve higher sales from new products, the push channel seems to be the dominant mechanism. This is particularly true when public procurement is not tailored in a way that requires firms to develop novel products and processes. In such circumstances, combined push and pull policies are likely to produce weaker effects than those achieved through push policies alone. However, the opposite finding holds when PPI is structured in a way that explicitly stimulates innovation. In this case, PPI alone generates the most substantial effects on innovations that are new to the market, and is not only beneficial to firms.[20] Caravella and Crespi (2021) find similar evidence in a study of the Italian manufacturing sector.

7 Discussion

Can public procurement be leveraged as an effective form of innovation policy? What can policymakers do to increase the effectiveness of such policy and remove associated frictions? How does PPI relate to other innovation policies? In other words: Where do we stand with our knowledge of PPI as an innovation policy? Based on our literature review, none of these questions can be answered unambiguously or conclusively, thus highlighting the need for additional research. In what follows, we summarize the main takeaways from literature and identify promising avenues for future research. We conclude with a discussion of the role PPI can play in addressing the current global challenges.

7.1 Assessment of the literature: takeaways and open questions

Does PPI spur innovation? While there is some evidence of the effectiveness of PPI in promoting business innovation, the body of work is still too small to draw conclusions about the determinants and modalities of success. Nevertheless, the evidence amassed to date suggests the following conclusions. First, the innovations triggered tend to be incremental rather than radical, suggesting that PPI promotes technology diffusion rather than breakthrough innovations. Second, PPI, similar to other innovation policies, seems particularly effective for new, small, and financially constrained firms. Third, the impact of PPI might be more substantial in catching-up economies and economically depressed areas.

New research should seek to confirm these findings and address some critical unanswered questions. On the one hand, further investigations are required at the firm level to understand whether PPI's impact on innovation persists over time. While most of the existing evidence comes from cross-sectional data, this question would require the availability of long time series to identify some of the longer-term effects—e.g., impact on sales or exports. Additional issues that deserve further investigation are spillover effects (i.e., the impact on firms not exposed to PPI) for which micro evidence is currently missing, and the impact of GPP as a demand-side environmental innovation policy, which is still under-researched both theoretically and empirically (see Cheng et al. 2018 and Chiappinelli 2022).

[20] In a related work, Stojčić (2021) finds that a clever combination of regulation, procurement, and financial incentives, along with private incentives, increases the likelihood of adoption of environmental innovations with social benefits.

How should PPI be designed to best spur innovation? The theoretical literature on the optimal design of PPI is quite extensive. The main insights from this scholarship are the following. First, the greater the economies of scope between the two phases, the more specific the innovation is to the public sector, and the better the information and capabilities of the buyer, the more desirable it is to bundle the R&D and commercial phases in PPI to stimulate innovation. Second, it may be beneficial to give the buyer more decision-making rights when the quality and effort of the innovation cannot be determined by the contract, provided the buyer has the right incentives and capabilities. Third, flexible award criteria (e.g., technology-neutral) and flexible award procedures (e.g., negotiation) might be better suited to promote innovation in contexts where leaving rents to the supplier is more of a concern for the regulator than efficiency losses. Fourth, increased competition could prove beneficial or detrimental to innovation, depending on the degree of uncertainty in contract requirements and supplier characteristics.

Further empirical research is needed to evaluate these theoretical findings. An open, policy-relevant question that needs to be addressed is whether and how PPI should be designed to encourage radical rather than incremental innovation and what role the design of risk–benefit sharing agreements (such as those envisaged by PCP) can play in this context.

What are the main barriers to PPI implementation? Recently, a research agenda has emerged on the role of buyer capabilities as a major factor influencing PPI performance. The existing literature is empirical and provides three main pieces of evidence. First, procurement personnel are important for project innovation; second, management practices within the contracting unit are relevant; third, capacity issues are particularly impactful when the role of procurement personnel is central to the R&D process.

