

# Public Procurement, the Nature of Innovation, and Growth: Firm-Level Evidence from Germany\*

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## Abstract

Public buyers often require proven technologies and established standards, which may encourage firms to improve existing products rather than develop new ones. Combining German firm-level innovation surveys with public procurement records, we find that product innovators are less likely to introduce products new to their markets in industries with larger public contracts and higher public-sector purchases. But whether this shift in innovation composition matters quantitatively for aggregate growth depends on general-equilibrium forces. We therefore extend and estimate a heterogeneous-firm endogenous-growth model in which procurement raises the relative profitability of incremental innovation. In the estimated model, reallocating procurement spending to an R&D tax credit instead raises growth by 8.8 basis points and welfare by 1.9 percent of permanent private consumption.

**Keywords:** public procurement, innovation composition, quality ladders, demand-side policy.

**JEL codes:** D22, H57, O31, O38, O41.

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# 1 Introduction

Public contracts fix technical standards and certification requirements before firms bid. Adapting a product that already meets them is often cheaper than developing a new one, and public demand may therefore favor incremental improvements. Because products developed for public buyers also reach private customers, the incentive extends beyond public sales.

In Germany, public procurement rose from 6.6 to 9.2 percent of GDP between 2007 and 2023 (Eurostat, 2026a), while novelty, the share of firms introducing products new to the market, fell from 20 to 8 percent (Figure 1). Because public purchases are more than four times business R&D spending (Eurostat, 2026b), even a small shift in the kind of products they reward can matter for aggregate innovation. We ask whether public demand and the design of public contracts are associated with innovation closer to existing products, and how much that matters for growth.

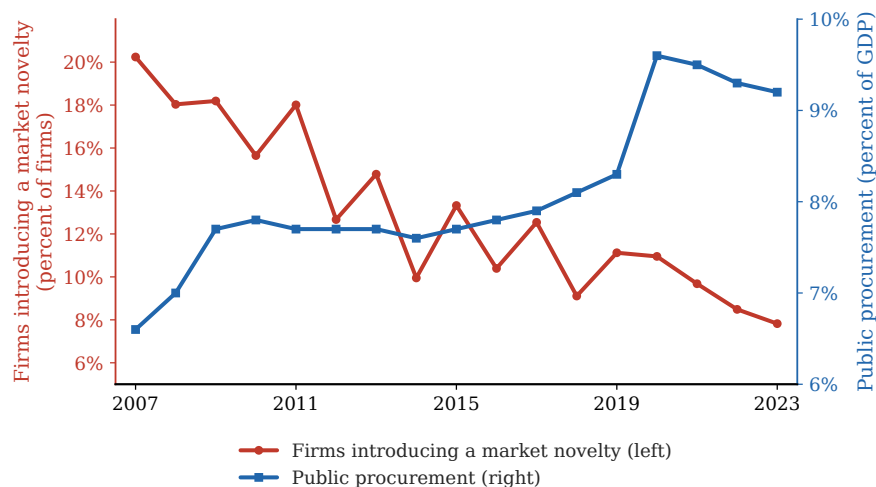


Figure 1: Public procurement rose as novelty fell

*Notes:* The red line plots novelty, defined as the share of firms introducing products new to the market, on the left axis. The blue line plots public procurement on the right axis, measured as the sum of intermediate consumption (government purchases of goods and services) and public investment (works), the two national-accounts components that map to competitively tendered contracts.

*Source:* Mannheim Innovation Panel, 2007–2023; Eurostat (2026a), Germany, 2007–2023.

We combine the Mannheim Innovation Panel, a large representative annual survey of German manufacturing and business-service firms run by ZEW, with German public contract awards published in Tenders Electronic Daily and with national input-output tables, over 2010–2022. The survey covers about 52,000 firm-years from nearly 12,000 firms, and the procurement records contain about 350,000 contract awards. For each industry and year, we count the awards and average their values, which separates how often public buyers purchase from the value of a typical contract, and the input-output tables add broad public-sector purchases relative to industry output. We relate these

measures jointly to innovation outcomes, controlling for firm and year effects, and express each association for a one-standard-deviation increase, relative to the mean. Three findings emerge.

First, larger public contracts are associated with less novelty among product innovators, by 2.6 percent of the mean. Second, more public contracts are associated with higher R&D intensity, by 11 percent of the mean, and with a smaller share of sales from new products, a combination consistent with R&D spent on adapting existing products to public requirements. Third, higher public-sector purchases, the industry-level counterpart of the aggregate series in Figure 1, are associated with less novelty among product innovators, by 5.4 percent of the mean, and have no association with R&D intensity. Public demand is thus associated with innovation closer to existing products.

Contract design is one natural candidate to explain these patterns. For example, in software procurement, compatibility requirements can favor integration with existing systems over new architectures. In medical-device procurement, certification requirements can favor proven technologies over untested diagnostic improvements. Public contracts are also large for the firms that win them, with awards in a given year equal to 7.4 percent of the winner’s same-year turnover at the median and 49.4 percent at the 90th percentile. A larger contract therefore raises the payoff from meeting such requirements with an adapted product, consistent with lower novelty among innovators where contracts are larger.

The within-firm estimates leave the aggregate consequences open. Higher profits on products sold to public buyers could draw more labor into innovation and offset the decline in novelty. To quantify these forces, we extend the [Klette and Kortum \(2004\)](#) model, the standard heterogeneous-firm model of endogenous growth, in which firms hold portfolios of product lines, improve product quality step by step, and lose lines to creative destruction.<sup>1</sup> We add one margin: firms choose both how much to innovate and what kind of innovation to pursue. Procurement enters as the aggregate level of public purchases, together with its split between incremental and frontier product lines. Purchases concentrated on incremental products lower the relative return to frontier innovation, and firms respond by pursuing more incremental improvements. In equilibrium, procurement lowers the share of frontier innovations and leaves innovation effort unchanged. Under free entry, higher profits from public demand raise the wage until the value of a product line again equals the labor cost of entry, and the higher wage raises the cost of innovation effort as much as its return. As a result, procurement affects growth only through the composition of innovation. The model therefore rationalizes the patterns in the German innovation and procurement microdata.

We estimate four structural parameters by generalized method of moments (GMM), targeting seven moments from German survey and administrative data on innovation composition and participation,

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<sup>1</sup>[Akcigit and Kerr \(2018\)](#), [Akcigit and Ates \(2023\)](#), and [Acemoglu et al. \(2018\)](#) extend the framework.

firm size and exit, R&D employment, and the profitability associated with novelty. The moments discipline parameters governing the quality improvements from incremental and frontier innovation, the resource cost of frontier innovation, and the cost of entry. Frontier innovations raise product quality about twice as much as incremental innovations. The estimated model closely matches the innovation and profitability moments. Beyond these targets, higher public demand in the model lowers novelty among product innovators, raises the share of firms that innovate, and leaves innovation effort unchanged, consistent with the evidence.

We conduct a range of numerical exercises to examine the quantitative importance of the mechanism. First, in our primary exercise, reallocating procurement funds to an R&D tax credit, modeled on Germany’s *Forschungszulage* (a rule-based credit on eligible R&D labor costs introduced in January 2020) and calibrated to match Germany’s current R&D tax subsidy rate, raises growth by about 9 basis points per year and welfare by 1.9 percent of permanent private consumption.<sup>2</sup> Most of the gain comes from higher innovation effort. The gains are moderately large and in line with other quantitative exercises. The growth gain equals one-quarter of German trend TFP growth, larger than the 5 basis-point gain from removing short-termism in [Terry \(2023\)](#) and smaller than the 12 basis-point cost of inventor monopsony in [Lehr \(2025\)](#). Second, a specification realignment inspired by open-topic competitions in U.S. defense research ([Howell et al., 2025](#)) gives frontier and incremental products the same procurement demand at a fixed budget. It raises growth by 0.4 basis points and leaves welfare unchanged. In summary, across exercises, procurement policy affects both the level and the composition of innovation in quantitatively meaningful ways, and growth and welfare respond more to the level.

The paper connects to four strands of the literature. First, we contribute to the endogenous-growth literature on innovation composition and misallocation.<sup>3</sup> [García-Macià et al. \(2019\)](#) document that growth comes mostly from incumbents improving existing products, and [Acemoglu et al. \(2022\)](#) show that the frontier-versus-incremental margin matters for long-run growth. We add a demand-side force to this margin. Procurement shifts the relative payoff between frontier and incremental innovation, changing its composition, while an R&D credit on effort changes its level. Whereas related work studies distortions in the allocation of innovation across firms, we examine how public demand shifts the allocation of innovation across types within firms.<sup>4</sup>

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<sup>2</sup>For evidence on R&D tax incentives and support policies, see [Chen et al. \(2021\)](#); [Dechezleprêtre et al. \(2023\)](#); [Chen and Xu \(2023\)](#); [Lerche \(2025\)](#); [Takalo et al. \(2026\)](#).

<sup>3</sup>See, for example, [Aghion and Howitt \(1992\)](#); [Klette and Kortum \(2004\)](#); [Acemoglu et al. \(2018\)](#); [Akcigit and Kerr \(2018\)](#); [Aghion et al. \(2023\)](#); [Akcigit and Ates \(2023\)](#); [Juhász et al. \(2024\)](#); [Terry \(2023\)](#); [Lehr \(2024, 2025\)](#); [Bachmann et al. \(2026\)](#). Our demand-side mechanism complements the supply-side evidence in [Bloom et al. \(2020\)](#) that ideas are getting harder to find.

<sup>4</sup>For instance, [Kogan et al. \(2017\)](#); [Manera \(2022\)](#); [Ayerst \(2022\)](#); [Liu et al. \(2022\)](#); [Aghion et al. \(2023\)](#); [de Ridder \(2024\)](#); [Lehr \(2024\)](#).

Second, we contribute to the empirical literature on public procurement and innovation. Much of this work studies purchases that target new technologies, often in defense and other markets where the government is the main buyer, and finds that public demand raises private innovation.<sup>5</sup> We study ordinary public purchases in industries in which firms sell to both public and private customers. In this setting, larger contracts and higher public demand are associated with innovation closer to existing products. Closest to our setting, [Krieger et al. \(2024\)](#) show that price-criterion tenders reduce product innovation among German firms. We move from individual tenders to the industry-level number and size of contracts and quantify their growth effects in an estimated model.

Third, we contribute to research on procurement contract design and innovation. [Howell et al. \(2025\)](#) show that open-format defense awards raise patenting and commercial adoption, while specification-based awards produce weaker frontier commercialization. [Clemens and Rogers \(2026\)](#) show historically that fixed-price contracts shift invention toward cost reduction, while quality-focused contracts shift patenting toward attributes buyers value. We embed the contrast between specified and open procurement in an estimated growth model, and our budget-neutral reform, modeled on open-topic defense competitions, quantifies its aggregate growth consequences.

Finally, we contribute to research on procurement and firm dynamics ([Ferraz et al., 2015](#); [di Giovanni et al., 2025](#)). [di Giovanni et al. \(2025\)](#) combine Spanish administrative, procurement, and credit data to show that public contracts ease firms' borrowing constraints and have persistent effects on firm growth. In their heterogeneous-firm model with borrowing constraints, revenue-neutral reforms that shift procurement toward small firms help constrained firms grow but lower GDP through capital misallocation. We also study how reallocating a fixed procurement budget affects aggregate outcomes, through the kind of innovation firms pursue. In our model, shifting procurement toward frontier products raises growth.

The paper proceeds as follows. Section 2 presents the data and empirical evidence. Section 3 develops the model. Section 4 reports the quantitative analysis. Section 5 presents the policy counterfactuals. Section 6 provides further discussion and robustness exercises. Section 7 concludes.

## 2 Data and Empirical Evidence

### 2.1 Data

We draw on two main data sources, the Mannheim Innovation Panel (MIP) and Tenders Electronic Daily (TED). The MIP reports innovation outcomes for about 52,000 firm-years from nearly 12,000

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<sup>5</sup>See [Lichtenberg \(1988\)](#); [Mowery \(2010\)](#); [Draca \(2013\)](#); [Slavtchev and Wiederhold \(2016\)](#); [Czarnitzki et al. \(2020\)](#); [Decarolis et al. \(2021\)](#); [Krieger and Zipperer \(2022\)](#); [Gross and Sampat \(2023\)](#); [Moretti et al. \(2025\)](#), and [Chiappinelli et al. \(2025\)](#) for a review.

