Quietly Ahead: The Diverging R&D Productivity of Public and Private Firms*†

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Abstract

Using 80 years of patent-level data, we show that unlisted firms are "quietly ahead" of stock market–listed firms in the innovation race. While unlisted firms produced less valuable innovations for much of the twentieth century, they have risen to a leading position in innovation value this century. This reversal is not explained by changes in patent characteristics or by shifts in market multiples applied to those characteristics. Instead, it reflects differences in technology-field allocation: beginning in the 1980s, unlisted firms reallocated R&D toward fields with rising market valuations and away from declining ones. A simple conceptual lens highlights how nimble reallocation toward high-value fields becomes more valuable as technological opportunities grow more dispersed and persistent. Unlisted firms—especially young and first-time patenters—adjust more nimbly to emerging value signals, aided by venture capital. As a result, their share of aggregate R&D value-add has more than tripled since 1985, despite stable patent shares and faster R&D spending growth among listed firms.

JEL classification: O31, O32, O33, L25, O41.
Keywords: Innovation, Technological change, Public and private firms, R&D allocation, Organizational form, Economic growth.

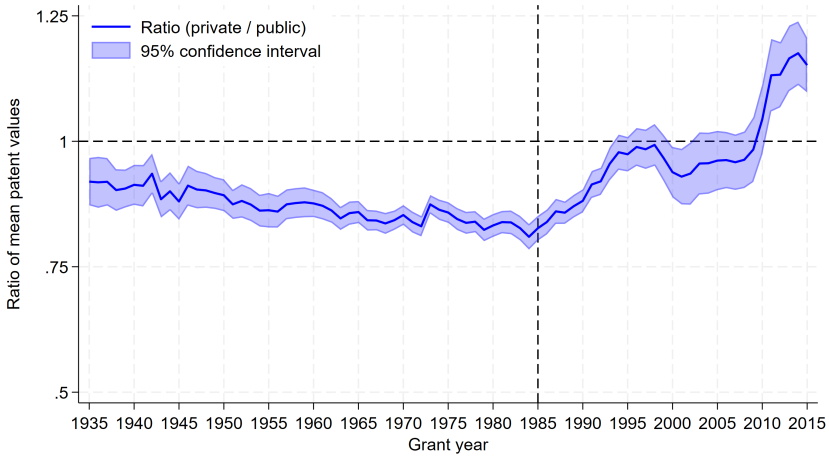
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1. Introduction

Innovation—much of it corporate—is the engine powering economic growth.[1] We document a shift in the relative roles of public (stock market listed) and private (unlisted) firms that standard narratives do not predict. Figure I tells the basic story. Abstracting from estimation details, the figure plots the ratio of the mean patent values of private and public firms over the eight decades through 2015, with 95% confidence intervals. In 1935, the mean value of patents granted to private firms was 92% of the mean value of patents granted to public firms. This ratio drifted downward for half a century, reaching a low of 81% in the mid-1980s. Over the next three decades, however, the trend reverses: private and public firms reach parity in the decade through 1994, remain at parity through 2010, and by 2015 private-firm patents are on average 15.2% more valuable.

Figure I: The Relative Value of Private- and Public-Firm Innovation, 1935-2015



Notes: This figure plots the ratio of mean patent values for private firms relative to public firms from 1935 to 2015. Details of our estimation approach can be found in Section 2. The 95% confidence intervals are based on standard errors clustered at the technology-field level.

This basic pattern is not only statistically significant; it is also robust to alternative measures: we show that private firms produce more breakthroughs and more disruptive innovations per dollar of R&D than public firms. In short, private companies have gone from clear laggards in the mid-twentieth century to quiet leaders in the innovation race today.

[1]See Aghion and Howitt (1998) for a canonical survey of theory linking firm-level innovation to long-run growth; see Bloom, Van Reenen, and Williams (2019) for empirical evidence.

The reversal in Figure I raises a natural question: why did private firms start overtaking public firms? Using a set of counterfactual exercises, we show that the reversal is not driven by two tempting explanations. Specifically, neither shifts in the characteristics of patented innovations (such as citation intensity or the incidence of breakthroughs) nor changes in the "valuation multiples" investors attach to those characteristics can explain the reversal. Instead, the key lies in where firms choose to innovate. Around the mid-1980s, private firms increasingly shifted innovative effort toward technology fields whose market valuations were rising and away from fields where valuations were stagnating or falling. In this sense, their innovation portfolios adjust more nimbly to signals about where the technology frontier is headed. As a result, private firms move from being overrepresented in low-value fields to being overrepresented in high-value fields.

To interpret both the reallocation patterns and their timing, we develop a simple model of technological reallocation in which firms allocate innovative effort across fields with time-varying opportunities. Private firms face lower adjustment frictions and therefore reallocate more nimbly toward rising-value technologies. Crucially, the model predicts that this advantage depends on the technological environment: when field-level opportunities are homogeneous or short-lived, nimbleness is weakly rewarded; when opportunities become more dispersed and persistent, nimbleness generates higher innovation value.

We then test the model's central implication directly. Using our field-level innovation values, we show that technological opportunities are persistent, but that their dispersion across fields increases sharply around the mid-1980s.[2] Seen through the lens of the model, this shift moves the economy into a regime in which rapid reallocation toward high-value technologies is substantially more rewarding, coinciding closely with the timing of the reversal and the emergence of private firms as leaders in innovation value.

[2]This pattern is consistent with a large literature arguing that the nature of technological opportunities changed markedly in the late twentieth century. General-purpose technologies such as information and communication technologies increased the dispersion of returns across downstream applications by creating highly scalable opportunities in some domains while leaving others largely unaffected (Bresnahan and Trajtenberg 1995; Helpman 1998). At the same time, innovation became more tightly linked to frontier science, increasing the persistence and skewness of technological payoffs across fields (Rosenberg 1982; Jones 2009).

Which private firms drive the shift? A striking share of the reversal is driven by first-time patenters and young private firms. Geography also matters. Private firms in California outperform public firms during the crucial decades of the 1970s and 1980s, while private firms in Massachusetts maintain an advantage from the 1970s through 2015. These patterns suggest an interaction between organizational form, firm life cycle, and local innovative environments.