However, these findings are founded on just a few studies, and further work is needed to generalize them and shed light on the black box of the buyer–innovator relationship. Unpacking this black box could lead to a better understanding of how bureaucracy can foster (or hinder) innovation (Kelman 2021) and what policies are needed to improve the capacity of public buyers. Additional theoretical work is also particularly needed. One important question in need of attention is how to improve risk management capabilities in the public sector to incentivize radical innovation in the procurement process.

What is the role of PPI in the innovation policy mix? Existing research on the theoretical and empirical evaluation of the relative performance of PPI compared to other innovation tools suggests that, on the one hand, PPI might be superior to some supply-side instruments if the projects are of high societal value and if the benefits of limiting crowding out are high; on the other hand, a consistent policy mix is more effective than using individual instruments.

However, this literature is limited and inconclusive. More (causal) evidence is needed to determine under what circumstances and to what extent PPI should be preferred over alternative innovation policy measures in the government toolkit and whether and with what instruments it should be complemented. This could imply gathering evidence on whether and how similar innovative projects perform differently in innovation output when funded and supported by alternative innovation policy instruments.

7.2 Policy implications for current global challenges

What is the role of PPI in the face of current societal challenges? Do we need more government intervention in innovation through PPI to address them? For example, looking at the threat of climate change, the necessary green transition requires widespread adoption of radical green innovations. These technologies often already exist but still need a business case for market-scale investment (see, e.g., Chiappinelli et al. 2021). While additional environmental policies may be needed to create a sufficient market, PPI can play an important role in the early adoption and diffusion of such technologies. In this sense, instruments such as Carbon Contracts for Differences (e.g. for low-carbon industrial processes) can play a crucial role. The potential market-pull role of PPI is especially relevant for sectors with a large environmental impact and where public authorities command substantial shares of the market.[21]

In addition, PPI can have an essential role in light of the need to accelerate the convergence of our economies toward ambitious emission reduction goals. PPI can be implemented by any contracting authority with any business, anywhere. Therefore, it provides a flexible and tangible instrument for governments to reduce their environmental impact and create lead markets for green options in the short term. This can also signal the commitment of governments to policies that require time and broad international adoption to be effective. In addition, generalizing the current evidence on general PPI to green innovation, PPI could be increasingly used for green public projects with new, small, and financially constrained companies, especially in catching-up regions. Such businesses and areas typically have a lower level of access to PPI programs, they may nevertheless be in a position to significantly reduce carbon emissions. In this sense, channeling resources to PPI may help achieve a sustainable growth path (Testa et al. 2011; Rainville 2021).

It is also worth highlighting the role of centralization in expanding the power of PPI as an innovation trigger in the healthcare market. For example, in line with Ahuja et al. (2021), there might be potential benefits in the further centralization of procurement of novel vaccines. These potential benefits include exploiting monopsony power to contain price levels, coordinating vaccine supply in low-income countries, leveraging economies of scale in contracting, planning, and supply chain investment, and facilitating efficient priority setting.[22] Whether expanding centralization of PPI generally boosts medical innovations and, in turn, health conditions worldwide is a fascinating topic that merits further investigation.

[21] Defense, health, construction, and transportation are examples of sectors both responsible for large shares of greenhouse gas emissions and dominated by public buyers (see, e.g., Wiedmann and Barrett 2011).

[22] Existing evidence of centralizing purchases of (non-innovative) drugs and medical devices (e.g., Clark et al. 2021; Wang and Zahur 2022) highlights similar benefits.

References

P. Aghion and P. Howitt. *Endogenous Growth Theory*, volume 1. The MIT Press, 1 edition, 1997.

A. Ahuja, S. Athey, A. Baker, E. Budish, J. C. Castillo, R. Glennerster, S. D. Kominers, M. Kremer, J. Lee, C. Prendergast, C. M. Snyder, A. Tabarrok, B. J. Tan, and W. Wiecek. Preparing for a Pandemic: Accelerating Vaccine Availability. *AEA Papers and Proceedings*, 111:331–35, 2021.