German firms over 2010–2022, and TED reports about 350,000 awards of German public contracts over the same years. We also use Eurostat input-output tables for the overall level of public demand, ORBIS financial accounts for the weight of awards in winners’ sales, and the IAB Establishment History Panel (BHP) for exit rates in the structural estimation.<sup>6</sup> Appendix A details variable construction, coverage, and descriptive statistics.

ZEW Mannheim runs the MIP, the German contribution to the Community Innovation Survey, annually on behalf of the German Federal Ministry of Education and Research. Its stratified random sample covers manufacturing and business-service firms and is refreshed each year to remain representative across size classes, industries, and regions; construction, agriculture, and the public sector are excluded.<sup>7</sup>

Our primary outcome, market novelty, indicates whether a firm introduced at least one product or service new to its market over the preceding three years. We measure it among product innovators, defined as firms introducing a new or significantly improved good or service (OECD and Eurostat, 2018), and each respondent assesses novelty relative to its own market.<sup>8</sup> The new-product sales share measures revenue from new or significantly improved products as a percentage of sales, also among product innovators. R&D intensity measures R&D expenditure as a percentage of sales for all firms, including zeros for firms without R&D. The outcomes describe the kind of products firms introduce, their commercial weight, and innovation effort.

TED, the European Commission’s official procurement journal, publishes the award notices that German public buyers at the federal, state, and municipal levels must disclose above EU value thresholds. The thresholds skew the records toward larger, project-based purchases; most routine commodity purchases fall below them. The 2010–2022 file contains 351,312 contract–winner awards mapped to twenty industries, each reporting product codes, award dates and values, buyers, and procurement characteristics. For each industry and year, we count the awards and average their values, and assign both measures to every firm in the industry-year cell. The count measures the extensive margin of public demand, how often public buyers purchase from an industry, and average size measures the intensive margin, how much is at stake in a typical contract. Total awarded value combines the two margins, which can matter for different reasons. More contracts may expose more firms to public requirements, while larger contracts raises the potential payoff from adapting products to meet them.

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<sup>6</sup>Data source: IAB Establishment History Panel 1975–2024 (BHP 7524 v1) (Ganzer et al., 2025).

<sup>7</sup>Data source: Mannheim Innovation Panel (MIP), ZEW, Mannheim, Germany (ZEW – Leibniz Centre for European Economic Research, 2023).

<sup>8</sup>Patent-based studies measure novelty by textual distance to earlier patents (Kelly et al., 2021) and impact by forward citations (Hall et al., 2005; Akcigit and Kerr, 2018); the survey also covers products that are never patented.

Figure 2 shows that the number and the size of public contracts capture different features of public demand. Half of all awards go to four industries, led by technical and R&D services (Panel A). The largest contracts are in IT and telecommunications and in mining and energy, where the average award exceeds one million euros (Panel C). Within industries, both measures also change from year to year, with standard deviations of 27 and 44 log points after removing industry and year averages (Panels B and D). The correlation is  $-0.17$ , which lets the regressions separate the two margins.

Eurostat’s domestic input-output tables measure the overall level of public demand as broad public-sector purchases, defined as purchases by public administration and defense, education, and health and social work, in percent of each industry’s domestic output. The measure is broad in two senses. It covers purchases of any size, including routine purchases below EU thresholds that TED misses, and its buyers include private schools and hospitals. It is the industry-level counterpart of the aggregate series in Figure 1, and aggregate procurement spending in the model is its economy-wide counterpart (Section 4.1).

## 2.2 Empirical Design

Public demand can shape innovation across an industry, including at firms that do not win contracts, because products developed for public buyers also reach private customers. We therefore relate firm-year innovation outcomes to the public demand facing each firm’s industry:

$$Y_{ist} = \alpha_i + \delta_t + \beta_1 \text{IHS}(\text{Count}_{st}) + \beta_2 \log \text{Size}_{st} + \varepsilon_{ist}, \quad (1)$$

where  $Y_{ist}$  is an innovation outcome for firm  $i$  in industry  $s$  and year  $t$ ,  $\text{Count}_{st}$  is the number of awards, and  $\text{Size}_{st}$  is their average value. The inverse hyperbolic sine (IHS) transformation behaves like a logarithm for large counts and remains defined at zero. The coefficient  $\beta_1$  captures the association with contract count, holding average size fixed;  $\beta_2$  captures the association with average size, holding count fixed. For broad public-sector purchases, we replace the two contract measures with purchases in percent of industry output (Appendix C.1).

Firm fixed effects,  $\alpha_i$ , absorb time-invariant firm characteristics, including permanent differences in firms’ orientation toward public or private buyers, and year effects,  $\delta_t$ , absorb aggregate shocks. The coefficients therefore measure within-firm associations with changes in industry exposure, averaged over contract winners, unsuccessful bidders, and non-participants. We report the association of a one-standard-deviation increase in each measure, relative to the outcome mean, pooled and for manufacturing, with standard errors clustered by industry.

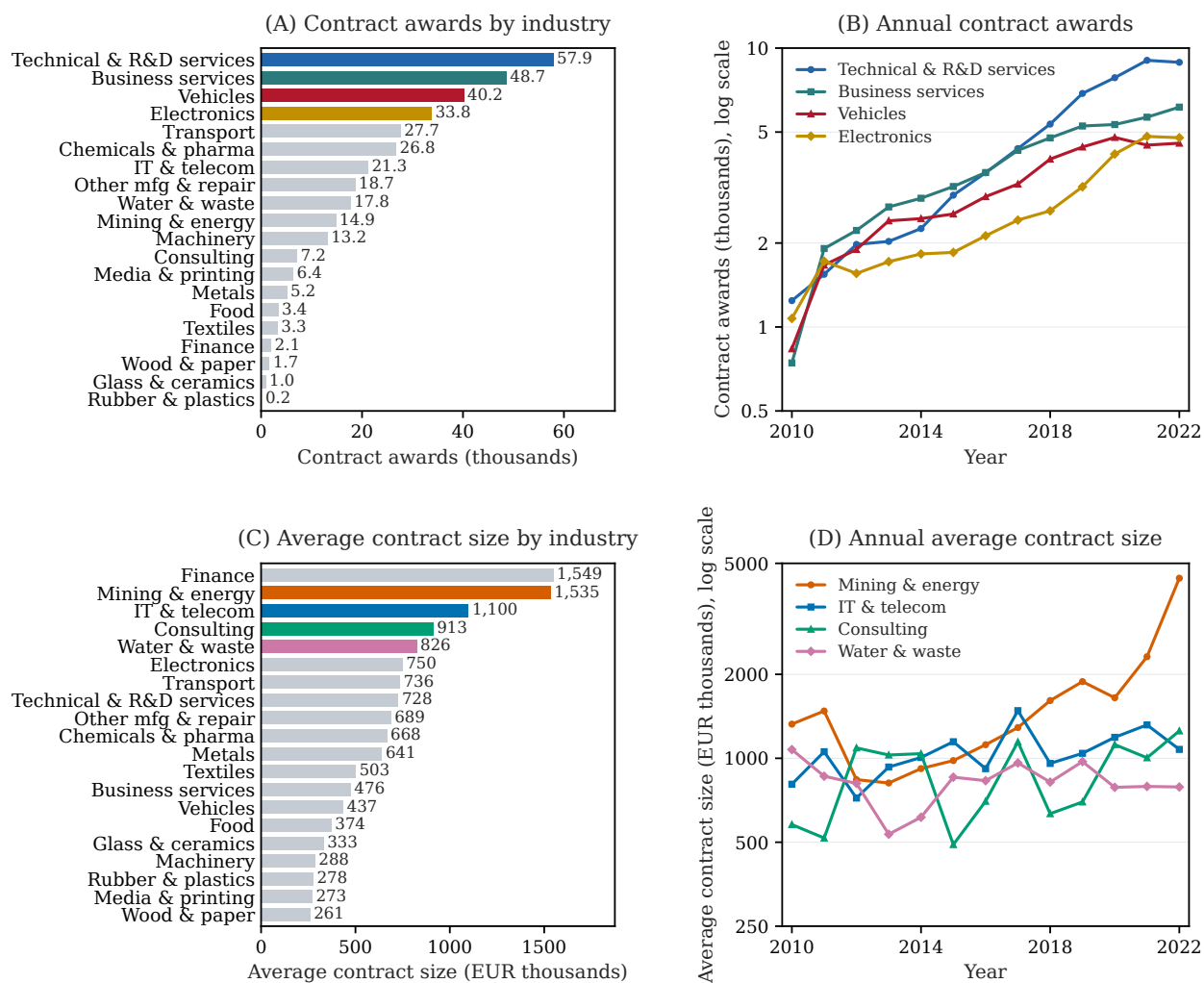


Figure 2: Public contracts across industries and over time, 2010–2022

*Notes:* Left panels rank industries by total awards (A) and average contract size (C). Right panels follow the highlighted industries on log scales; finance, with about 50 valued awards a year, is not highlighted. Average size divides the value of non-framework awards with usable prices, winsorized at the 99.9th percentile, by the number of such awards. Wholesale is excluded. Awards are in thousands; sizes are in thousands of current euros.

*Source:* Authors' calculations using TED awards, 2010–2022.

## 2.3 Results

Table 1 reports the baseline estimates, for the contract measures in Panel A and for broad public-sector purchases in Panel B. In Panel A, column (1) examines the kind of products innovators introduce. Holding the number of contracts fixed, a one-standard-deviation increase in average contract size corresponds to a 1.07 percentage-point lower probability that an innovator introduces a product new to the market, 2.6 percent of the mean. In manufacturing, the decline is 1.44 points, 3.0 percent of the mean. The number of contracts has no such association, with a coefficient of 0.43 points. Larger public contracts are thus associated with innovation closer to existing products.

Columns (2) and (3) turn to the share of sales from new products and to R&D intensity. At a given average size, a one-standard-deviation increase in the number of contracts corresponds to a 1.59 percentage-point lower new-product sales share, 6 percent of the mean, and to 0.12 percentage points higher R&D intensity, 11 percent of the mean. Firms in industries with more public contracts thus spend more on R&D but earn more of their revenue from products they already sell. By contrast, larger contracts are associated with lower R&D intensity, by 3 percent of the mean. Together, the three columns indicate that the number of contracts moves with how much firms spend on innovation, and their size with how close to existing products innovators stay.

Panel B turns to broad public-sector purchases. A one-standard-deviation increase in these purchases corresponds to a 2.26 percentage-point lower probability of market novelty among product innovators, 5.4 percent of the mean, and to a 3.28-point decline in manufacturing. It also corresponds to a 1.31-point lower new-product sales share, 4.9 percent of the mean. Unlike the number of contracts, broad purchases have no association with R&D intensity. Public demand as a whole is therefore associated with innovation closer to existing products.

What does a lower novelty share among innovators mean? The share divides the number of firms with market novelties by the number with any product innovation, and it falls when the first shrinks or the second grows. Appendix Table C4 estimates each separately. In manufacturing, where the size association is concentrated, larger contracts are associated with more firms with product innovations, 0.90 percentage points for a one-standard-deviation increase, and no change in the share of firms with market novelties. Broad public-sector purchases are instead associated with fewer firms introducing market novelties, mainly in manufacturing. Both patterns point to a composition of innovation closer to existing products.