Finally, we explore the aggregate consequences. We construct a time series of private firms' share of total R&D value-add, defined as the aggregate value of corporate patents net of R&D spending. Since 1985, that share has more than tripled. This macro shift is not due to a surge in private-firm patenting or faster growth in private-firm R&D spending relative to public-firm spending—indeed, the opposite is true. Instead, the rising contribution of private firms reflects the steadily increasing value of the patents private firms are granted.

This paper documents a fundamental shift in the organization of innovative activity in the United States. Over much of the twentieth century, public firms dominated high-value corporate innovation. Since the mid-1980s, however, private firms have emerged as leading producers of high-value patented innovation. We show that this reversal is not explained by shifts in the characteristics of patented inventions or by changes in the market "multiples" attached to those characteristics. Instead, it reflects an increasingly large advantage of private firms in reallocating inventive effort toward rising-value areas of the technological frontier and away from stagnating or declining areas. By linking organizational form to the speed and direction of technological reallocation, our findings illuminate how technological opportunity and market pricing interact to shape long-run patterns of innovation and economic growth.

Our paper contributes to the Schumpeterian growth literature surveyed by Aghion and Howitt (1998) and developed in subsequent work (Klette and Kortum 2004; Jones 2005; Akcigit and Kerr 2018). While this tradition emphasizes that long-run growth is driven by quality-improving innovation and by the reallocation of inventive effort toward high-opportunity technologies, canonical models typically abstract from heterogeneity in organizational form, treating firms as identical producers of innovation. We provide long-horizon empirical evidence that the

structure and identity of innovating firms—private versus public, young versus established—systematically shape the value of innovative output.[3] Consistent with the reallocation mechanism emphasized in Schumpeterian models, we show that private firms have become increasingly effective at shifting R&D toward rising-value fields, yielding a long-run reversal in the relative value of private- and public-firm innovation. By demonstrating that organizational form governs the speed and direction of technological reallocation, our findings extend a core channel in Schumpeterian growth theory.

Our results also speak to broader literatures in corporate finance and venture capital. In corporate finance, a large body of work examines how ownership structure (Aghion, Van Reenen, and Zingales 2013), financial constraints (Brown, Fazzari, and Petersen 2009; Acharya and Xu 2017), and market pressures (Baber, Fairfield, and Haggard 1991; Dechow and Sloan 1991) shape firms' innovative activity. Studies document that public firms face pressures to meet short-term earnings targets (Stein 1989; Asker, Farre-Mensa, and Ljungqvist 2015) and may underinvest in long-term innovation relative to private firms, while governance, incentive design, and managerial horizons can influence the risk profile and quality of innovation (Holmström 1989; Lerner, Sorensen, and Strömberg 2011). We complement this literature by showing that organizational form predicts not only the amount or type of innovative activity, but the value of innovation, and that this gap has widened markedly over time.

Finally, our paper connects to the literature on venture capital and entrepreneurial innovation. Venture capital has been shown to accelerate commercialization, scale frontier technologies, and support young firms in high-opportunity sectors.[4] We document that the reversal in

[3] A related literature studies how going public affects a firm's innovative output. It finds that the transition from private to public markets decreases patent quality among U.S. biotech firms (Aggarwal and Hsu 2014), U.S. firms more broadly (Bernstein 2015), Chinese firms (Cong and Howell 2021), and European firms (Larrain et al. 2025). Gao, Hsu, and Li (2018) further show that patents by public firms rely more on existing knowledge and are less likely to be in new technology classes than those of large private firms during 1997–2008. Our focus is distinct in that we compare the value of patents produced by all private and public U.S. firms over a long time horizon and study the evolution of their relative innovation performance.

[4] A large literature links venture capital to greater innovative activity and technological progress. Early work shows that patenting increases with VC investment (Kortum and Lerner 2000), and subsequent studies document that VC financing is associated with higher-impact innovation and entrepreneurial activity (Mollica and Zingales 2007; Bernstein, Giroud, and Townsend 2016). Venture capital also shapes the *type* of innovation pursued: firms backed by more failure-tolerant VCs produce patents with greater impact (Tian and Wang 2011), and periods of abundant VC funding are associated with riskier, more innovative projects and higher-quality

private-firm innovation value is disproportionately driven by young and VC-backed firms, consistent with an amplifying role for venture capital in the post-1980s innovation regime. In this way, our evidence bridges Schumpeterian growth models—where entrepreneurial entrants drive creative destruction—with modern corporate finance models emphasizing the role of specialized financiers in fostering high-growth innovation.

Together, these literatures underscore the importance of institutional context, investor structure, and organizational form in shaping innovative performance. Our paper contributes a new fact of first-order importance: over the past century, the identity of the marginal innovator has shifted decisively, with private firms emerging as the leading producers of high-value patented innovation.

The remainder of the paper proceeds as follows. Section 2 describes the data and the construction of patent-level and field-level measures of innovation value. Section 3 introduces a simple model of technological reallocation that highlights how organizational nimbleness affects innovation outcomes when technological opportunities differ across technology fields. Section 4 documents a sharp increase around the mid-1980s in the dispersion of field-level innovation values, a shift that makes nimbleness increasingly valuable. Section 5 shows that private firms respond more quickly to these changing opportunities, reallocating inventive effort toward rising-value fields more rapidly than public firms. Section 6 examines the aggregate implications, documenting a substantial rise in private firms' share of economy-wide R&D value-add. Section 7 concludes.

2. Data and Measurement

We construct a comprehensive dataset of U.S. corporate patents and their market values in three steps. First, we identify all patents granted to U.S. firms between 1926 (the beginning of CRSP coverage) and 2020, and classify each patent by the organizational form of the assignee, distinguishing between public (stock market listed) and private (unlisted) firms. Second, fol-

patents (Nanda and Rhodes-Kropf 2013; Howell et al. 2020). At the aggregate level, VC-backed firms account for a disproportionate share of R&D spending among U.S. public companies (Gornall and Strebulaev 2021).

lowing Kogan et al. (2017), we estimate the market values of patents granted to public firms using stock price responses to patent grant announcements. Third, following Kline et al. (2019), we impute the values of patents granted to private firms using comparable information from public firms.