J. J. Anton and D. A. Yao. Split Awards, Procurement, and Innovation. *The RAND Journal of Economics*, pages 538–552, 1989.

K. Arrow. Economic Welfare and the Allocation of Resources for Invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, pages 609–626. Princeton University Press, 1962.

S. Arrowsmith. Horizontal Policies in Public Procurement: A Taxonomy. *Journal of Public Procurement*, 10(2):149–186, 2010.

B. Aschhoff and W. Sofka. Innovation on Demand—Can Public Procurement Drive Market Success of Innovations? *Research Policy*, 38(8):1235–1247, 2009.

P. Azoulay, J. S. Graff Zivin, D. Li, and B. N. Sampat. Public R&D Investments and Private-Sector Patenting: Evidence from NIH Funding Rules. *The Review of Economic Studies*, 86(1):117–152, 2019.

P. Bajari and S. Tadelis. Incentives versus Transaction Costs: A Theory of Procurement Contracts. *Rand Journal of Economics*, pages 387–407, 2001.

P. Bajari, R. McMillan, and S. Tadelis. Auctions Versus Negotiations in Procurement: An Empirical Analysis. *The Journal of Law, Economics, and Organization*, 25(2): 372–399, 2008.

P. Bajari, S. Houghton, and S. Tadelis. Bidding for Incomplete Contracts: An Empirical Analysis of Adaptation Costs. *American Economic Review*, 104(4):1288–1319, 2014.

A. Baltrunaite, C. Giorgiantonio, S. Mocetti, and T. Orlando. Discretion and supplier selection in public procurement. *The Journal of Law, Economics, and Organization*, 37(1):134–166, 2021.

A. A. Batabyal. Book Review: Michael Kremer and Rachel Glennerster, Strong Medicine: Creating Incentives for Pharmaceutical Research on Neglected Diseases. Princeton University Presss, Princeton, NJ and Oxford, UK. 2004. 153 pp. Hb, ISBN: 0-691-12113-3. *Journal of Agricultural and Environmental Ethics*, 18(4):415, 2005.

M. Beraja, A. Kao, D. Y. Yang, and N. Yuchtman. Ai-tocracy. NBER Working Paper 29466, National Bureau of Economic Research, 2021.

E. R. Berndt and J. A. Hurvitz. Vaccine Advance-Purchase Agreements For Low-Income Countries: Practical Issues. *Health Affairs*, 24(3):653–665, 2005.

E. R. Berndt, R. Glennerster, M. R. Kremer, J. Lee, R. Levine, G. Weizsäcker, and H. Williams. Advance Market Commitments for Vaccines Against Neglected Diseases: Estimating Costs and Effectiveness. *Health Economics*, 16(5):491–511, 2007.

M. C. Best, J. Hjort, and D. Szakonyi. Individuals and Organizations as Sources of State Effectiveness. NBER Working Paper 23350, National Bureau of Economic Research, 2017.

V. Bhattacharya. An Empirical Model of R&D Procurement Contests: An Analysis of the DOD SBIR Program. *Econometrica*, 89(5):2189–2224, 2021.

N. Bloom, J. Van Reenen, and H. Williams. A Toolkit of Policies to Promote Innovation. *Journal of Economic Perspectives*, 33(3):163–84, 2019.

S. Brammer and H. Walker. Sustainable procurement in the public sector: An international comparative study. *International Journal of Operations & Production Management*, 31(4):452–476, 2011.

R. Bronzini and E. Iachini. Are Incentives for R&D effective? Evidence from a Regression Discontinuity Approach. *American Economic Journal: Economic Policy*, 6(4):100–134, 2014.

J. R. Bruce and J. M. de Figueiredo. Innovation in the U.S. Government. NBER Working Paper 27181, National Bureau of Economic Research, 2020.

J. R. Bruce, J. M. de Figueiredo, and B. S. Silverman. Public Contracting for Private Innovation: Government Capabilities, Decision Rights, and Performance Outcomes. *Strategic Management Journal*, 40(4):533–555, 2019.