Why might public demand favor existing products? Intuitively, public buyers reward products that meet their specifications, and adapting a product that already meets them is often cheaper than developing a new one. Public demand may then raise the return to incremental improvements

TABLE 1—PUBLIC DEMAND AND INNOVATION OUTCOMES

|                                               | (1)<br>Market novelty<br>among product<br>innovators (pp) | (2)<br>New-product sales<br>(% of total sales) | (3)<br>R&D expenditure<br>(% of sales) |
|-----------------------------------------------|-----------------------------------------------------------|------------------------------------------------|----------------------------------------|
| <b>Panel A. Contract records</b>              |                                                           |                                                |                                        |
| <i>All industries</i>                         |                                                           |                                                |                                        |
| Contract count                                | 0.43<br>(1.59)                                            | −1.59*<br>(0.81)                               | 0.12***<br>(0.04)                      |
| Relative to mean (%)                          | 1.0                                                       | −5.9                                           | 10.9                                   |
| Average contract size                         | −1.07*<br>(0.62)                                          | 0.36<br>(0.26)                                 | −0.03*<br>(0.02)                       |
| Relative to mean (%)                          | −2.6                                                      | 1.3                                            | −2.8                                   |
| Observations                                  | 14,081                                                    | 13,872                                         | 51,823                                 |
| <i>Manufacturing</i>                          |                                                           |                                                |                                        |
| Contract count                                | 0.57<br>(2.12)                                            | −2.15**<br>(0.87)                              | 0.13**<br>(0.06)                       |
| Relative to mean (%)                          | 1.2                                                       | −8.2                                           | 9.5                                    |
| Average contract size                         | −1.44***<br>(0.45)                                        | 0.38<br>(0.27)                                 | −0.05**<br>(0.02)                      |
| Relative to mean (%)                          | −3.0                                                      | 1.5                                            | −3.4                                   |
| Observations                                  | 8,779                                                     | 8,696                                          | 24,078                                 |
| <b>Panel B. Broad public-sector purchases</b> |                                                           |                                                |                                        |
| <i>All industries</i>                         |                                                           |                                                |                                        |
| Broad public-sector purchases                 | −2.26*<br>(1.13)                                          | −1.31*<br>(0.64)                               | −0.01<br>(0.04)                        |
| Relative to mean (%)                          | −5.4                                                      | −4.9                                           | −0.7                                   |
| Observations                                  | 14,993                                                    | 14,762                                         | 55,868                                 |
| <i>Manufacturing</i>                          |                                                           |                                                |                                        |
| Broad public-sector purchases                 | −3.28**<br>(1.28)                                         | −0.28<br>(0.43)                                | 0.01<br>(0.03)                         |
| Relative to mean (%)                          | −6.8                                                      | −1.1                                           | 0.4                                    |
| Observations                                  | 9,328                                                     | 9,246                                          | 25,796                                 |
| Firm and year FE                              | Yes                                                       | Yes                                            | Yes                                    |

*Notes:* Entries are percentage-point changes in each outcome for a one-SD increase in each measure, with SEs clustered by industry in parentheses (20 industries in Panel A, 21 in Panel B); relative rows divide the change by the outcome mean. Panel A enters IHS(contract count) and log average non-framework contract value in the firm's industry and year jointly, excluding wholesale (Appendix A.2). Panel B uses purchases by public administration and defense, education, and health and social work, in percent of industry output. Columns (1) and (2) condition on product innovation; column (3) includes firms without R&D. All regressions include firm and year fixed effects, 2010–2022. SDs are computed in each estimation sample. Manufacturing rows come from one regression interacting the measures with manufacturing status; services estimates and unstandardized coefficients are in Tables C3 and C1. \* $p < 0.10$ , \*\* $p < 0.05$ , \*\*\* $p < 0.01$ .

*Source:* Authors' calculations using the Mannheim Innovation Panel, Eurostat and TED awards.

relative to frontier novelties, consistent with lower novelty among innovators where broad public-sector purchases are higher. The contract measures fit the same logic. More contracts would call for more R&D spent on adapting existing products, consistent with higher R&D intensity and a smaller share of sales from new products. Larger contracts would raise the stakes of meeting a given specification. In ORBIS financial accounts matched to award records, a winner's awards in a given year equal 7.4 percent of its turnover at the median and 49.4 percent at the 90th percentile, and tender texts contain about as much specification language in large and small tenders for the same product (Appendices B.2 and C.8). The model in Section 3 formalizes the first channel, in which public demand raises the profits of incremental product lines.

The associations hold in several checks reported in Appendix C. On a common sample of product innovators observed for all three outcomes, the estimates keep their signs and similar magnitudes (Appendix Table C5). The manufacturing association between contract size and novelty strengthens with industry-specific trends, which also absorb differential changes in TED coverage, and pre-period tests do not detect differential trends (Appendices C.4 and C.6). Appendix C.4 also reports wild-cluster bootstrap  $p$ -values, which are designed for settings with few clusters.

Three remarks help interpret these results. First, the estimates are associations rather than causal effects. Public demand varies at the industry level, where contract characteristics move with the products, buyers, and suppliers in each industry. Contract winners also differ from other firms: in manufacturing, their product innovation rate is 15.6 percentage points higher, and they grow before their first observed award (Appendices B and C.7). Firm fixed effects absorb permanent differences across firms, but not changes in industry conditions.

Second, the findings are consistent with contract-level evidence from German tenders (Krieger et al., 2024) and specification-based defense awards in the United States (Howell et al., 2025). These studies provide complementary evidence on how procurement requirements relate to innovation.

Third, the estimates describe differences in innovation across industries, not their aggregate consequences. Those depend on how procurement affects entry, wages, and creative destruction. We therefore develop a quantitative model in which firms choose between frontier and incremental innovation, and use it to evaluate the growth implications of alternative procurement policies.

### 3 A Quality-Ladder Model with Procurement

We build a quality-ladder growth model to quantify how public demand affects the composition of innovation and aggregate growth. The framework draws on Klette and Kortum (2004), where firms operate portfolios of product lines subject to creative destruction, and on the quality-ladder tradition

of [Aghion and Howitt \(1992\)](#); [Aghion et al. \(2023\)](#). We extend this standard heterogeneous-firm growth model by letting firms choose, in addition to how much to innovate, whether each innovation targets a frontier or an incremental improvement, as in [Acemoglu et al. \(2022\)](#). Procurement affects this choice through relative payoffs. Incremental lines sell to both private and government buyers, while frontier lines sell to private buyers only, and procurement therefore raises the return to incremental innovation and compresses the premium to frontier innovation. The economy consists of a representative household, a final-good sector, heterogeneous incumbent firms that innovate, entrants that acquire product lines, and a government that buys from incremental lines. Appendix Table D1 summarizes the model's definitions and equations.

### 3.1 Environment

Time is continuous,  $t \in [0, \infty)$ . The economy has a unit mass of product lines, indexed by  $j \in [0, 1]$ . The quality leader of each line produces it, and a firm can lead many lines.

*Households.* A representative household supplies labor inelastically, owns all firms, and has preferences over consumption paths

$$\int_0^\infty e^{-\rho t} \log C_t dt.$$

Aggregate private expenditure is the numeraire.

*Production.* A competitive final-good sector combines the output  $y_j$  of all lines with a log aggregator:

$$Y = \exp\left(\int_0^1 \log y_j dj\right). \quad (2)$$

The quality leader of line  $j$  produces its output with linear technology,

$$y_j = q_j \ell_j^P,$$

where  $q_j$  is the quality of the line and  $\ell_j^P$  is production labor.

*Firms and innovation.* A firm is described by its portfolio  $(n_I, n_F)$  of incremental and frontier lines, with  $N = n_I + n_F$  lines in total. Firms grow by innovating. Each line generates innovation attempts at Poisson rate  $x \geq 0$ , the innovation effort rate. A successful innovation improves on a rival's line, which the innovating firm takes over. With probability  $\mu \in [0, 1]$ , the frontier share, the innovation is a frontier improvement that raises quality by the factor  $\lambda_F$ ; with probability  $1 - \mu$ , it is an incremental improvement that raises quality by  $\lambda_I$ , where  $\lambda_F > \lambda_I > 1$ . The step also sets the new leader's quality lead over the next-best competitor. A firm with  $N$  lines therefore adds

incremental and frontier lines at rates

$$x(1 - \mu)N \quad \text{and} \quad x\mu N,$$

respectively. Creative destruction displaces each existing line at rate  $\tau > 0$ , determined in equilibrium by incumbent innovation and entry.

*Innovation costs.* Innovation uses R&D labor. Per line, a firm choosing effort  $x$  and frontier orientation  $\mu$  hires

$$\ell_R(x, \mu) = c_x x^\zeta + \frac{\kappa}{\eta} \mu^\eta, \quad c_x > 0, \zeta > 1, \kappa > 0, \eta > 1, \quad (3)$$

units of R&D labor, at monetary cost  $w \ell_R(x, \mu)$ . The first term is the labor cost of innovation effort and the second the labor cost of frontier orientation. Both are paid at the same wage  $w$ , and their relative cost therefore does not depend on the wage level. R&D costs do not depend on other firms' innovation, and no knowledge spillover favors one type of innovation over the other. The composition wedge studied here comes from procurement. Private and social returns to innovation still differ through the standard quality-ladder channels. Two forces push the private return below the social return. An innovator earns only the limit-pricing markup on its improvement, and only until a rival displaces it, while the higher quality persists in all future output. A third force pushes the other way, because taking over a rival's line transfers that rival's profits to the innovator.

*Entry.* Outside entrants acquire an existing product line by using  $\ell_E$  units of setup labor, with monetary entry cost  $w \ell_E$ . Entry is untargeted: entrants arrive randomly and take ownership of an incumbent line with equal probability, independently of its type or quality level. Entry governs firm turnover and the scale of creative destruction; quality growth comes from incumbent innovation.

*Government.* The government spends  $T \geq 0$  on procurement, measured relative to aggregate private expenditure, and finances it with a lump-sum tax of the same amount on households. In the benchmark, it buys only from incremental lines, whose attributes are easier to specify, monitor, and verify than those of frontier projects, and spreads spending evenly across them. With a share  $1 - \mu$  of incremental lines, each receives government demand  $G = T/(1 - \mu)$  relative to its private demand, while frontier lines sell to private buyers only. Government purchases are real goods, produced with the same technology and workforce as private sales. The asymmetry is a reduced-form demand wedge. Appendix E.6 derives it from a buyer penalty for procurement failure; scoring rules, audit requirements, or career incentives that reward compliance would generate the same wedge.

*Labor allocation.* The fixed labor endowment  $\bar{L}$  is used in production, incumbent R&D, and entry.

### 3.2 Agent Problems

*Household.* The household owns all firms, with value  $A_t$ , and solves

$$\max_{\{C_t\}} \int_0^\infty e^{-\rho t} \log C_t dt \quad \text{subject to} \quad \dot{A}_t = r_t A_t + w_t \bar{L} - T - P_t C_t. \quad (4)$$

where  $P_t$  is the price of the final good. Line values, profits, and wages are measured in units of private expenditure, normalized to  $P_t C_t = 1$ . With log utility, the Euler equation then gives a constant interest rate

$$r = \rho. \quad (5)$$

*Pricing.* Each quality leader sets the Bertrand limit price against the next-best rival. With the log aggregator, private expenditure is the same on every line and equals one in expenditure units. The leader prices at the rival's marginal cost, a markup  $\lambda_k$  over its own, and earns the profit share

$$\bar{\pi}_k = \frac{\lambda_k - 1}{\lambda_k}, \quad k \in \{I, F\}, \quad \bar{\pi}_F > \bar{\pi}_I > 0. \quad (6)$$

Government purchases add demand equal to a share  $G$  of private demand on each incremental line, sold at the same price. Per-line flow profits are

$$\pi_I(G) = \bar{\pi}_I(1 + G), \quad (7)$$

$$\pi_F(G) = \bar{\pi}_F. \quad (8)$$

The frontier premium equals

$$\pi_F(G) - \pi_I(G) = \bar{\pi}_F - \bar{\pi}_I(1 + G). \quad (9)$$

Higher government demand raises incremental profits and leaves frontier profits unchanged, compressing the flow payoff difference that makes frontier lines privately attractive. The premium remains positive for  $G < G^* \equiv \bar{\pi}_F / \bar{\pi}_I - 1$ .