2.1. Identifying Public- and Private-firm Patents

Since its founding in 1836, the United States Patent and Trademark Office has issued more than eleven million patents. Our objective is to identify patents granted to U.S. corporations and to distinguish between those held by public firms and those held by private firms. We exclude patents assigned to individuals, universities, hospitals, non-profit organizations, government entities, and foreign corporations, as our focus is on domestic corporate innovation.

We construct the sample using three conceptual filters. First, we identify whether a patent assignee is a firm rather than a non-corporate entity. Second, among corporate assignees, we determine whether the firm is domestic or foreign, excluding patents assigned to foreign firms even when those firms file patents in the United States or are cross-listed on U.S. exchanges. Third, for domestic firms, we classify each patent according to whether the assignee is publicly listed or privately held at the time of the patent grant.

To implement the first filter, we use assignee information from Google Patents, the USPTO PatentsView database, the USPTO Patent Assignment database, and textual parsing of patent documents. While PatentsView provides standardized assignee classifications from 1976 onward, for earlier patents we rely on our own classification procedures and on information from Fleming et al. (2019).

To determine whether a corporate assignee is domestic or foreign, we combine location information from PatentsView, the USPTO Assignment database, Fleming et al. (2019), and the PatentCity database of Bergeaud and Verluise (2024). A particular challenge arises when foreign firms patent through U.S. subsidiaries, which appear as domestic assignees in patent records. To address this, we use listing information for foreign firms from LSEG Datastream

and perform record linkage between patent assignees and internationally listed firms, allowing us to exclude patents filed by U.S. subsidiaries of foreign corporations.

Finally, we classify domestic corporate patents as public- or private-firm patents. Our starting point is the latest patent–firm linking table from Kogan et al. (2017), which links patents granted since 1926 to firms in the CRSP database. We refine and extend this table in several steps. First, we match patent assignees to firms listed on the American Stock Exchange prior to 1962, before CRSP coverage of AMEX firms begins. Second, using corporate ownership trees from the National Establishment Time Series (NETS) database, we identify patents granted to subsidiaries of public firms over the period 1989–2019.[5] Third, we manually review approximately 3.2 million patent–firm links, identifying an additional 450,000 public-firm patents that are coded as private in Kogan et al.'s latest linking table, reclassifying roughly 28,000 of Kogan et al.'s public-firm patents as private or something else, and correcting 20,000 erroneous CRSP permco links.

Our final analysis sample consists of 3,462,008 patents granted to U.S. public and private firms between 1935 and 2015. Public firms account for 2,260,195 patents (65.3%), while private firms account for 1,201,813 patents (34.7%). We classify a firm as publicly traded if it has a common share listed on the NYSE, AMEX, NASDAQ, a regional exchange, or the over-the-counter market.

2.2. Estimating the Value of Public Patents

To estimate the economic value of patents granted to public firms, we build on the methodology of Kogan et al. (2017), who infer patent values from stock market reactions to patent grant announcements. The key insight is that equity prices are forward-looking and therefore reflect the private value that investors assign to newly granted intellectual property. Specifically, Kogan et al. identify patent grant dates using USPTO records and measure abnormal stock returns in a narrow event window following the grant. Under the assumption that patent

[5]This step captures patents assigned to subsidiaries whose names bear little resemblance to their publicly listed parent, and corrects errors arising from fuzzy name matching in extant linking tables.

grants convey new information about monopoly rents associated with the innovation, the stock price reaction isolates the component of firm value attributable to the patent. Filtering these returns from background volatility yields a patent-level estimate of private economic value that is comparable across firms, industries, and time.

Rather than relying on the original linking table in Kogan et al. (2017), we reestimate the entire valuation procedure using our revised and corrected patent–firm matches described in Section 2.1. As a result, our estimates of public-firm patent values are internally consistent with our classification of organizational form and are directly comparable to the values we later impute for private firms.

Apart from the updated firm–patent linkages, we follow Kogan et al. (2017) closely in terms of event-window construction, return filtering, and distributional assumptions. We therefore inherit the desirable properties of their measure—most notably, its grounding in asset prices and its ability to capture economically meaningful heterogeneity in innovation value—while ensuring that the public-firm benchmark is measured as accurately as possible.

2.3. Imputing the Value of Private-Firm Patents

Because private firms are not publicly traded, their patent values cannot be inferred directly from stock market reactions. We therefore impute the value of patents granted to private firms using observable patent characteristics, drawing on the relationship between those characteristics and market-based patent values estimated for public firms.

Our approach follows Kline et al. (2019), who extrapolate the patent valuation framework of Kogan et al. (2017) to unlisted firms. In our implementation, we estimate the mapping from patent characteristics to economic value using the reestimated public-firm patent values described in Section 2.2, ensuring full consistency between the valuation of public- and private-firm patents.

Specifically, we regress the market value of patents granted to public firms on a set of patent

characteristics that have been shown to predict innovation value.[6] To allow the valuation relationship to evolve over time and across technologies, we estimate this model recursively using rolling ten-year windows and include grant-year fixed effects and technology-field fixed effects at the Cooperative Patent Classification (CPC) main group level.[7]

Formally, for patent i granted in year t, we estimate the following Poisson specification:

$$v_{it} = \exp(\beta_t X_i + \pi_j + \phi_t + \varepsilon_{it}), \tag{1}$$

where v_{it} denotes the market value of the patent as inferred from stock prices, X_i is the vector of patent characteristics, π_j are technology-field fixed effects, and ϕ_t are grant-year fixed effects. Estimation over rolling windows yields a time series of coefficient estimates which we use to compute the imputed value $\tilde{v}_{it}$ of each private-firm patent granted in year t.

The Online Appendix provides additional detail and diagnostics for the imputation procedure. Figure IA.1 reports the rolling-window coefficient estimates from equation (1). While magnitudes vary over time, patent values are consistently increasing in citations, claims, generality, and originality, and are higher for breakthrough and strategic patents. Figure IA.2 reports diagnostics on model fit and coverage, including pseudo-R^2 measures, the number of public patents and technology fields used in estimation, and the incidence of excluded singletons. Finally, Figure IA.3 validates the imputation by comparing out-of-sample imputed values to market-based patent values for public firms after absorbing grant-year fixed effects, showing a close within-year alignment between the two measures.