K. A. Bryan and H. L. Williams. Innovation: Market Failures and Public Policies. In *Handbook of Industrial Organization*, volume 5, pages 281–388. Elsevier, 2021.

A. Bucciol, R. Camboni, and P. Valbonesi. Purchasing Medical Devices: The Role of Buyer Competence and Discretion. *Journal of Health Economics*, 74, 2020.

L. Cabral, G. Cozzi, V. Denicolò, G. Spagnolo, and M. Zanza. *Procuring Innovations*, page 483–529. Cambridge University Press, 2006.

S. Caravella and F. Crespi. The role of public procurement as innovation lever: evidence from italian manufacturing firms. *Economics of Innovation and New Technology*, 30 (7):663–684, 2021. doi: 10.1080/10438599.2020.1761591. URL `https://doi.org/10.1080/10438599.2020.1761591`.

P. Castelnovo, S. Clò, and M. Florio. A Quasi-Experimental Design to Assess the Innovative Impact of Public Procurement: An Application to the Italian Space Industry. *Technovation*, 121:102683, 2023.

Y.-K. Che and I. Gale. Optimal Design of Research Contests. *American Economic Review*, 93(3):646–671, 2003.

Y.-K. Che, E. Iossa, and P. Rey. Prizes versus Contracts as Incentives for Innovation. *The Review of Economic Studies*, 88(5):2149–2178, 2021.

W. Cheng, A. Appolloni, A. D'Amato, and Q. Zhu. Green Public Procurement, Missing Concepts and Future Trends – A critical review. *Journal of Cleaner Production*, 176: 770–784, 2018.

O. Chiappinelli. Determinants and effectiveness of green public procurement adoption. In *Handbook of Labor, Human Resources and Population Economics*. Springer Nature, 2022.

O. Chiappinelli, T. Gerres, K. Neuhoff, F. Lettow, H. de Coninck, B. Felsmann, E. Joltreau, G. Khandekar, P. Linares, J. Richstein, A. Śniegocki, J. Stede, T. Wyns, C. Zandt, and L. Zetterberg. A Green COVID-19 Recovery of the EU Basic Materials Sector: Identifying Potentials, Barriers and Policy Solutions. *Climate Policy*, 21(10): 1328–1346, 2021.

R. Clark, D. Coviello, and A. De Leverano. Centralized Procurement and Delivery Times: Evidence from a Natural Experiment in Italy. ZEW Discussion Paper 21-063, ZEW–Leibniz-Centre for European Economic Research, 2021.

B. Clarysse, M. Wright, and P. Mustar. Behavioural Additionality of R&D Subsidies: A Learning Perspective. *Research Policy*, 38(10):1517–1533, 2009.

J. Clemens and P. Rogers. Demand Shocks, Procurement Policies, and the Nature of Medical Innovation: Evidence from Wartime Prosthetic Device Patents. NBER Working Paper 26679, National Bureau of Economic Research, 2020.

V. Costantini, F. Crespi, C. Martini, and L. Pennacchio. Demand-Pull and Technology-Push Public Support for Eco-Innovation: The Case of the Biofuels Sector. *Research Policy*, 44(3):577–595, 2015.

V. Costantini, F. Crespi, and A. Palma. Characterizing the Policy Mix and its Impact on Eco-Innovation: A Patent Analysis of Energy-Efficient Technologies. *Research Policy*, 46(4):799–819, 2017.

G. Cozzi and G. Impullitti. Technology Policy and Wage Inequality. Working Paper 2008-23, Business School - Economics, University of Glasgow, 2008.

D. Czarnitzki, P. Hünermund, and N. Moshgbar. Public Procurement of Innovation: Evidence from a German Legislative Reform. *International Journal of Industrial Organization*, 71:102620, 2020.

A. De Chiara and E. Iossa. Public Procurement as a Demand-Side Policy: Project Competition and Innovation Incentives. CEPR Discussion Paper No. 13664, CEPR, 2019.