*Incumbent firms.* Firms take per-line government demand  $G$  as given, since each firm is small relative to aggregate spending. A firm with portfolio  $(n_I, n_F)$  chooses common per-line innovation effort  $x$  and frontier orientation  $\mu$  and earns flow profits

$$n_I \pi_I(G) + n_F \pi_F(G) - (n_I + n_F) w \ell_R(x, \mu).$$

Each existing line generates innovation opportunities at rate  $x$ . Conditional on arrival, the firm creates an incremental line with probability  $1 - \mu$  and a frontier line with probability  $\mu$ . Rivals displace each existing line at rate  $\tau$ . The portfolio HJB is

$$\begin{aligned}
rV(n_I, n_F; G) = \max_{x, \mu} & \left\{ \underbrace{n_I \pi_I(G) + n_F \pi_F(G)}_{\text{flow operating profits}} - \underbrace{(n_I + n_F) w \ell_R(x, \mu)}_{\text{innovation and frontier-orientation costs}} \right. \\
& + (n_I + n_F) x \left[ (1 - \mu) \underbrace{\left( V(n_I + 1, n_F; G) - V(n_I, n_F; G) \right)}_{\text{arrival of a new incremental line}} \right. \\
& \quad \left. + \mu \underbrace{\left( V(n_I, n_F + 1; G) - V(n_I, n_F; G) \right)}_{\text{arrival of a new frontier line}} \right] \\
& + \tau n_I \underbrace{\left( V(n_I - 1, n_F; G) - V(n_I, n_F; G) \right)}_{\text{destruction of an incremental line}} \\
& \left. + \tau n_F \underbrace{\left( V(n_I, n_F - 1; G) - V(n_I, n_F; G) \right)}_{\text{destruction of a frontier line}} \right\}. \tag{10}
\end{aligned}$$

Profits, innovation arrivals, and destruction risks operate independently across lines, and the firm faces no firm-level resource constraint. The value function is therefore linear in the portfolio,

$$V(n_I, n_F; G) = n_I v_I(G) + n_F v_F(G), \tag{11}$$

and the marginal value of an additional line depends only on its type. Let

$$\mathbb{E}[v] \equiv (1 - \mu) v_I(G) + \mu v_F(G) \tag{12}$$

denote the expected value of an additional line. Substituting (11) into the portfolio HJB reduces the problem to two value equations:

$$(r + \tau) v_I(G) = \pi_I(G) - w \ell_R(x, \mu) + x \mathbb{E}[v], \tag{13}$$

$$(r + \tau) v_F(G) = \pi_F(G) - w \ell_R(x, \mu) + x \mathbb{E}[v]. \tag{14}$$

The equations differ only in flow profits. The value equations and the optimality conditions below jointly determine  $(v_I, v_F, x, \mu)$  for a given  $G$  and  $\tau$ . Appendix D.2 derives the system.

*Optimality.* The effort first-order condition is

$$wc_x \zeta x^{\zeta-1} = \mathbb{E}[v]. \quad (15)$$

The frontier-choice condition is

$$w\kappa\mu^{\eta-1} = x(v_F - v_I). \quad (16)$$

Equation (15) says that firms raise innovation effort until the marginal labor cost of another arrival equals the expected value of the additional line. Equation (16) requires the marginal labor cost of frontier orientation to equal the arrival rate times the value premium of a frontier line over an incremental line. Condition (16) holds for an interior choice  $\mu^* \in (0, 1)$ ; Appendix D.2 states the KKT conditions at the corners.

*Entrants.* An entrant acquires a random existing line, whose type follows the equilibrium line distribution, and its expected value is therefore  $\mathbb{E}[v]$ . Free entry equates this value to the setup cost:

$$\mathbb{E}[v] = w\ell_E. \quad (17)$$

### 3.3 General Equilibrium

The balanced-growth-path equilibrium combines the agents' problems with three aggregate conditions: consistency of the line mass, labor-market clearing, and fiscal balance.

*Line mass.* The unit mass of product lines is fixed, and each line changes hands when an incumbent innovates on it or an entrant acquires it. Let  $\tau$  denote the rate at which a given line changes hands and  $e$  the rate at which outside entrants acquire lines. Incumbents hold the unit mass of lines, and each line generates innovations at the Poisson rate  $x$ , each of which takes over a rival's line. Incumbents therefore take over lines at aggregate rate  $x$ , and the total ownership-change rate satisfies

$$x + e = \tau. \quad (18)$$

Hence  $e = \tau - x$ , aggregate entry labor is  $\ell_E(\tau - x)$ , and equilibrium requires  $x < \tau$ .

*Labor market.* The log aggregator makes the final-good sector spend the same amount on every line, one unit of private expenditure, and the government adds purchases  $G$  on each incremental line. Revenue is  $R_j = 1 + G$  on an incremental line and  $R_j = 1$  on a frontier line. The leader has marginal cost  $w/q_j$  and charges the rival's marginal cost,  $p_j = \lambda_k w/q_j$ . Its production labor is

$$\ell_j^P = \frac{y_j}{q_j} = \frac{R_j}{p_j q_j} = \frac{R_j}{\lambda_k w},$$

and wages absorb a share  $1/\lambda_k = 1 - \bar{\pi}_k$  of revenue. With a unit mass of lines, a share  $\mu$  of which are frontier lines, the production wage bill is

$$wL_P = \frac{(1 - \mu)(1 + G)}{\lambda_I} + \frac{\mu}{\lambda_F}. \quad (19)$$

Aggregate R&D labor equals the per-line requirement  $\ell_R(x, \mu)$  in (3), and entry uses  $\ell_E$  units per entrant. Labor-market clearing requires that production, R&D, and entry labor exhaust  $\bar{L}$ :

$$\bar{L} = L_P + \ell_R + \ell_E(\tau - x). \quad (20)$$

*Fiscal balance and household budget.* The government spreads its spending  $T$  over the  $1 - \mu^*$  incremental lines, each receiving  $G$ , and collects a tax equal to  $T$ . Its budget balances when

$$T = (1 - \mu^*)G. \quad (21)$$

The household owns all incumbent firms. The return on this wealth equals incumbents' operating profits net of R&D costs,  $\Pi_{\text{net}}$ , less the value of the lines that entrants take over,  $(\tau - x)\mathbb{E}[v] = w\ell_E(\tau - x)$  by free entry. On the balanced-growth path, wealth is constant, and (4) gives

$$P_t C_t = w\bar{L} + \Pi_{\text{net}} - w\ell_E(\tau - x) - T = 1, \quad (22)$$

where the last equality is the normalization. The household spends its wages and incumbents' net profits after paying the tax and the setup cost of entrants, which free entry equates to the value of the lines they take over.

*Growth.* Balanced-growth output growth  $g$  is

$$g = x \left[ (1 - \mu) \log \lambda_I + \mu \log \lambda_F \right]. \quad (23)$$

Only incumbent innovation appears in (23). Entrants change who owns a line and the size distribution of firms, and they add no quality steps.

**Definition 3.1** (General equilibrium). Given aggregate procurement spending  $T$ , the labor endowment  $\bar{L}$ , the discount rate  $\rho$ , and the innovation cost scale  $c_x$ , a balanced-growth-path general equilibrium is a collection of line values  $(v_I, v_F)$ , an innovation effort rate  $x$ , a frontier share  $\mu \in [0, 1]$ , a wage  $w$ , and a creative destruction rate  $\tau > x$  such that (i) line values satisfy the value equations (13) and (14) at the interest rate  $r = \rho$  from (5); (ii) firms choose innovation

effort according to (15) and frontier orientation according to (16), with the corner conditions in Appendix D.2; (iii) free entry (17) holds; (iv) the labor market clears according to (20); and (v) per-line procurement satisfies the fiscal rule (21).

The equilibrium is a system of six equations in six unknowns,  $(v_I, v_F, x, \mu, w, \tau)$ , once the fiscal rule substitutes  $G = T/(1 - \mu)$ . To solve it, we update the wage, the destruction rate, and per-line demand until the incumbent conditions, free entry, labor-market clearing, and the spending rule hold jointly (Appendix D.4). Counterfactuals vary  $T$  or the procurement allocation rule and re-solve the system, holding structural parameters and the innovation cost functions fixed.

### 3.4 Characterization

*Procurement and the frontier premium.* Subtracting (13) from (14) gives the frontier premium:

$$v_F(G) - v_I(G) = \frac{\pi_F(G) - \pi_I(G)}{r + \tau} = \frac{\bar{\pi}_F - \bar{\pi}_I(1 + G)}{r + \tau}. \quad (24)$$

Government demand raises incremental-line profits and leaves frontier-line profits unchanged, and at a given creative-destruction rate the premium therefore falls as  $G$  rises. On the interior region, substituting (24) into (16) gives

$$\mu(G) = \left[ \frac{x^*(G)}{\kappa w(G)} \cdot \frac{\bar{\pi}_F - \bar{\pi}_I(1 + G)}{r + \tau} \right]^{1/(\eta-1)}. \quad (25)$$

The constrained policy is the projection of  $\mu(G)$  onto  $[0, 1]$ .<sup>9</sup>

In equation (25), a firm pursues frontier innovations until the extra cost of doing so equals the extra value of a frontier line, which is its profit premium over an incremental line, earned until a rival displaces it. Government demand changes this trade-off in three ways. Incremental lines now also sell to the government, which narrows the profit premium. Government demand also draws labor into production and can raise the wage, which makes frontier orientation more expensive. It also changes how fast rivals displace lines, and with it how long a frontier line keeps its premium. Innovation effort does not respond. Free entry ties the value of a line to the labor cost of entry, and when public demand raises profits, the wage rises until the return to effort again equals its cost. An R&D credit lowers that cost and raises effort. When the cost of effort rises with frontier orientation, procurement also moves effort, and the growth effects of both policies change by at most 0.2 basis points (Section 6.3). Proposition 3.2 states when the first two channels dominate the third.

<sup>9</sup>Both line types earn positive flow profits for all  $G \geq 0$ . The condition  $G < G^*$  keeps the frontier premium positive; Appendix D.2 states the optimality condition when counterfactuals reach the corner  $\mu^* = 1$ .

**Proposition 3.2** (Procurement and frontier orientation). *Suppose free entry holds, the frontier share is interior,  $\mu^* \in (0, 1)$ , and the flow profit premium  $D(G) \equiv \bar{\pi}_F - \bar{\pi}_I(1 + G)$  is positive. Then:*

- (i) *innovation effort  $x^*$  does not depend on government demand  $G$ ;*
- (ii) *the frontier share falls with  $G$  if and only if*

$$\underbrace{\frac{\bar{\pi}_I}{D(G)}}_{\text{premium compression}} + \underbrace{\frac{1}{w(G)} \frac{\partial w(G)}{\partial G}}_{\text{wage}} + \underbrace{\frac{1}{r + \tau} \frac{\partial \tau}{\partial G}}_{\text{creative destruction}} > 0.$$

Appendix D.2 gives the proof.

The frontier share falls when premium compression and any wage increase outweigh the creative-destruction term. In the estimated model, creative destruction slows as procurement rises, which lengthens the life of a frontier line and works against the decline, and the condition still holds.

In the model, higher  $T$  raises  $G$ , lowers the frontier share, and leaves effort unchanged. Growth therefore responds to procurement only through the composition of innovation. Section 4.3 maps  $T$  and  $G$  to the public-demand measures of Section 2.

*Labor reallocation.* Procurement also raises production labor  $L_P$  on incremental lines, which competes with incumbent R&D and entry for the fixed endowment in (20). Because the endowment is fixed, every counterfactual growth gain reallocates labor across production, R&D, and entry.

*Composition wedge.* The composition shift is a dynamic allocation wedge. Under Bertrand pricing, frontier lines earn a higher operating-profit share than incremental lines ( $\bar{\pi}_F > \bar{\pi}_I$ ) and generate larger quality steps ( $\lambda_F > \lambda_I$ ). Procurement raises only the incremental payoff. The private return to frontier orientation therefore falls even though the growth contribution of a frontier step remains high. Appendix D.3 formalizes and distinguishes it from a static markup-dispersion channel.

### 3.5 Stationary Distribution

Firms differ in how many lines they hold and how many of them are frontier lines. Two equilibrium objects determine both. The first is how often a line that changes hands goes to an incumbent, which governs firm size. The second is the frontier share  $\mu^*$ , which governs portfolio composition.

Let  $N = n_I + n_F$  denote total firm scope. A firm gains lines by displacing rivals at rate  $x^*N$  and loses lines to rivals at rate  $\tau N$ , and each entrant begins with a single line. The probability that a line

changing hands goes to an incumbent is

$$\theta \equiv \frac{x^*}{\tau} \in (0, 1),$$

and higher  $\theta$  means larger firms. In steady state, the flow of firms that grow from  $n - 1$  to  $n$  lines equals the flow of firms that shrink from  $n$  to  $n - 1$ ,

$$x^*(n - 1) \Pr(N = n - 1) = \tau n \Pr(N = n), \quad n \geq 2.$$

Solving this recursion gives the logarithmic distribution of [Klette and Kortum \(2004\)](#),

$$\Pr(N = n) = \frac{\theta^n}{n[-\log(1 - \theta)]}, \quad n \geq 1, \quad (26)$$

named after its normalizing constant,  $-\log(1 - \theta) = \sum_{n \geq 1} \theta^n / n$ . The probability of a large portfolio falls geometrically with size, at rate  $\theta$ , because each additional line must be won before one is lost.