Our data allow us to observe how the value of innovation varies over time, both across or-

[6]The characteristics include forward citations over a five-year window, the number of independent claims, measures of generality and originality (Trajtenberg, Henderson, and Jaffe 1997; Hall, Jaffe, and Trajtenberg 2001), an indicator for breakthrough inventions (Kelly et al. 2021), and an indicator for strategic patents (Veihl 2022). In early estimation windows beginning with 1926–1935, citation-based measures are unavailable; in these windows, the specification excludes citations, generality, and originality, which enter once the data coverage permits.

[7]CPC main groups are granular technology fields defined by an eight-character code. The firms in our sample patent in 7,211 distinct CPC main groups. One example is C12N15/00, "Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation or purification; Use of hosts therefor."

ganizational forms and across technology fields, and how firms reallocate inventive effort in response to changing technological opportunities. The next section introduces a simple model to organize these patterns and clarify the role of organizational nimbleness.

3. A Simple Model of Technological Reallocation

Schumpeterian growth theory (Aghion and Howitt 1992, 1998) emphasizes that long-run growth depends on the direction of technological change and on how rapidly economies reallocate inventive effort toward high-opportunity technologies. Canonical models assume homogeneous firms and treat innovation productivity as independent of organizational form. This section develops a stylized model that extends this framework by introducing heterogeneity in adjustment frictions across public and private firms. In this environment, the ability to respond nimbly to emerging technological opportunities becomes an important determinant of innovation value. When technological opportunities are relatively uniform and shocks are short-lived, differences in nimbleness matter little. But as the dispersion and persistence of field-level opportunities increase, the Schumpeterian mechanism amplifies the advantage of nimble firms. The model therefore embeds our empirical reversal—that private firms reallocate R&D toward rising-value technologies more rapidly than public firms since the mid 1980s—within a familiar growth-theory logic: organizational form shapes the speed of creative destruction.[8]

3.1. Environment

There are two technology fields, $j \in \{A, B\}$. In each period t, field j has a "technology opportunity value" $v_{j,t}$. These values summarize the expected market return to an innovation in that field (for example, through higher patent citations, commercialization prospects, or stock-market multiples).

Two types of firms operate: private firms (indexed P) and public firms (indexed U). Each

[8] A formal derivation with proofs can be found in Appendix A.

firm allocates its innovative effort across the two fields. Let

$$s_{i,j,t} \in [0,1], \qquad i \in \{P,U\}, \qquad \sum_j s_{i,j,t} = 1,$$

denote the share of effort that firm type i devotes to field j.

Technology-field values evolve according to:

$$v_{A,t} = \mu + \epsilon_t, \qquad v_{B,t} = \mu - \epsilon_t,$$

where ϵ_t is persistent over short horizons. Persistence ensures there is value in adjusting one's portfolio when the relative attractiveness of fields changes.

3.2. Firm Problem

Firm type i chooses $s_{i,t} = (s_{i,A,t}, s_{i,B,t})$ each period to maximize the value of its R&D portfolio net of quadratic adjustment costs:

$$\Pi_{i,t} = \sum_j s_{i,j,t} v_{j,t} - \frac{\kappa_i}{2} \sum_j \left(s_{i,j,t} - s_{i,j,t-1}\right)^2. \tag{2}$$

The parameter $\kappa_i > 0$ captures organizational inertia, that is, frictions associated with shifting scientific direction, reorganizing research teams, or revising project portfolios. We assume $\kappa_P < \kappa_U$: public firms face higher effective costs of changing R&D direction due to (i) the need to disclose private information to dispersed shareholders (an Arrow 1962–style appropriation problem), (ii) reliance on verifiable hard information before executing a pivot, or (iii) stronger stock-price and career penalties for unsuccessful pivots.[9]

[9]We treat the higher adjustment cost of public firms as a reduced-form representation of several micro-foundations. In an Arrow (1962) information environment, justifying a pivot to outside investors requires public firms to disclose more of their informational advantage, raising the effective cost of changing direction relative to closely held private firms. Governance and financing frictions further amplify this gap: dispersed shareholders and independent boards rely more heavily on hard, verifiable signals (Holmström 1979; Stein 2002), and public managers face stronger stock-price and career penalties for failed pivots (Stein 1989; Holmström 1999; Gibbons and Murphy 1992). Appendix B provides formal microfoundations showing how each of these mechanisms yields a higher effective adjustment friction κ_U for public firms than κ_P for private firms.

Let $\lambda_{i,t}$ be the multiplier on the constraint $\sum_j s_{i,j,t} = 1$. The first-order condition yields:

$$s_{i,j,t} - s_{i,j,t-1} = \frac{1}{\kappa_i}\left(v_{j,t} - \bar{v}_t\right), \qquad \bar{v}_t \equiv \tfrac{1}{2}(v_{A,t} + v_{B,t}). \tag{3}$$

Thus, firms increase their allocation to fields whose value exceeds the average, and the speed of this adjustment is governed by $1/\kappa_i$. Private firms adjust more aggressively in response to shocks.

3.3. Innovation Value

Define the expected value of innovative output for type i as:

$$V_{i,t} = \sum_j s_{i,j,t} v_{j,t}.$$

Because $s_{i,j,t}$ moves in proportion to $(v_{j,t} - \bar{v}_t)/\kappa_i$, it follows that:

$\mathbb{E}[V_{P,t}] > \mathbb{E}[V_{U,t}]$ whenever the dispersion or persistence of field values is sufficiently large.

Private firms, by reallocating more rapidly, devote a larger share of their inventive effort to high-v fields. This mechanism delivers the central empirical prediction: private firms' innovations are more valuable on average when technology opportunities are shifting.

3.4. A Simple Reversal Mechanism

The model naturally generates a reversal in the relative performance of private and public firms. Suppose the economy switches between two regimes $R \in \{0, 1\}$, each characterized by a variance and persistence pair (σ_R^2, ρ_R) governing the process for ϵ_t:

- Regime 0 (low volatility, low persistence), reflecting the mid-20th century: technology field values move little; shocks dissipate quickly.