G. de Rassenfosse, A. Jaffe, and E. Raiteri. The Procurement of Innovation by the US Government. *PloS one*, 14(8):e0218927, 2019.

F. Decarolis, L. M. Giuffrida, E. Iossa, V. Mollisi, and G. Spagnolo. Bureaucratic Competence and Procurement Outcomes. *The Journal of Law, Economics, and Organization*, 36(3):537–597, 2020.

F. Decarolis, G. de Rassenfosse, L. M. Giuffrida, E. Iossa, V. Mollisi, E. Raiteri, and G. Spagnolo. Buyers' Role in Innovation Procurement: Evidence from U.S. Military R&D Contracts. *Journal of Economics & Management Strategy*, 2021.

A. Dechezleprêtre, E. Einiö, R. Martin, K.-T. Nguyen, and J. Van Reenen. Do Tax Incentives for Research Increase Firm Innovation? An RD Design for R&D. NBER Working Paper 22405, National Bureau of Economic Research, 2016.

J. Edler. The impact of policy measures to stimulate private demand for innovation. *Handbook of innovation policy impact*, 2016.

J. Edler and L. Georghiou. Public procurement and innovation—resurrecting the demand side. *Research Policy*, 36(7):949–963, 2007.

C. Edquist. Innovation-related public procurement as a demand-oriented innovation policy instrument. Papers in Innovation Studies 2015/28, Lund University, CIRCLE - Center for Innovation, Research and Competences in the Learning Economy, Lund, 2015.

C. Edquist and L. Hommen. Systems of Innovation: Theory and Policy for the Demand Side. *Technology in Society*, 21(1):63–79, 1999.

C. Edquist and L. Hommen. Public Technology Procurement and Innovation Theory. In *Public technology procurement and innovation*, pages 5–70. Springer, 2000.

C. Edquist and J. M. Zabala-Iturriagagoitia. Public Procurement for Innovation as Mission-Oriented Innovation Policy. *Research Policy*, 41(10):1757–1769, 2012.

C. Edquist and J. M. Zabala-Iturriagagoitia. Pre-Commercial Procurement: A Demand or Supply Policy instrument in Relation To Innovation? *R&D Management*, 45(2): 147–160, 2015.

C. Edquist and J. M. Zabala-Iturriagagoitia. Functional Procurement for Innovation, Welfare, and the Environment. *Science and Public Policy*, 47(5):595–603, 2020.

C. Edquist, N. Vonortas, and J. Zabala-Iturriagagoitia. Introduction: Public procurement for Innovation. *Edquist, C., Vonortas, NS and Zabala-Iturriagagoitia, and Edler, J.(Eds.). Public Procurement for Innovation, Edward Elgar, Cheltenham*, pages 1–34, 2015.

N. Fabra, J.-P. Montero, et al. Technology-Neutral vs. Technology-Specific Procurement. CEPR Discussion Papers 15554, CEPR, 2020.

E. Feinerman and J. Lipow. Is There a Bias Toward Excessive Quality in Defense Procurement? *Economics Letters*, 71(1):143–148, 2001.

L. Fleming, H. Greene, G. Li, M. Marx, and D. Yao. Government-Funded Research Increasingly Fuels Innovation. *Science*, 364(6446):1139–1141, 2019.

R. L. Fullerton and R. P. McAfee. Auctioning Entry into Tournaments. *Journal of Political Economy*, 107(3):573–605, 1999.

L. Georghiou, J. Edler, E. Uyarra, and J. Yeow. Policy Instruments for Public Procurement of Innovation: Choice, Design and Assessment. *Technological Forecasting and Social Change*, 86:1–12, 2014.

P. Geroski. Procurement Policy as a Tool of Industrial Policy. *International Review of Applied Economics*, 4(2):182–198, 1990.

C. Ghisetti. Demand-Pull and Environmental Innovations: Estimating the Effects of Innovative Public Procurement. *Technological Forecasting and Social Change*, 125: 178–187, 2017.