Each new line is frontier with probability  $\mu^*$ , independently of the firm's other lines, and destruction and entry do not depend on line type. Given  $N = n$ , the number of frontier lines is binomial,

$$\Pr(n_F = b \mid N = n) = \binom{n}{b} (\mu^*)^b (1 - \mu^*)^{n-b}, \quad (27)$$

and the joint distribution of portfolios is

$$\Gamma(n_I, n_F) = \Pr(N = n_I + n_F) \binom{n_I + n_F}{n_F} (\mu^*)^{n_F} (1 - \mu^*)^{n_I}. \quad (28)$$

The scope distribution also delivers the model counterparts of two estimation moments, the large-firm share and annual firm exit ([Section 4](#)).

Procurement moves the cross section through both scalars. A lower frontier share shifts every portfolio toward incremental lines, and slower creative destruction raises  $\theta$  and makes firms larger. [Proposition 3.3](#) states three implications for observable firm characteristics.

**Proposition 3.3** (Cross-sectional implications of procurement). *Let  $s_F \equiv n_F / N$  denote a firm's frontier share. Under  $\Gamma$ :*

- (i) *The average frontier share across firms equals the frontier share of new lines,  $\mathbb{E}[s_F] = \mu^*$ .*

- (ii) *The share of firms without a frontier line averages, over the size distribution, the probability  $(1 - \mu^*)^n$  that all  $n$  lines of a firm are incremental:*

$$\Pr(n_F = 0) = \sum_{n \geq 1} \Pr(N = n)(1 - \mu^*)^n = \frac{-\log(1 - \theta(1 - \mu^*))}{-\log(1 - \theta)},$$

*which rises when  $\mu^*$  falls and falls when  $\theta$  rises.*

- (iii) *Average operating profit per line is  $\mu^* \bar{\pi}_F + (1 - \mu^*) \bar{\pi}_I(1 + G)$ .*

In the estimated model, higher government demand lowers  $\mu^*$  and raises  $\theta$ . Firms become larger and hold a smaller share of frontier lines. Since larger firms are more likely to hold at least one frontier line, the two forces move the share of firms without frontier lines in opposite directions. They also explain why novelty among innovators can fall while the share of innovative firms rises, the pattern in the manufacturing evidence of Section 2. The next section estimates the four structural parameters by matching seven moments on innovation, firm size, exit, R&D labor, and profitability.

## 4 Quantitative Analysis

The quantitative analysis fits the model to innovation composition and firm dynamics, then compares policy reforms along the composition and effort margins. The data sources play distinct roles. The contract records motivate the mechanism, the MIP and BHP moments discipline the parameters, and the input-output associations test the model's response to public demand.

### 4.1 Parameterization

*Empirical sample.* Innovation moments come from the 2009–2018 MIP, with 51,185 firm-years and 16,578 product innovators. Firm size comes from the ZEW population frame, where mean employment of approximately 54 workers among firms with at least five employees maps model labor units to employees. Exit comes from the BHP. Appendix E.1 describes the samples.

*Externally calibrated objects.* We set the household discount rate to  $\rho = 0.04$ , a standard value in the quantitative growth literature, which gives  $r = \rho$  in expenditure units. Annual TFP growth is  $\bar{g} = 0.34\%$ , the 2000–2019 trend of German TFP in the Penn World Table (Feenstra et al., 2015). The curvature of the effort cost,  $\zeta = 2$ , matches the R&D-elasticity calibration in Acemoglu et al. (2018), which draws on microeconomic estimates of the elasticity of innovation output to R&D, and the curvature of the frontier-orientation cost is a quadratic normalization,  $\eta = 2$ .

*Procurement spending.* Aggregate procurement spending  $T$  matches the share of public purchases in the output of MIP-covered industries, 2.5 percent in the 2019 national accounts. Public purchases are the goods and services the government buys as intermediate inputs plus its investment in equipment and software. The measure is narrower than the 9.2 percent of GDP in Figure 1, which also includes construction and industries outside the survey. The model measures procurement relative to private spending, and a public share of 2.5 percent of output corresponds to public purchases of 2.6 cents per euro of private spending,  $T = 0.026$ . In the benchmark, the government buys only from incremental lines. Spread over the 71 percent of lines that are incremental,  $T$  gives each incremental line government demand equal to 3.7 percent of its private demand,  $G_I = 0.037$ , and frontier lines receive none,  $G_F = 0$ . The benchmark is close to German practice. Procedures designed to buy innovative products (competitive dialogue and innovation partnerships) cover about 0.1 percent of German contract awards and 1 percent of their value (Appendix E.10), and many contract notices specify existing equipment, compatibility, or delivery requirements (Appendix Table C13). Table 2 lists the parameters and their sources.

## 4.2 Estimation

We estimate the structural parameter vector  $\psi = (\lambda_I, \lambda_F, \kappa, \ell_E)$  by overidentified GMM, targeting seven moments with direct model counterparts: (i) novelty among product innovators, (ii) the novelty revenue share among new products, (iii) the share of firms with a product innovation, (iv) the large-firm share, (v) annual exit, (vi) the R&D personnel share, and (vii) the profitability gap associated with market novelty. The GMM objective is

$$\hat{\psi} = \arg \min_{\psi} [m(\psi) - \hat{m}]^T W [m(\psi) - \hat{m}],$$

where  $m(\psi)$  stacks the model moments,  $\hat{m}$  their empirical counterparts, and  $W$  is the inverse of the empirical covariance of the moments, with MIP sampling uncertainty clustered by firm. Appendix E.1 describes the samples and the measurement of each moment.

Growth is not a targeted moment. For each candidate  $\psi$ , the innovation cost scale  $c_x$  adjusts so that the model matches German TFP growth of 0.34 percent exactly. The estimated parameters therefore govern innovation composition and firm dynamics independently of the level of growth, and growth moves freely in the counterfactuals.

*Identification.* The system has four estimated parameters and seven targeted moments, which yield three overidentifying restrictions. All seven moments discipline the parameters jointly, and Appendix Figure E1 shows how each moment responds to each parameter. Two groups of moments are the main source of discipline for the two blocks of the model.

The composition moments, novelty among product innovators, the novelty revenue share, and the profitability gap, are the main source of discipline for the frontier-choice block  $(\lambda_I, \lambda_F, \kappa)$ . A higher  $\kappa$  raises the cost of frontier-oriented innovation, lowers frontier orientation, and reduces novelty among product innovators and the novelty revenue share. The quality steps shape the profit premium  $\bar{\pi}_F - \bar{\pi}_I$ . Under limit pricing, a line's markup equals its quality step, and a larger frontier step therefore raises the novelty revenue share and the profitability gap between innovators with and without market novelties.

The scope-and-entry moments, the large-firm share, annual exit, the share of firms with a product innovation, and the R&D personnel share, are the main source of discipline for  $\ell_E$ . A higher  $\ell_E$  raises the labor cost of entry, lowers entry, and slows the rate at which entrants break up incumbent portfolios. Firms become larger, exit falls, and the R&D share of labor rises.

*Measurement.* The model moments are constructed as in the data. We interpret frontier innovations as products new to the market. Novelty among product innovators uses exact three-year probabilities that account for firm survival and entry, and annual exit is the probability that a firm loses all its lines. The BHP exit target measures establishment exits, a proxy for firm exit whose role we assess below. The associations between public demand and innovation in Section 2 are not targeted, and Section 4.3 compares them with the model.

TABLE 2—MODEL PARAMETERS

|                                                           | Symbol                 | Value  | Standard error or source                                         |
|-----------------------------------------------------------|------------------------|--------|------------------------------------------------------------------|
| <i>Panel A. Estimated parameters (GMM, seven moments)</i> |                        |        |                                                                  |
| Frontier quality step                                     | $\lambda_F$            | 1.154  | (0.027)                                                          |
| Incremental quality step                                  | $\lambda_I$            | 1.074  | (0.011)                                                          |
| Frontier-orientation cost                                 | $\kappa$               | 0.100  | (0.047)                                                          |
| Setup labor per entrant                                   | $\ell_E$               | 1.383  | (0.098)                                                          |
| <i>Panel B. Externally calibrated</i>                     |                        |        |                                                                  |
| Household discount rate                                   | $\rho$                 | 0.040  | Standard value in the growth literature                          |
| Annual TFP growth                                         | $\bar{g}$              | 0.34%  | <a href="#">Feenstra et al. (2015)</a>                           |
| Aggregate procurement spending                            | $T$                    | 0.026  | 2019 national accounts                                           |
| Innovation-effort cost curvature                          | $\zeta$                | 2.000  | <a href="#">Acemoglu et al. (2018)</a>                           |
| Frontier-orientation cost curvature                       | $\eta$                 | 2.000  | Normalization                                                    |
| Mean employment, firms with $\geq 5$ workers              | $\bar{L}_{\text{pop}}$ | 54.37  | ZEW population frame                                             |
| <i>Panel C. Implied objects</i>                           |                        |        |                                                                  |
| Innovation cost scale                                     | $c_x$                  | 18.735 | Matches annual TFP growth $\bar{g}$                              |
| Government demand per incremental line                    | $G_I$                  | 0.037  | $T$ spread evenly over incremental lines; none on frontier lines |
| Frontier per-line profit                                  | $\bar{\pi}_F$          | 0.134  | Bertrand pricing                                                 |
| Incremental per-line profit                               | $\bar{\pi}_I$          | 0.069  | Bertrand pricing                                                 |
| Wage                                                      | $w$                    | 0.972  | Labor-market clearing                                            |

*Notes:* The model is overidentified, with seven empirical moments and four estimated parameters. Panel A reports GMM estimates with standard errors in parentheses; the covariance of the empirical moments clusters MIP moments at the firm level and adds nonsampling uncertainty for the revenue and R&D shares and cross-year variation for size and exit. Per-line profits follow from the quality steps under Bertrand pricing,  $\bar{\pi}_k = (\lambda_k - 1)/\lambda_k$ , and exclude government purchases. Aggregate model labor is normalized to one, and  $\bar{L}_{\text{pop}}$  maps model labor to employees. The cost scale  $c_x$  is set to match annual TFP growth at each parameter vector.

*Source:* Authors' calculations using MIP, ZEW population frames, BHP, and input-output accounts.

*Baseline estimates.* The frontier quality step  $\hat{\lambda}_F = 1.154$  implies a 15.4 percent quality improvement per frontier innovation, and the incremental step  $\hat{\lambda}_I = 1.074$  implies a 7.4 percent improvement, about half as large. Firms with market novelties are more profitable in the data, and the larger frontier step reproduces that profitability gap. Under limit pricing, the steps are also the markups of the two line types, and markups of 15 and 7 percent bracket the 10 percent average markup in [Akcigit and Ates \(2023\)](#).

Under Bertrand competition, per-line profit shares follow from the quality steps,  $\bar{\pi}_F = 13.4$  percent and  $\bar{\pi}_I = 6.9$  percent, a frontier premium of 6.5 percentage points. Procurement erodes the premium. Incremental lines sell to both private and government buyers, which raises their profits by the factor  $(1 + G_I)$ , and frontier lines sell to private buyers only. As  $G_I$  rises, the gap narrows and frontier orientation ( $\mu^*$ ) falls. The frontier-orientation cost  $\hat{\kappa} = 0.100$  implies that orienting innovation

toward the frontier absorbs 14 percent of incumbent R&D labor. Given the estimates, entry absorbs 0.7 percent of the labor force and clears the free-entry condition at the estimated creative-destruction rate of 4.2 percent.

TABLE 3—MODEL FIT: EMPIRICAL AND MODEL MOMENTS

| Targeted moment (%)                      | Data | (Std. error) | Model |
|------------------------------------------|------|--------------|-------|
| Novelty among product innovators         | 37.6 | (0.7)        | 37.6  |
| Novelty revenue share among new products | 25.4 | (5.3)        | 28.3  |
| Firms with a product innovation          | 25.8 | (0.4)        | 26.2  |
| Large-firm share                         | 2.8  | (0.1)        | 2.4   |
| Annual exit                              | 2.4  | (0.2)        | 1.7   |
| R&D personnel share                      | 3.4  | (0.3)        | 3.0   |
| Profitability gap (pp)                   | 0.43 | (0.34)       | 0.65  |

*Notes:* All moments are in percent, except the profitability gap, which is in percentage points. Innovation moments come from the 2009–2018 MIP with population raking weights, and the profitability gap from the 2003–2017 waves. Firm size comes from the ZEW population frame and exit from the BHP. Standard errors cluster MIP moments at the firm level and add nonsampling uncertainty for the revenue and R&D shares; size and exit use cross-year variation. The large-firm share is the share of firms with at least 250 workers among firms with at least five. Annual exit is the BHP establishment-exit rate. The R&D target imputes values above the survey’s top code. The profitability gap is the within-firm return-on-sales gap between product innovators with and without market novelties.