- Regime 1 (higher volatility and persistence), reflecting the late 20th century: technology field values become more heterogeneous (say due to the arrival of general purpose technologies such as ICT); shocks persist.

Let the advantage of private firms in regime R be:

$$\Delta_R \equiv \mathbb{E}[V_{P,t} \mid R] - \mathbb{E}[V_{U,t} \mid R].$$

One can show that

$$\Delta_0 < 0 \quad \text{when } (\sigma_0^2, \rho_0) \text{ are low,}$$

because nimbleness yields little benefit and public firms' scale or stability may dominate; and that

$$\Delta_1 > 0 \quad \text{when } (\sigma_1^2, \rho_1) \text{ are high,}$$

because private firms' lower adjustment costs allow them to exploit persistent differences in field-level opportunities.

If the economy transitions from Regime 0 to Regime 1, the model predicts a reversal in the relative value of private- and public-firm innovation—as documented in our data.

3.5. Interpretation

In this framework:

- κ_i captures organizational inertia, bureaucracy, disclosure frictions, and internal coordination costs.
- Increases in (σ_R^2, ρ_R) capture rising dispersion and persistence in technological opportunities, plausibly linked to the ICT revolution, the growth of specialized scientific domains, and intensified market pricing of technological fields.
- Venture capital can be interpreted as reducing κ_P for young private firms.

The model delivers a sharp implication: when technological opportunities become more

dispersed and/or persistent, organizational nimbleness becomes increasingly valuable, shifting innovative leadership toward private firms. Testing this implication is the main focus of the paper.

4. The Evolution of Technological Opportunities

The model predicts that the advantage of nimble firms depends on the interaction of dispersion and persistence of technological opportunities: nimbleness becomes valuable when technological opportunities are sufficiently dispersed across fields and sufficiently persistent over time. A regime change can therefore arise when either dimension crosses a threshold, holding the other fixed at a high level. In this section, we test this prediction directly by examining how the cross-field distribution and time-series dynamics of field-level innovation values evolve over time.

4.1. Dispersion Across Technology Fields

To quantify how the dispersion of technological opportunities evolves over time, we construct a time series of the cross-sectional variance of innovation values across technology fields. In each year, we compute the value of a technology field as the mean Kogan et al. (2017) value of patents granted to public firms in that field. Focusing on public-firm patents avoids any reliance on imputed values and ensures that changes in dispersion are directly grounded in asset-price-based measures of innovation value. We then estimate the cross-field variance of these field-level values for each year in the sample. To quantify sampling uncertainty, we construct 95% confidence intervals using bootstrap standard errors clustered at the technology-field level, with 100 bootstrap iterations.

To assess whether the evolution of dispersion exhibits discrete shifts rather than gradual drift, we test for structural breaks in the variance series using the multiple-break methodology of Bai and Perron (1998). Specifically, we model the variance series as an autoregressive process of order 1 and estimate the model in first differences to ensure stationarity. We follow the

sequential testing procedure proposed by Bai and Perron, which tests for the presence of multiple breaks at unknown dates. Break dates are chosen to minimize the sum of squared residuals subject to a trimming factor that enforces a minimum separation between breaks. Consistent with Bai and Perron (2006), we set the trimming factor to 20% of the sample length to allow for serial correlation. This approach allows us to identify both the timing and statistical significance of changes in the dispersion of technological opportunities across fields.

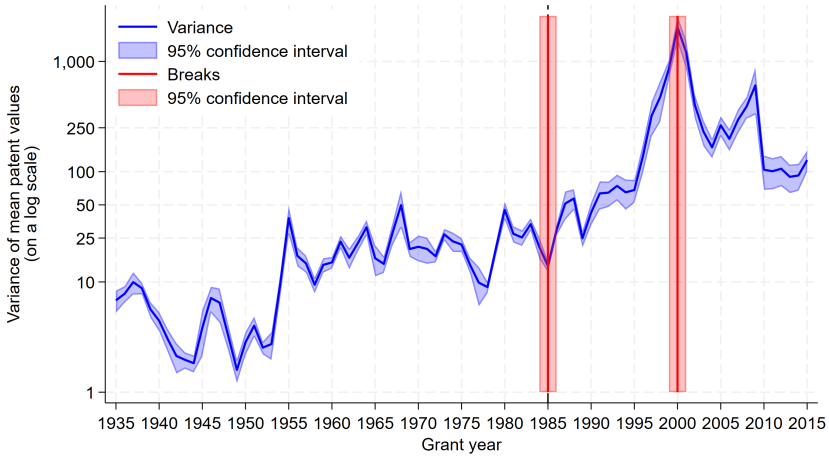
Figure II plots the resulting variance series together with 95% confidence intervals. Vertical red lines indicate the structural breaks identified by the Bai and Perron (1998) procedure, with shaded regions denoting 95% confidence intervals for the estimated break dates. The primary break of interest occurs in 1985, when cross-field dispersion in innovation value rises sharply. This timing coincides closely with the onset of the reversal in relative innovation value between private and public firms. A second break occurs around 2000, coinciding with the bursting of the dot-com bubble, after which dispersion declines but remains elevated relative to much of the twentieth century.[10]

4.2. Persistence of Technological Opportunities

While dispersion determines the stakes associated with reallocating innovative effort across technology fields, persistence determines whether such reallocation is likely to pay off. If differences in field-level innovation value are short-lived, rapid movement across fields amounts to chasing noise. If they are persistent, by contrast, firms that reallocate more quickly can systematically align their innovation portfolios with higher-value opportunities. We therefore examine the extent to which technology-field innovation values persist over time. Our goal is not to identify discrete regime shifts in persistence, but to establish whether field-level differences in innovation value are sufficiently long-lived for reallocation to be economically meaningful. We find that persistence is high throughout the sample, indicating that differences in field-level

[10]To verify that the 1985 break is not mechanically driven by the dot-com period, we re-estimate the break timing excluding post-1999 observations (see Figure IA.4 in the Online Appendix). This procedure yields a structural break in 1986, with a 95% confidence interval spanning 1985–1987.