L. M. Giuffrida and E. Raiteri. Buyers' Workload and R&D Procurement Outcomes: Evidence From the US Air Force Research Lab. Discussion Paper 21-059, ZEW-Centre for European Economic Research, 2021.

R. Glennerster, M. Kremer, and H. Williams. Creating Markets for Vaccines. *Innovations: Technology, Governance, Globalization*, 1(1):67–79, 01 2006. ISSN 1558-2477. doi: 10.1162/itgg.2006.1.1.67. URL `https://doi.org/10.1162/itgg.2006.1.1.67`.

A. Gök and J. Edler. The Use of Behavioural Additionality Evaluation in Innovation Policy Making. *Research Evaluation*, 21(4):306–318, 2012.

J. Grandia. The Role of Change Agents in Sustainable Public Procurement Projects. *Public Money & Management*, 35(2):119–126, 2015.

G. M. Grossman and E. Helpman. Quality Ladders in the Theory of Growth. *The Review of Economic Studies*, 58(1):43–61, 1991.

M. Guerzoni and E. Raiteri. Demand-Side vs. Supply-Side Technology Policies: Hidden treatment and New Empirical Evidence on the Policy Mix. *Research Policy*, 44(3): 726–747, 2015.

O. Hart, A. Shleifer, and R. W. Vishny. The Proper Scope of Government: Theory and an Application to Prisons. *The Quarterly Journal of Economics*, 112(4):1127–1161, 11 1997.

J. Haskel and G. Wallis. Public Support for Innovation, Intangible Investment and Productivity Growth in the UK Market Sector. *Economics letters*, 119(2):195–198, 2013.

J. Horbach, C. Rammer, and K. Rennings. Determinants of Eco-Innovations by Type of Environmental Impact—The role of Regulatory Push/Pull, Technology Push and Market Pull. *Ecological Economics*, 78:112–122, 2012.

S. T. Howell. Financing Innovation: Evidence from R&D Grants. *American Economic Review*, 107(4):1136–64, 2017.

S. T. Howell, J. Rathje, J. Van Reenen, and J. Wong. Opening up Military Innovation: Causal Effects of 'Bottom-Up' Reforms to U.S. Defense Research. NBER Working Paper 28700, National Bureau of Economic Research, 2021.

E. Iossa, F. Biagi, and P. Valbonesi. Pre-Commercial Procurement, Procurement of Innovative Solutions and Innovation Partnerships in the EU: Rationale and Strategy. *Economics of Innovation and New Technology*, 27(8):730–749, 2018.

S. Kelman. Bureaucracies as Innovative Organizations. Working Paper 21-017, HKS Faculty Research, June 2021.

E. Kesidou and P. Demirel. On the Drivers of Eco-Innovations: Empirical Evidence from the UK. *Research Policy*, 41(5):862–870, 2012.

M. Kremer, J. Levin, and C. M. Snyder. Advance Market Commitments: Insights from Theory and Experience. *AEA Papers and Proceedings*, 110:269–73, 2020.

M. Kremer, J. Levin, and C. M. Snyder. Designing Advance Market Commitments for New Vaccines. *Management Science*, 68(7):4786–4814, 2022.

B. Krieger and V. Zipperer. Does Green Public Procurement Trigger Environmental Innovations? *Research Policy*, 51(6):104516, 2022.

V. Lember, R. Kattel, and T. Kalvet. Public Procurement and Innovation: Theory and Practice. In *Public procurement, innovation and policy*, pages 13–34. Springer, 2014.

J. Lerner. The Government as Venture Capitalist: the Long-Run Impact of the SBIR Program. *The Journal of Private Equity*, 3(2):55–78, 2000.

F. R. Lichtenberg. The Private R&D Investment Response to Federal Design and Technical Competitions. *The American Economic Review*, 78(3):550–559, 1988.

A. N. Link and J. R. Link. *Government as Entrepreneur*. Oxford University Press, 2009.

A. N. Link and J. T. Scott. Employment Growth from Public Support of Innovation in Small Firms. *Economics of Innovation and New Technology*, 21(7):655–678, 2012.