*Source:* Authors’ calculations using the estimated model, the MIP, ZEW population frames, and BHP.

*Model fit.* Table 3 reports the model’s fit. First, five of the seven moments lie within two standard errors of their targets, and the four innovation and profitability moments lie within one. At the estimate, 37.6 percent of product innovators introduce a market novelty, as in the data, and 29.1 percent of new lines are frontier lines. Second, the gaps are concentrated in the large-firm share (2.4 versus 2.8 percent) and annual exit (1.7 versus 2.4 percent).

### 4.3 Comparative Statics and the Reduced-Form Evidence

Figure 3 traces the model’s endogenous variables as aggregate procurement spending rises, holding the innovation cost scale fixed. The pattern is a composition shift. The frontier share and novelty among product innovators fall, firms grow larger, creative destruction slows, and innovation effort does not move. The model generates these patterns without targeting them. These predictions are consistent with the negative association between broad public-sector purchases and novelty, and the absence of a statistically detectable association with R&D intensity (Section 2).

Why does novelty fall as procurement spending rises? Higher spending raises per-line profits on incremental lines, which sell to both private and government buyers, and leaves frontier-line

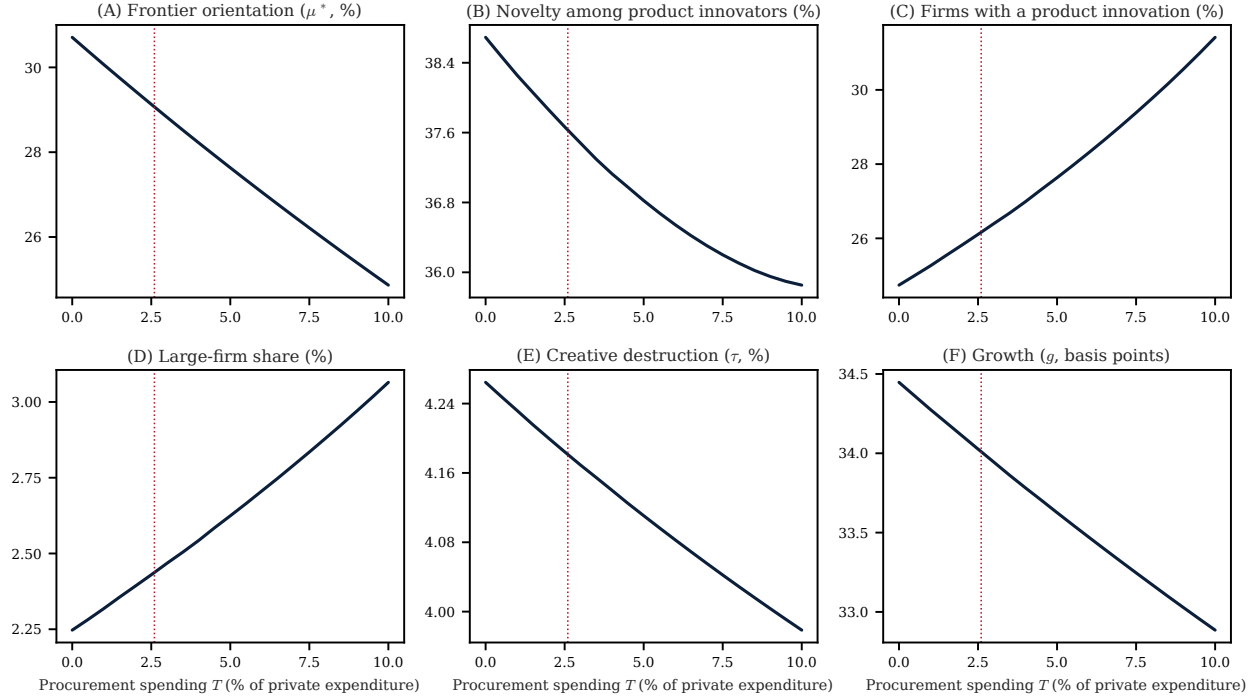


Figure 3: Comparative statics over procurement spending

*Notes:* The figure reports six model outcomes as functions of aggregate procurement spending  $T$ , at the estimated parameters and with the innovation cost scale  $c_x$  held fixed. The dotted vertical line marks the benchmark  $T = 0.026$ . Panels report frontier orientation  $\mu^*$ , novelty among product innovators, the share of firms with a product innovation, the share of firms with at least 250 workers among firms with at least five, creative destruction  $\tau$ , and growth  $g$ . Innovation effort is constant at  $x = 0.037$  over the range. The horizontal axis reports procurement spending as a percent of private expenditure. Novelty and the share of firms with a product innovation use the three-year mappings of the estimation. *Source:* Authors' calculations from the estimated model.

profits unchanged. The narrower frontier premium lowers the return to frontier innovation, and incumbents respond by lowering their frontier orientation ( $\mu^*$ ), the share of new lines at the frontier. From zero spending to the benchmark, frontier orientation falls from 30.7 to 29.1 percent, and the share of product innovators with a market novelty falls from 38.7 to 37.6 percent. Broad public-sector purchases, the empirical counterpart of procurement spending, are also associated with lower novelty. For a one-percentage-point increase in procurement exposure, the model predicts a 0.42-point decline, compared with 1.11 points in the data. The model reproduces the sign of this untargted association and about two-fifths of its size.

Procurement also changes who holds product lines. Producing for the government takes workers, which raises the wage and makes entry more expensive. With fewer entrants, incumbents keep their lines longer and hold more of them. Larger firms innovate on more lines, and the share of firms with a product innovation rises from 24.7 to 26.2 percent. Most of this increase comes from firms introducing only incremental products, and the share of all firms with a market novelty rises only slightly, from 9.6 to 9.8 percent. Novelty among product innovators therefore falls in part

because more firms innovate. A similar pattern appears in the manufacturing evidence, where larger contracts are associated with greater product innovation but lower novelty conditional on innovating.<sup>10</sup>

Why does innovation effort not move? Combining the incumbent's effort condition with free entry makes effort depend only on the entry requirement and the cost of effort, neither of which changes with procurement. Firms therefore innovate as often as before, consistent with the absence of a statistically detectable association between broad public-sector purchases and R&D intensity in the data. With fewer frontier innovations, average quality improvements are smaller, and annual growth falls by 0.44 basis points from zero procurement to the benchmark.

The model thus distinguishes two margins through which policy affects growth: innovation effort and innovation composition. Procurement concentrated on incremental lines moves the composition and leaves effort unchanged. An R&D credit lowers the private marginal cost of effort and raises the rate at which firms improve product quality. Section 5 quantifies how much each margin contributes to growth and welfare.

## 5 Policy Counterfactuals

We conduct a series of counterfactual experiments to understand the quantitative implications of our estimated model. In each experiment, we change one policy object and hold the estimated parameters and the innovation cost scale fixed. First, in our primary exercise, the government reallocates procurement funds to an R&D tax credit modeled to match Germany's current R&D tax subsidy rate. Second, in a specification realignment, the government keeps total procurement spending fixed and gives frontier and incremental product lines the same public demand. Table 4 summarizes the results.

For each experiment, we maintain a common approach to adjusting the fiscal details of the model. A lump-sum tax on households finances procurement purchases and credit payments, and the fiscal accounting therefore matters only through the use of public resources. The experiments differ in whether procurement funds are redeployed to R&D support or reallocated across product lines at a fixed budget. Labor-market clearing counts the full labor requirements of innovation effort and frontier orientation. We measure welfare as the permanent percentage change in real private consumption that makes households indifferent between the benchmark and the policy, including the transition from the benchmark stock of products (Appendix D.5). Government purchases enter

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<sup>10</sup>In manufacturing, a one-standard-deviation increase in average contract size corresponds to 0.90 percentage points more firms with a product innovation, 1.44 points less novelty among product innovators, and a 0.09-point lower share of all firms with a market novelty (Appendix Table C4).

as a resource cost. With aggregate quality  $Q_t$  and stock frontier share  $\mathcal{M}_t$ , Bertrand prices and the log aggregator imply that real consumption per unit of quality,  $c_t = C_t/Q_t$ , satisfies

$$\log c_t = -\log w_t - (1 - \mathcal{M}_t) \log \lambda_I - \mathcal{M}_t \log \lambda_F. \quad (29)$$

At a common initial quality level, the steady-state consumption equivalent is

$$\text{CEV}_{B,A}^{\text{ss}} = 100 \left\{ \exp \left[ \Delta \log c + \frac{g_B - g_A}{\rho} \right] - 1 \right\}. \quad (30)$$

### 5.1 Main Counterfactual: An R&D Tax Credit

R&D tax credits are the standard instrument for supporting private innovation effort (Hall and Van Reenen, 2000; Bloom et al., 2002). Germany introduced one in January 2020, the *Forschungszulage*, which refunds 25 percent of eligible R&D personnel costs.<sup>11</sup> Our primary exercise asks how growth and welfare change when part of the procurement budget finances the same kind of credit.

In practice, we model the credit to match the 19 percent implied R&D tax subsidy rate for German firms in 2023 (OECD, 2024). Reallocating one-quarter of benchmark procurement spending, about 0.6 percent of output in the surveyed industries, to a subsidy on the effort cost of incumbent R&D pays 17.7 percent of those costs in steady state. The remaining purchases continue to serve incremental lines. The incumbent Bellman equations become

$$(r + \tau)v_k = \bar{\pi}_k(1 + G_k) - w \left[ (1 - s)c_x x^\zeta + \frac{\kappa}{\eta} \mu^\eta \right] + x \mathbb{E}[v], \quad k \in \{I, F\}. \quad (31)$$

The credit lowers the cost of effort only. Combining the effort condition with free entry gives

$$x(s) = \left( \frac{\ell_E}{(1 - s)c_x \zeta} \right)^{1/(\zeta-1)}.$$

Higher effort also raises the frontier share, because the value of frontier orientation grows with the number of innovations it applies to (equation (25)).

Table 4 reports the results. First, the credit raises innovation effort by about one-fifth. Incumbents draw the additional R&D workers mostly from production and partly from entry, which shrinks as incumbents take over a larger share of creative destruction. Higher effort also raises the payoff to frontier orientation, and the frontier share of new lines rises by about 4.6 percentage points. Second,

<sup>11</sup>The credit also covers part of the payments for contract research. The assessment base is capped per firm, at 10 million euros since 2024, and small and medium-sized firms receive 35 percent.

annual growth rises by about 9 basis points, five-sixths of it from higher effort. Third, welfare rises by 1.9 percent of permanent consumption. A larger frontier share raises average markups and lowers consumption per unit of quality (Peters, 2020), but faster quality growth makes up for the loss within about three years. Reallocating the entire procurement budget nearly triples the growth gain (Section 6.4).

## 5.2 Procurement Allocation at a Fixed Budget

The credit changes how much the government spends on innovation effort. Procurement design offers a second margin, what the government buys at a given budget. In the benchmark, public demand reaches only incremental lines, as it does when buyers specify proven products. Open-topic competitions in U.S. defense research, which let firms propose the technology, raise commercial innovation among participating firms (Howell et al., 2025), and the innovation-policy literature advocates functional specifications, which describe the need a purchase must meet (Uyarra et al., 2014; Edquist and Zabala-Iturriagagoitia, 2020). Our second experiment, a specification realignment, follows the same logic and lets frontier lines serve public demand as well. In practice, we give every line, frontier and incremental, the same government demand and keep total procurement spending at its benchmark value (Appendix E.4).

Table 4 reports the results. First, incremental lines lose their demand advantage, the frontier premium widens, and the frontier share of new lines rises by about 1.6 percentage points, one-third of the response to the credit. Second, innovation effort does not change, because free entry fixes it. Third, annual growth rises by about 0.4 basis points and welfare is unchanged. A larger frontier share raises growth and, at once, markups and prices, and the two nearly offset (Section 6.1). For composition reforms, growth therefore overstates the welfare gain, and only policies that raise innovation effort move welfare.

Why does the credit raise growth so much more than the realignment? Growth comes from incremental and frontier innovations, and a frontier innovation adds about twice as much quality as an incremental one. For a given level of innovation effort, the economy therefore faces a growth frontier, along which each basis point of incremental growth given up yields about two basis points of frontier growth,

$$\frac{g_I}{\log \lambda_I} + \frac{g_F}{\log \lambda_F} = x, \quad (32)$$

where  $g_I$  and  $g_F$  are the growth contributions of incremental and frontier lines and  $x$  is innovation effort. The realignment moves the economy along the frontier. The credit raises effort and shifts the whole frontier out by about one-fifth. Moving along the frontier leaves welfare almost unchanged,

because the dynamic gain from faster growth offsets the static cost of higher markups on frontier lines (Peters, 2020). Panel A of Figure 4 in Section 6.1 draws the frontier and its shift.