Figure II: Dispersion of Innovation Value Across Technology Fields



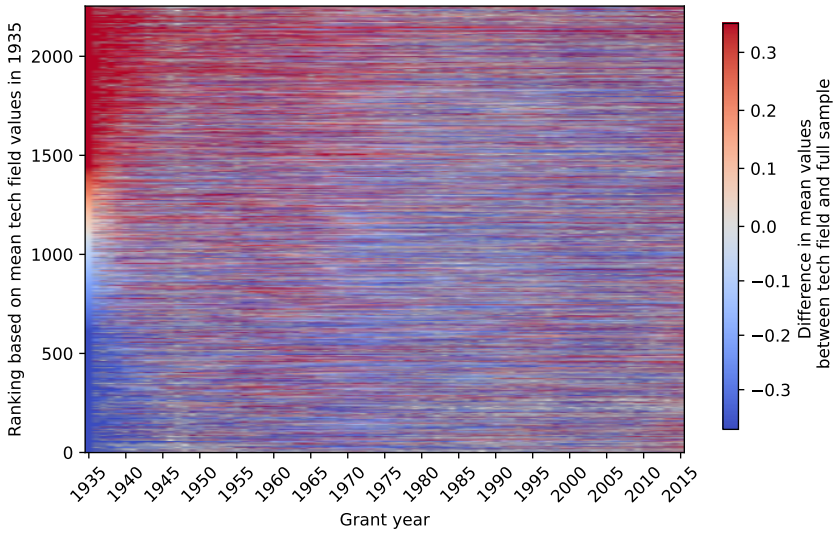
Notes: This figure plots the cross-sectional variance of technology-field innovation values over time. Field-level values are computed as the mean non-imputed market value of public-firm patents granted within a technology field in a given year. Shaded bands denote 95% confidence intervals, constructed using bootstrap standard errors clustered at the technology-field level. Vertical lines indicate estimated structural breaks in the variance series, identified using the multiple-break methodology of Bai and Perron (1998) applied to an autoregressive specification estimated in first differences. Break dates are chosen to minimize the sum of squared residuals subject to a trimming factor of 20%, following Bai and Perron (2006).

innovation value endure over economically relevant horizons.

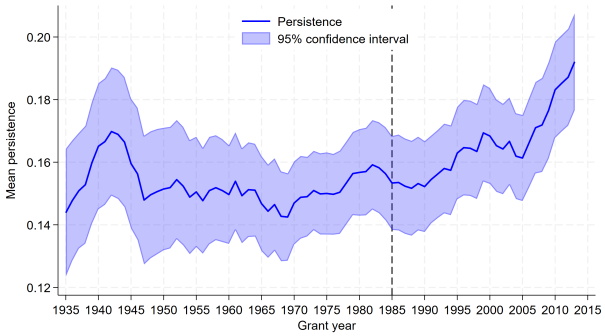
We assess persistence using two complementary approaches. First, we present a nonparametric visualization of persistence across the distribution of technology fields. Panel (a) of Figure III displays a heatmap of relative field-level innovation values over time, with technology fields ordered by their mean value in 1935. This visualization allows us to trace whether fields that are relatively high- or low-value at the beginning of the sample remain so subsequently, without imposing parametric structure or focusing on average behavior alone. The heatmap reveals substantial stability in relative rankings over time, with low- and especially high-value fields remaining visually distinct over long horizons.

Second, we construct summary measures of persistence based on rank stability. Panels (b) and (c) of Figure III report the fraction of technology fields that remain in the same value decile over quinquennial periods. Panel (b) reports average persistence across all fields, while Panel (c) focuses on persistence among fields initially ranked in the top decile. These measures confirm that persistence is quantitatively meaningful and remains high over time, with little evidence of a sharp structural break comparable to that observed for cross-field dispersion.

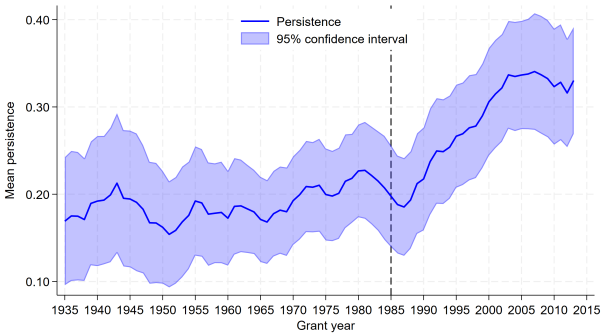
Figure III: Technology Fields: Persistence of Values



Panel (a) Ranking based on mean tech field values in 1935



Panel (b) Average persistence



Panel (c) Persistence in the top decile

Notes: This figure illustrates the persistence of technology-field innovation values over time. Panel (a) presents a heatmap of relative field-level values, with grant years on the x-axis and technology fields on the y-axis, sorted by their mean innovation value in 1935. Colors indicate the deviation of a field's mean value from the cross-field average in a given year. The sample includes 2,254 technology fields with at least one patent in 1935 and in at least 25 additional years between 1935 and 2015; the color scale is truncated at the 25th and 75th percentiles. Panel (b) reports the average persistence of field-level values over quinquennial periods, where persistence is defined as remaining in the same value decile at the beginning and end of the period. Panel (c) reports persistence for fields initially ranked in the top decile. In both panels, we plot 5-year centered moving averages. Shaded bands denote 95% confidence intervals, constructed using bootstrap standard errors clustered at the technology-field level.

4.3. Persistent Heterogeneity and the Return to Nimbleness

Taken together, the evidence in Sections 4.1 and 4.2 points to a shift in the technological environment that has first-order implications for the value of organizational nimbleness.

Throughout the sample period, differences in innovation value across technology fields are sufficiently persistent for reallocation to be economically meaningful. What changes around the mid-1980s is not the durability of these differences, but their magnitude. The sharp increase in cross-field dispersion documented in Section 4.1 implies that aligning innovative effort with the right technologies becomes substantially more important.