G. Loury. Market Structure and Innovation. *The Quarterly Journal of Economics*, 93 (3):395–410, 1979.

T. P. Lyon. Does Dual Sourcing Lower Procurement Costs? *The Journal of Industrial Economics*, 54(2):223–252, 2006.

S. M. Maurer and S. Scotchmer. Procuring knowledge. In *Intellectual property and entrepreneurship*. Emerald Group Publishing Limited, 2004.

M. Mazzucato. The Entrepreneurial State. *Soundings*, 49(49):131–142, 2011.

R. N. McKean. Reviewed Work: The Weapons Acquisition Process: Economic Incentives by Frederic M. Scherer. *The American Economic Review*, 54(6):1169–1171, 1964. ISSN 00028282. URL `http://www.jstor.org/stable/1809536`.

E. Moretti, C. Steinwender, and J. Van Reenen. The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers. NBER Working Paper 26483, National Bureau of Economic Research, 2019.

R. R. Nelson. The Simple Economics of Basic Scientific Research. *Journal of Political Economy*, 67(3):297–306, 1959.

G. F. Nemet. Demand-Pull, Technology-Push, and Government-Led Incentives for Non-Incremental Technical Change. *Research Policy*, 38(5):700–709, 2009.

G. F. Nemet, V. Zipperer, and M. Kraus. The Valley of Death, the Technology Pork Barrel, and Public Support for Large Demonstration Projects. *Energy Policy*, 119: 154–167, 2018.

K. Neuhoff, N. May, and J. C. Richstein. Renewable Energy Policy in the Age of Falling Technology Costs. Discussion Papers of DIW Berlin 1746, DIW Berlin, German Institute for Economic Research, 2018.

G. Orsatti, F. Perruchas, D. Consoli, and F. Quatraro. Public Procurement, Local Labor Markets and Green Technological Change. Evidence from US Commuting Zones. *Environmental and Resource Economics*, 75(4):711–739, 2020.

A. Rainville. Stimulating a More Circular Economy through Public Procurement: Roles and Dynamics of Intermediation. *Research Policy*, 50(4):104–193, 2021.

J. F. Reinganum. Innovation and Industry Evolution. *The Quarterly Journal of Economics*, 100(1):81–99, 1985.

J. C. Richstein and K. Neuhoff. Carbon contracts-for-difference: How to de-risk innovative investments for a low-carbon industry? *Science*, 25(8):104700, 2022.

E. B. Roberts. What We've Learned: Managing Invention and Innovation. *Research-Technology Management*, 31(1):11–29, 1988.

W. P. Rogerson. Profit Regulation of Defense Contractors and Prizes for Innovation. *Journal of Political Economy*, 97(6):1284–1305, 1989.

W. P. Rogerson. Economic Incentives and the Defense Procurement Process. *Journal of Economic Perspectives*, 8(4):65–90, 1994.

W. P. Rogerson. Chapter 12 Incentive models of the Defense Procurement Process. In *Handbook of Defense Economics*, volume 1, pages 309–346. Elsevier, 1995.

P. M. Romer. Endogenous Technological Change. *Journal of Political Economy*, 98(5, Part 2):S71–S102, 1990.

V. W. Ruttan. Is War Necessary for Economic Growth? Military Procurement and Technology Development. Technical report, University of Minnesota, Department of Applied Economics, 2006.

P. Santoleri, A. Mina, A. Di Minin, and I. Martelli. The Causal Effects of R&D Grants: Evidence from a Regression Discontinuity. *The Review of Economics and Statistics*, pages 1–42, 2022.

S. Scotchmer. *Innovation and incentives*. MIT press, 2004.

K. Selviaridis. Effects of Public Procurement of R&D on the Innovation Process: Evidence from the UK Small Business Research Initiative. *Journal of Public Procurement*, 2020.