### 5.3 How Large Are the Gains?

TABLE 4—POLICY COUNTERFACTUALS AT THE ESTIMATED MODEL

| Policy                    | Innovation effort (%) | Frontier share (pp) | Production labor (%) | R&D labor (%) | Entry labor (%) | Growth (bp/yr) | Welfare, CEV (%) |
|---------------------------|-----------------------|---------------------|----------------------|---------------|-----------------|----------------|------------------|
| R&D credit                | 21.55                 | 4.56                | -1.0                 | 45.8          | -63.9           | 8.81           | 1.92             |
| Specification realignment | 0.00                  | 1.64                | -0.2                 | 1.6           | 16.9            | 0.44           | 0.00             |

*Notes:* Changes relative to the benchmark, with  $T = 0.026$ ,  $g = 0.0034$ ,  $x = 0.0369$ , and  $\mu = 0.2907$ , holding structural parameters and the innovation cost scale  $c_x$  fixed. Innovation effort is the arrival rate of incumbent innovations, and the frontier share is the share of new lines at the frontier. Labor columns report steady-state percentage changes in production, incumbent R&D, and entry labor, which sum to the fixed labor endowment. The R&D credit reallocates one-quarter of  $T$  to a credit of 17.7 percent on incumbent R&D effort costs; the remaining three-quarters purchase incremental products. Specification realignment holds total procurement spending fixed and sets equal government demand per line on frontier and incremental lines. Welfare is the permanent percentage change in private real consumption, including the transition. Government purchases enter as a resource cost.

*Source:* Authors' calculations at the seven-moment estimate.

The credit's welfare gain is moderately large and in line with other quantitative exercises in the endogenous growth and related literatures. Each innovation raises quality permanently, while the innovating firm earns profits only until a rival displaces it. Private returns to innovation effort therefore fall short of social returns, and the credit closes part of the gap. The 1.9 percent gain exceeds the 1.1 percent gain from removing short-termism in Terry (2023). The welfare costs of 10 percent inflation (Lucas, 2000) and of business cycles (Krusell et al., 2009) are each about 1 percent of consumption, half the gain from the credit. The gain is smaller than the welfare costs of R&D misallocation and inventor monopsony in Lehr (2024, 2025), 5 and 8 percent of consumption, respectively. Valuing the public services that the credit displaces lowers its welfare gain to 1.2 percent (Section 6.3).

To further contextualize our results, note that the growth gain translates directly into productivity, because output in a quality-ladder model grows only through quality improvements. The credit adds about one-quarter to German trend TFP growth of 34 basis points, and growing at the faster rate raises private consumption by about 0.6 percent after ten years. The gain exceeds the 4.7 basis-point growth gain from removing short-termism in Terry (2023) and is smaller than the 12 basis-point growth cost of inventor monopsony in Lehr (2025).

## 6 Discussion, Extensions, and Robustness

We relax the main assumptions of the benchmark, examine how the economy adjusts after the credit, and check the credit against parameter uncertainty. Table 5 at the end of the section reports the credit's effects in each extension and parameter check.

### 6.1 Why Composition Barely Moves Welfare

Why does shifting procurement toward frontier lines raise growth but leave welfare almost unchanged? A frontier innovation adds more quality than an incremental one, and its producer charges a higher markup. A larger frontier share therefore brings a dynamic gain, faster growth, and a static cost, a higher price level (Peters, 2020). Figure 4 shows both. With effort fixed, one more frontier innovation replaces one incremental innovation and adds about twice as much quality, and moving all purchases to frontier lines raises growth from 34.0 to 35.3 basis points (Panel A). The credit shifts the whole line outward and raises growth to 42.8 basis points. The consumption cost of a higher frontier share rises almost one for one with its growth gain (Panel B).

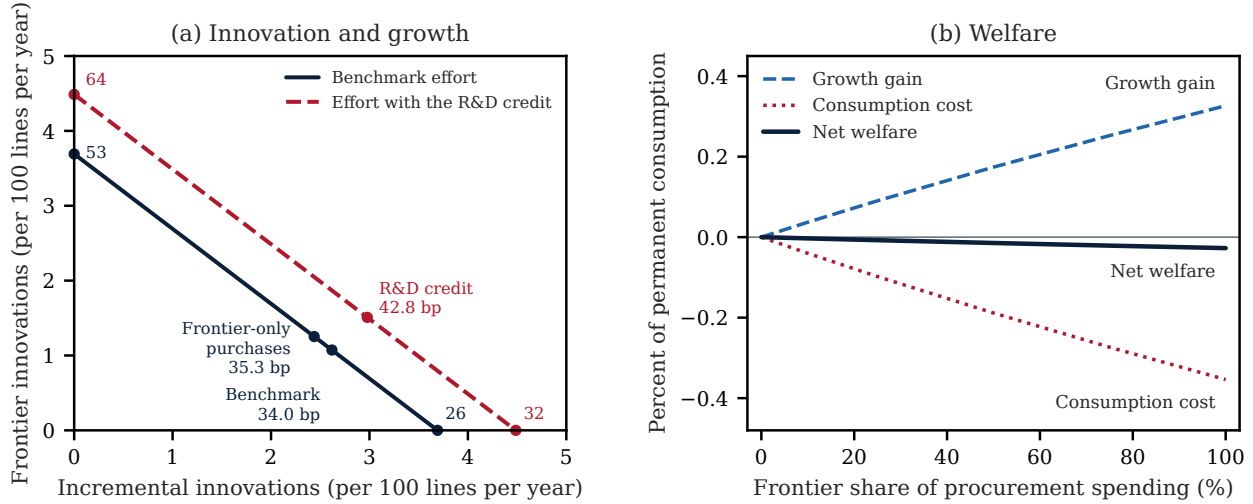


Figure 4: Innovation, growth, and welfare as procurement shifts toward frontier lines

*Notes:* Panel A plots innovations per 100 product lines per year at benchmark effort (solid) and with the R&D credit (dashed); numbers are annual growth in basis points. Panel B splits the steady-state welfare change from a higher frontier share of procurement, at a fixed budget, into the growth gain (the change in growth divided by the discount rate) and the change in log real consumption per unit of quality. Parameters and the innovation cost scale  $c_x$  are held fixed. *Source:* Authors' calculations at the estimated model.

The cost arrives at once, while the gain accumulates slowly. A higher frontier share raises markups, and hence prices, immediately, whereas the extra quality it brings arrives only as lines innovate, at rate  $x$  per year, and households discount future gains at rate  $\rho$ . With effort fixed by free entry, the growth gain is worth  $x/\rho$  times the price-level cost and the two nearly offset (Appendix E.9

derives this result). As a result, the split of procurement between line types matters little for welfare. Raising welfare requires raising innovation effort, which is what the credit does, with a growth gain several times its consumption cost.

## 6.2 Transition Dynamics

When does the credit start to raise consumption? We start the economy at the benchmark steady state and introduce the credit at date zero as an unexpected, permanent change; households and firms then foresee the full path to the new steady state (Appendix D.5). Figure 5 traces the economy after the credit starts. The credit works like an investment. Firms hire researchers as soon as the credit is in place, and the workers they hire leave production. Households therefore consume less at first. The return comes gradually, as more product lines receive innovations each year and quality rises faster than before. The stock of products shifts toward frontier lines only as old lines are replaced. Consumption overtakes its path without the credit after about three years, and the gap keeps widening because growth stays permanently higher. Appendix E.11 compares the model's adjustment after a procurement shock with local projections in the data.

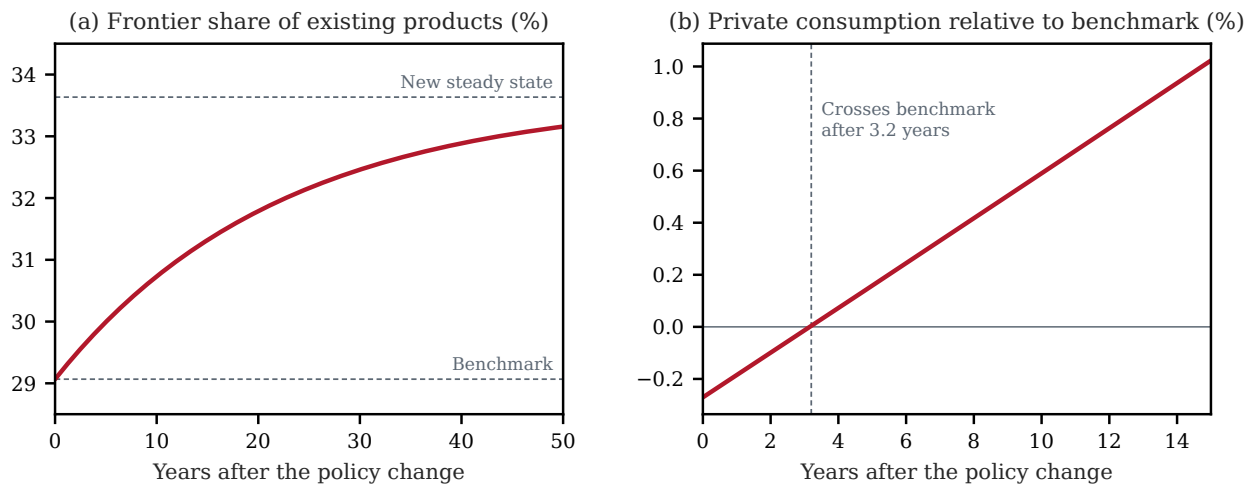


Figure 5: Transition after the R&D credit

*Notes:* Paths start from the benchmark steady state at the date of an unanticipated, permanent policy change. Panel A reports the frontier share of existing products, which moves from the benchmark toward the new steady state; the frontier share of new lines jumps to its new steady-state value on impact. Panel B reports private consumption relative to its benchmark path over the first 15 years, the change in real consumption per unit of quality plus the accumulated change in quality growth; the dashed line marks the date at which consumption overtakes the benchmark path. The R&D credit reallocates one-quarter of procurement spending to incumbent effort costs. Parameter estimates and the innovation cost scale  $c_x$  are held fixed.

*Source:* Authors' calculations at the estimated model.

### 6.3 Do the Benchmark Assumptions Drive the Results?

We relax four assumptions of the benchmark: that the government buys only from incremental lines, that the preference of public buyers for incremental lines is given, that public services carry no utility value, and that the costs of innovation effort and frontier orientation add up.

*CES government demand.* The benchmark lets the government buy only from incremental lines. We replace this assumption with CES government demand. The government chooses its purchases  $g_j$  of each product line to maximize a CES index of public consumption,

$$\max_{\{g_j\}} C_G = \left( \int_0^1 \omega_j^{1/\sigma_G} g_j^{\frac{\sigma_G-1}{\sigma_G}} dj \right)^{\frac{\sigma_G}{\sigma_G-1}} \quad \text{s.t.} \quad \int_0^1 p_j g_j dj \leq T, \quad (33)$$

where  $\sigma_G$  is the elasticity of substitution across lines,  $\omega_j = 1$  on incremental lines, and  $\omega_j = (1 + \xi_G)^{-\sigma_G}$  on frontier lines. The wedge  $\xi_G > -1$  captures a preference or specification against frontier purchases. Spending per frontier line relative to spending per incremental line is then

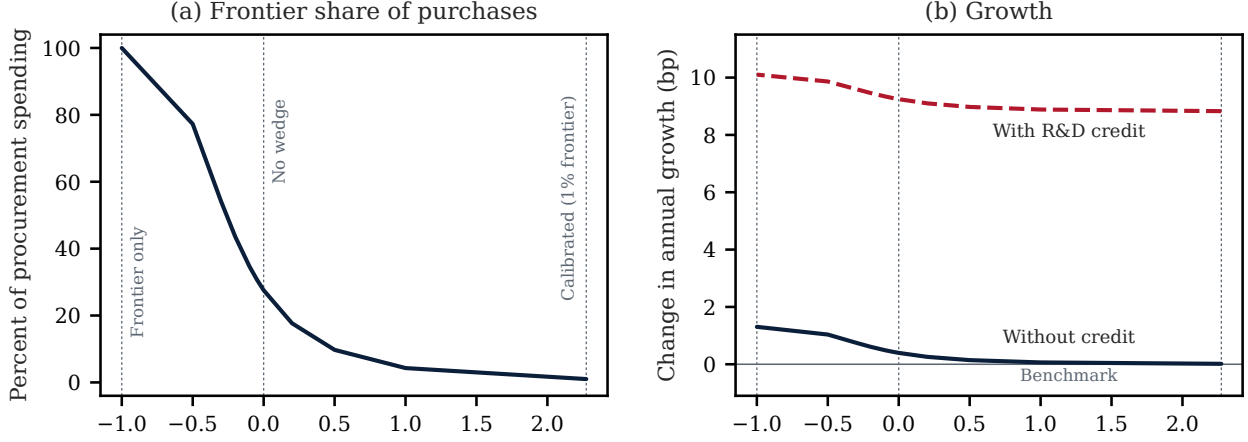
$$\frac{G_F}{G_I} = (1 + \xi_G)^{-\sigma_G} \left( \frac{\lambda_F}{\lambda_I} \right)^{1-\sigma_G}. \quad (34)$$

A larger wedge moves purchases toward incremental lines, and an infinite wedge recovers the benchmark, in which the government buys only incremental goods. A negative wedge favors frontier purchases, and as  $\xi_G$  approaches  $-1$  the government buys only frontier goods. Frontier goods also carry higher prices, and with  $\sigma_G > 1$  the government buys less of them even without a wedge. We set the elasticity to 3, following [Hsieh and Klenow \(2009\)](#), and hold all estimated parameters fixed (Appendix E.4).