In the model, nimble firms—those that face lower adjustment frictions—benefit disproportionately when technological opportunities are both persistent and heterogeneous. When dispersion is low, persistence alone does not generate large gains from rapid reallocation. As dispersion rises, however, the same degree of persistence operates in an environment with much higher stakes, amplifying the returns to reallocating inventive effort toward rising-value fields. The timing of the increase in dispersion therefore moves the economy into a regime in which organizational differences in adjustment speed translate into systematic differences in innovation value from the mid 1980s onwards.

This mechanism provides a natural interpretation of the reversal we document. Private firms need not become more nimble over time for their relative innovation value to rise. Rather, a change in the structure of technological opportunities—toward more persistently heterogeneous fields—makes pre-existing differences in organizational flexibility increasingly consequential.

5. Reallocation, Innovation Value, and the Private-Firm Reversal

This section documents the empirical reversal in innovation value between private and public firms and examines its sources. We begin by formalizing the baseline comparison underlying Figure I, describing the construction of our relative-innovation-value measure deferred in the introduction. We then show that the reversal is robust to alternative measures of innovative performance that do not rely on imputed patent values. Next, we use counterfactual decompositions to assess competing explanations for the reversal. These exercises demonstrate that

the shift is not driven by changes in the characteristics of patented innovations or by changes in how markets price those characteristics, but instead by differences in the technology fields in which firms choose to innovate. Finally, we explore the cross-sectional sources of the reversal, showing that it is disproportionately driven by young private firms and first-time patenters, consistent with the role of organizational nimbleness emphasized in the model.

5.1. Baseline Measure of Relative Innovation Value

Our baseline measure compares the average value of patents granted to private and public firms in each year. Because patent values are highly right-skewed, we summarize innovation value using the geometric mean. Specifically, for a set of patents granted in year t, the geometric mean value is

$$\mathrm{GM}(\tilde{v}_t) = \exp\left(\frac{1}{N_t}\sum_{i=1}^{N_t}\log(\tilde{v}_{it})\right),$$

where $\tilde{v}_{it}$ denotes the imputed value of patent i and N_t is the number of patents in the group. Our baseline statistic is the ratio of the geometric mean value of patents granted to private firms to that of patents granted to public firms in year t,

$$\frac{\mathrm{GM}(\hat{v}_t^P)}{\mathrm{GM}(\hat{v}_t^U)},$$

where superscripts P and U continue to index private- and public-firm patents, respectively. This statistic is the object plotted in Figure I and serves as our primary measure of relative innovation value over time.

As noted in the introduction, this measure reveals a pronounced reversal in relative innovation value over time. Private firms trail public firms for much of the mid-twentieth century, start catching up in the mid 1980s, reach parity in the mid 1990s, and subsequently emerge as the leading producers of high-value patented innovation.[11]

[11]Figure IA.5 in the Online Appendix shows that using the ratio of arithmetic instead of geometric means results in nearly identical levels and dynamics.

5.2. Alternative Measures

We next examine whether the private-firm reversal depends on our baseline measure of patent values. To do so, we consider a set of alternative measures of innovative performance that vary in both their economic construction and their reliance on imputed patent values. We begin with an accounting-based measure of R&D value-add, which allows us to assess whether private firms simply increase R&D spending to generate higher innovation value. We then turn to patent-based outcome measures—breakthrough and disruptive innovations per dollar of R&D—that do not rely on market-based valuation or imputation. Finally, we present a nonparametric field-level test that uses only non-imputed public-firm patent values to examine whether private firms disproportionately enter high-value technological fields. Across all four exercises, we obtain the same qualitative pattern as in the baseline, confirming that the reversal is not driven by any single measure or by the imputation procedure.

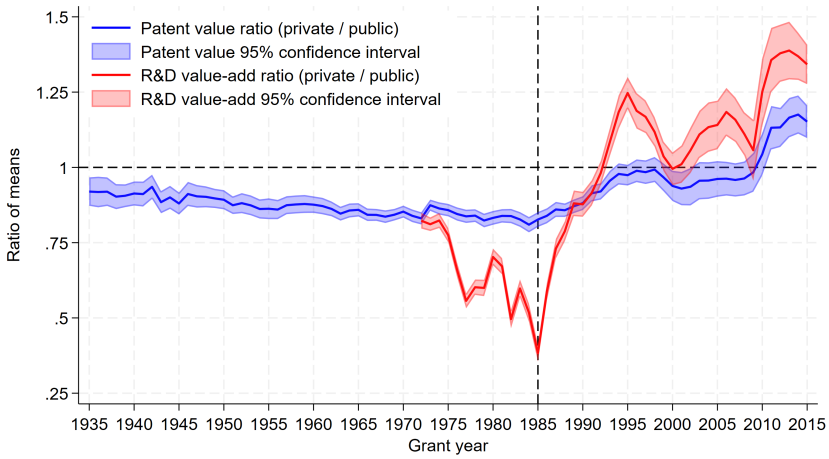
To construct the alternative measures in this section, we require estimates of aggregate R&D spending by public and private firms. The measurement of public-firm R&D expenditures is facilitated by changes in U.S. accounting standards in the 1970s. In 1972, the Accounting Principles Board and the Securities and Exchange Commission made the disclosure of R&D expenses mandatory for public firms, and in 1975 the Financial Accounting Standards Board required firms to expense all R&D expenditures in the year incurred rather than capitalizing them (Nix and Nix 1992). These reforms allow us to observe firm-level R&D spending for publicly listed U.S. firms from 1972 onward using Compustat data. We aggregate these firm-level expenditures to obtain annual public-firm R&D spending and infer private-firm R&D spending by subtracting public-firm R&D from the National Science Foundation's estimates of total U.S. corporate R&D expenditures.

Our first robustness exercise uses these data to construct a measure of *R&D value-add*. For each firm type and year, we compute the aggregate market value of patented innovation using the Kogan-style patent values and subtract aggregate R&D expenditures, normalizing by the number of patents granted. This measure captures the net-of-R&D-cost value of the average

patent and directly addresses the concern that private firms may generate higher innovation value simply by spending more on R&D.