V. Slavtchev and S. Wiederhold. Does the Technological Content of Government Demand Matter for Private R&D? Evidence from US States. *American Economic Journal: Macroeconomics*, 8(2):45–84, 2016.

C. M. Snyder, K. Hoyt, D. Gouglas, T. Johnston, and J. Robinson. Designing Pull Funding For A COVID-19 Vaccine. *Health Affairs*, 39(9):1633–1642, 2020.

N. Stojčić. Social and private outcomes of green innovation incentives in european advancing economies. *Technovation*, 104:102270, 2021.

N. Stojčić, S. Srhoj, and A. Coad. Innovation Procurement as Capability-Building: Evaluating Innovation Policies in Right Central and Eastern European Countries. *European Economic Review*, 121:103330, 2020.

T. Takalo, T. Tanayama, and O. Toivanen. Estimating the Benefits of Targeted R&D Subsidies. *The Review of Economics and Statistics*, 95(1):255–272, 2013.

C. R. Taylor. Digging for golden carrots: An analysis of research tournaments. *The American Economic Review*, 85(4):872–890, 1995.

F. Testa, F. Iraldo, and M. Frey. The Effect of Environmental Regulation on Firms' Competitive Performance: The case of the Building & Construction Sector in Some EU Regions. *Journal of Environmental Management*, 92(9):2136–2144, 2011.

F. Testa, E. Annunziata, F. Iraldo, and M. Frey. Drawbacks and Opportunities of Green Public Procurement: An Effective Tool for Sustainable Production. *Journal of Cleaner Production*, 112:1893–1900, 2016. Embedding Sustainability Dynamics in Supply Chain Relationship Management and Governance Structures.

M. Turner. Vaccine procurement during an influenza pandemic and the role of advance purchase agreements: Lessons from 2009-h1n1. *Global Public Health*, 11(3):322–335, 2016.

E. Uyarra. The Impact of Public Procurement of Innovation. In *Handbook of innovation policy impact*, pages 355–381. Edward Elgar Publishing, 2016.

E. Uyarra, J. Edler, J. Garcia-Estevez, L. Georghiou, and J. Yeow. Barriers to Innovation Through Public Procurement: A Supplier Perspective. *Technovation*, 34(10):631–645, 2014.

R. Veugelers. Which Policy Instruments to Induce Clean Innovating? *Research Policy*, 41(10):1770–1778, 2012.

S. J. Wallsten. The Effects of Government-Industry R&D Programs on Private R&D: The Case of the Small Business Innovation Research Program. *The RAND Journal of Economics*, pages 82–100, 2000.

L. X. Wang and N. Zahur. Procurement Institutions and Essential Drug Supply in Low and Middle-Income Countries. *Available at SSRN 3926761*, 2022.

T. Wiedmann and J. Barrett. A Greenhouse Gas Footprint Analysis of UK Central Government, 1990–2008. *Environmental Science & Policy*, 14(8):1041–1051, 2011.

R. Wilkinson, M. Mabile, M. Montejo, H. Nilsson, R. O'Leary, G. Piga, P. Tronslin, E. Ward, L. Georghiou, J. Cave, et al. Procurement for Research and Innovation. Report of an Expert Group on measures and actions to assist in the development of procurement practices favourable to private investment in R&D and innovation. Eu expert group report sept. 2005, European Commission, 2005.

O. Williamson. Public and Private Bureaucracies: a Transaction Cost Economics Perspectives. *The Journal of Law, Economics, and Organization*, 15(1):306–342, 1999.

Download ZEW Discussion Papers:

https://www.zew.de/en/publications/zew-discussion-papers

or see:

https://www.ssrn.com/link/ZEW-Ctr-Euro-Econ-Research.html
https://ideas.repec.org/s/zbw/zewdip.html

//

IMPRINT

ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung GmbH Mannheim

ZEW – Leibniz Centre for European Economic Research

L 7,1 · 68161 Mannheim · Germany
Phone +49 621 1235-01
info@zew.de · zew.de