We set the wedge  $\xi_G$  so that 1 percent of public purchases goes to innovative products, as in the data (Section 4.1), which requires  $\xi_G = 2.27$ . In this economy, the credit has the same effect as in the benchmark (Panel A of Table 5), because the government still buys almost only incremental goods.

What if the government bought more from the frontier? Figure 6 lowers the wedge until the government buys only frontier goods. The frontier share of purchases rises from 1 to 100 percent (Panel A), and growth rises by at most 1.3 basis points (Panel B). The credit adds about 9 basis points of growth at every wedge. Appendix Table E2 reports the full set of CES allocations.

*Buyer incentives.* Why would public buyers favor incremental lines? Evidence on procurement officials suggests that they bear more of the cost of a failed purchase than they share in the gain from a successful one ([Tukiainen et al., 2024](#); [Gerardino et al., 2024](#); [Czarnitzki et al., 2020](#)). We let each buyer value a product by its quality net of an expected failure penalty  $\phi_G$ . A buyer then



Preference wedge on frontier purchases,  $\xi_G$  (frontier preference to the left, incremental bias to the right)

**Figure 6: CES government demand: the preference wedge on frontier purchases**

*Notes:* The horizontal axis is the CES preference wedge on frontier purchases,  $\xi_G$ , with elasticity  $\sigma_G = 3$ ; the wedge rises from left to right. Panel A reports the share of procurement spending on frontier lines. Panel B reports the change in annual growth relative to the incremental-only benchmark, without and with the R&D credit, which reallocates one-quarter of the budget. Dotted lines mark the wedge calibrated to 1 percent frontier purchases, no wedge, and frontier-only purchases. Parameter estimates and the innovation cost scale  $c_x$  are held fixed.

*Source:* Authors' calculations at the estimated model.

purchases only incremental products, as in the benchmark, when

$$\phi_G \geq \frac{\log(\lambda_F/\lambda_I)}{f_F - f_I}, \quad (35)$$

where  $f_F - f_I$  is the extra probability that a frontier purchase fails. We match it to the innovation survey, where firms miss frontier-type objectives 18 percentage points more often than incremental ones, which puts the threshold at about five times the frontier quality premium (Appendix E.6). Because the penalty is not observed, we let a quarter of buyers, and then all of them, buy frontier products. Growth rises by at most 1.3 basis points, and the credit still adds 8.8 basis points, because innovation effort does not depend on how procurement is allocated.

*Public services.* The benchmark gives government purchases no value to households, which could overstate the gain from cutting them. We add public services to household utility as a separate good, since households do not buy infrastructure or hospital equipment themselves,

$$u_t = \log C_t + \alpha_Q \log Q_t^{\text{gov}}, \quad (36)$$

where  $Q_t^{\text{gov}}$  is government purchases in quality units, and value a euro of public purchases like a euro of private consumption (Appendix E.7). The credit's welfare gain falls from 1.9 to 1.2 percent,

because it diverts funds from public services. Aggregating public services across lines with the CES index of equation (33) gives the same 1.2 percent (Panel C of Table 5).

*The structure of R&D costs.* In the benchmark, the costs of effort and frontier orientation add up, and procurement leaves effort unchanged. We instead bundle the two costs, which makes each unit of effort more expensive for frontier-oriented firms (Appendix E.8). With an elasticity of substitution of 3 between the two costs, procurement raises effort by 1.16 percent and lowers the frontier share by 3.2 percentage points, and growth falls by 0.4 basis points, as in the benchmark. The credit raises growth by 8.7 basis points (Panel D of Table 5).

## 6.4 Other Robustness Checks

*Parameter uncertainty.* We move each estimated parameter by one standard error, keeping the innovation cost scale to match trend growth (Panel E of Table 5). The credit raises growth by 6.5 to 10.4 basis points and welfare by 1.3 to 2.1 percent. The smallest gains arise where the credit stops entry, because additional researchers must then come from production, which raises the wage and dampens effort. Moving the parameters changes the exact magnitudes but preserves our conclusions.

*The response of R&D to the credit.* The credit's gains depend on how strongly R&D responds to its price. In the model, a 1 percent fall in the after-credit price raises R&D by 2 percent, within the range of 1 to 2.6 estimated for R&D support in OECD countries, the United Kingdom, and Germany (Bloom et al., 2002; Gucer and Liu, 2019; Dechezleprêtre et al., 2023; Stehnen et al., 2024). We vary the elasticity within this range and it raises growth by 3.4 and 9.4 basis points, respectively, against 8.8 at the estimate (Panel F of Table 5).

*The size of the credit.* The size of the credit is a policy choice, and its gains could depend on it. We vary the share of the procurement budget reallocated to the credit up to the full budget (Appendix E.5). Gains rise steadily as incumbents take over creative destruction from entrants. Reallocating the entire budget raises growth by 24.4 basis points and welfare by 5.1 percent. The full reallocation requires a credit of 41.5 percent, more than twice the current German subsidy rate.

In summary, across the specifications in Table 5, the credit raises growth by 3.4 to 10.4 basis points and welfare by 0.8 to 2.1 percent, and it raises innovation effort by at least 8 percent in every case.

TABLE 5—THE R&amp;D CREDIT ACROSS EXTENSIONS AND ROBUSTNESS CHECKS

| Specification                                   | Innovation effort (%) | Frontier share (pp) | Welfare gain (%) | Growth gain (bp/yr) |
|-------------------------------------------------|-----------------------|---------------------|------------------|---------------------|
| <b>Baseline</b>                                 | 21.55                 | 4.56                | 1.92             | 8.81                |
| <i>A. Government demand (CES)</i>               |                       |                     |                  |                     |
| Calibrated wedge                                | 21.55                 | 4.56                | 1.92             | 8.81                |
| No wedge                                        | 21.55                 | 4.42                | 1.94             | 8.85                |
| <i>B. Buyers purchasing frontier products</i>   |                       |                     |                  |                     |
| A quarter                                       | 21.55                 | 4.27                | 1.93             | 8.80                |
| All                                             | 21.55                 | 3.65                | 1.97             | 8.80                |
| <i>C. Public services valued in utility</i>     |                       |                     |                  |                     |
| Linear index                                    | 21.55                 | 4.56                | 1.22             | 8.81                |
| CES index                                       | 21.55                 | 4.56                | 1.17             | 8.81                |
| <i>D. R&amp;D labor as a bundle</i>             |                       |                     |                  |                     |
| Elasticity of substitution 3                    | 22.50                 | 3.04                | 1.96             | 8.65                |
| <i>E. Parameter uncertainty</i>                 |                       |                     |                  |                     |
| Incremental step, $-1$ SE <sup>†</sup>          | 18.94                 | 4.00                | 1.53             | 7.93                |
| Incremental step, $+1$ SE                       | 22.25                 | 3.92                | 1.96             | 8.62                |
| Frontier step, $+1$ SE                          | 23.55                 | 5.45                | 2.09             | 10.14               |
| Frontier-orientation cost, $-1$ SE              | 23.89                 | 7.67                | 2.11             | 10.37               |
| Frontier-orientation cost, $+1$ SE <sup>†</sup> | 17.03                 | 2.07                | 1.26             | 6.45                |
| Entry cost, $-1$ SE                             | 22.67                 | 4.61                | 2.03             | 9.24                |
| Entry cost, $+1$ SE <sup>†</sup>                | 18.46                 | 3.54                | 1.46             | 7.39                |
| <i>F. Elasticity of R&amp;D to its price</i>    |                       |                     |                  |                     |
| Elasticity 1.1                                  | 8.63                  | 1.57                | 0.75             | 3.40                |
| Elasticity 2.1                                  | 22.81                 | 4.90                | 2.04             | 9.36                |

*Notes:* Effects of the R&D credit relative to each specification's own benchmark, without re-estimation. Panel D combines the labor costs of effort and frontier orientation in a constant-returns bundle and recalibrates both cost parameters. Panels E and F recalibrate the innovation cost scale to match trend growth, and Panel F sets the curvature of the effort cost so that R&D responds to its after-credit price with the elasticity shown (2 at the estimate). Welfare gains are in consumption-equivalent terms and include the transition, except in Panel D, which reports the steady-state change. Sections 6.3 and 6.4 describe each specification. Panel E omits the frontier step one standard error lower, at which no benchmark with positive entry matches trend growth. <sup>†</sup>The credit stops entry (Appendix E.5).

*Source:* Authors' calculations at the seven-moment estimate.

## 7 Conclusion

In the data, public procurement in Germany has grown while fewer firms introduce products new to their market. We propose that the two may be related. Our proposed channel is that public specifications reward firms for adapting products they already sell, which lowers the relative return to frontier innovation.

Three patterns characterize the evidence. First, novelty among product innovators is lower in industries where public contracts are larger. Second, in industries with more public contracts, firms spend more on R&D but earn a smaller share of sales from new products. Third, broad public-sector purchases are also associated with lower novelty among manufacturing innovators.

We build a quality-ladder model with procurement, extending [Klette and Kortum \(2004\)](#) with a choice between frontier and incremental innovation, and estimate four parameters by GMM to match seven moments from German survey and administrative data. In the estimated model, firms respond to procurement with fewer frontier innovations, while higher profits raise the wage until entry again breaks even, which holds innovation effort at its benchmark level. Growth then responds to procurement only through whether firms pursue frontier or incremental improvements.

The primary counterfactual reallocates procurement funds to an R&D tax credit modeled to match Germany's current R&D tax subsidy rate. Growth rises by 8.8 basis points per year, about one-quarter of TFP growth, and welfare by 1.9 percent of permanent private consumption. Gains of this size are moderately large by the standards of quantitative growth exercises and make the use of procurement funds a relevant margin for innovation policy. Giving frontier and incremental products the same procurement demand at a fixed budget adds 0.4 basis points of growth and no welfare gain, because faster quality growth offsets the higher markups of frontier products. Across counterfactuals, the destination of public funds matters more for growth than their contractual form.

The results highlight a distinction between the private and aggregate consequences of procurement. For a winning firm, public awards are economically important, amounting to 7.4 percent of annual turnover at the median. Such contracts can reward firms for adapting products they already sell to meet public specifications. Yet in the estimated model, even redirecting all procurement toward frontier products raises annual growth by only 1.3 basis points. An R&D credit instead increases innovation effort, whose private return falls short of its social return. Our findings are consistent with long-standing concerns that specification-heavy procurement favors incremental over frontier innovation ([Uyarra et al., 2014](#); [OECD, 2017](#); [Edquist and Zabala-Iturriagagoitia, 2020](#)). Similar mechanisms may operate in US defense contracting ([Howell et al., 2025](#)), historical medical procurement ([Clemens and Rogers, 2026](#)), and government R&D programs ([Moretti et al., 2025](#)).

More broadly, the results suggest that the aggregate benefits of innovation policy depend not only on which technologies public demand rewards, but also on how public resources affect firms' incentives to innovate.

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