Figure IV plots the ratio of average R&D value-add for private and public firms from 1972 through 2015, alongside our baseline relative innovation value series. The reversal is even more pronounced when R&D costs are netted out. Private firms' R&D value-add reaches a low point in 1985—when the average net value of a private-firm patent is roughly 40% that of a public-firm patent—before rising sharply thereafter. By the early 1990s, private firms reach parity, and by 2015 their average R&D value-add exceeds that of public firms by approximately 30%. These patterns indicate that the baseline measure is, if anything, conservative: the growing private-firm advantage reflects higher net innovation value rather than increased R&D spending.

Figure IV: Private vs. Public R&D value-add



Notes: This figure compares the baseline measure of relative innovation value—the ratio of the geometric mean value of patents granted to private firms relative to public firms—with an alternative measure based on R&D value-add. R&D value-add is defined as the aggregate market value of patented innovation net of aggregate R&D expenditures, normalized by the number of patents granted to each firm type in a given year. Public-firm R&D expenditures are obtained from Compustat and are available from 1972 onward following mandatory disclosure and expensing requirements. Private-firm R&D expenditures are inferred by subtracting public-firm R&D from the National Science Foundation's estimates of total U.S. corporate R&D spending. The figure shows that the reversal in relative innovation value is even more pronounced when innovation value is measured net of R&D costs. The 95% confidence intervals are based on standard errors clustered at the technology-field level.

Our second and third robustness exercises use patent-based outcome measures that do not rely on market-based valuation or imputation. Specifically, we compute the number of breakthrough patents—defined following Kelly et al. (2021)—and the number of disruptive

patents—defined following Park, Leahey, and Funk (2023) and Macher, Rutzer, and Weder (2024)—per $100 million of R&D spending for private and public firms. These measures capture high-impact and paradigm-shifting innovation outcomes using observable patent characteristics alone.

Figure V reports the resulting time series. Panels (a) and (b) plot, respectively, the number of breakthrough and disruptive patents per $100 million of R&D for private and public firms, along with the difference between the two series and corresponding 95% confidence intervals. Consistent with the baseline results, private firms produce significantly fewer breakthrough and disruptive patents per dollar of R&D for much of the mid-twentieth century. This pattern reverses in the mid-1980s: private firms reach parity by the late 1980s and, from the early 1990s onward, consistently outperform public firms on both measures.

Figure V: Public vs. Private Breakthroughs and Disruptive Patents



Panel (a) Breakthrough patents per R&D $

Panel (b) Disruptive patents per R&D $

Notes: This figure presents alternative, outcome-based measures of innovative performance for public and private firms, scaled by R&D spending. Panel (a) reports the number of breakthrough patents—defined following Kelly et al. (2021)—per $100 million of R&D for private and public firms, as well as the difference between the two series. Panel (b) reports the corresponding measure for disruptive patents, based on the data shared by Macher, Rutzer, and Weder (2024) and measured as patents in the top decile of their disruptiveness measure adjusted for grant-year fixed effects. R&D expenditures for public firms are obtained from Compustat and are available from 1972 onward; private-firm R&D expenditures are inferred by subtracting public-firm R&D from the National Science Foundation's estimates of total U.S. corporate R&D spending. Shaded bands denote 95% confidence intervals for the private–public differences, clustered at the technology-field level.

As a final and particularly stringent robustness exercise, we examine whether private firms disproportionately enter high-value technology fields using a measure that does not rely on

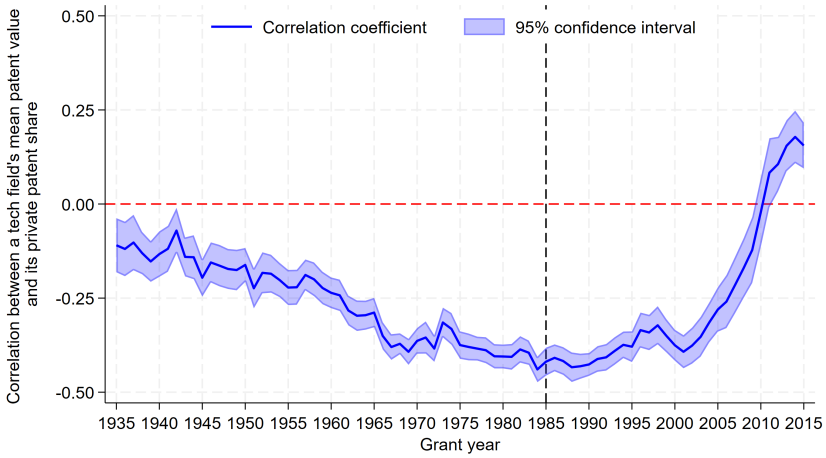
any imputation of private-firm patent values. For each year, we compute the cross-sectional correlation between a technology field's innovation value and its private-firm share of patents. Field-level innovation value is measured as a ten-year moving average of non-imputed patent values based exclusively on public-firm patents, ensuring that the measure reflects only observed market valuations. We use moving averages to smooth short-run fluctuations in patent values and focus on persistent differences across fields.

The analysis is conducted on annual cross sections of technology fields. Correlation estimates are weighted by the number of public and private patents granted in each field-year. This weighting reflects both the precision of field-level value estimates and the fact that patents are very unevenly distributed across fields, ensuring that the analysis captures the behavior of the average patent rather than the average technology field. The resulting correlation therefore provides a nonparametric test of whether private firms increasingly concentrate their innovative activity in higher-value technology fields.

Figure VI reports the resulting correlation coefficients over time. The pattern exhibits a pronounced U-shape. Over much of the twentieth century, the correlation between technology-field values and private-firm patent shares becomes increasingly negative, reaching a low point around the mid-1980s. Thereafter, the correlation rises steadily, indicating that private firms increasingly concentrate their patenting activity in higher-value technology fields.

Unlike the baseline and the other alternative measures, the correlation turns positive only in the late 2000s. This delayed crossover is not surprising given the stringency of the test: because field values are constructed exclusively from public-firm patent valuations and smoothed over a ten-year window, the measure responds slowly to changes in private-firm innovation behavior. Nonetheless, the upward shift in the correlation after the mid-1980s reinforces the central conclusion that private firms increasingly reallocate inventive effort toward higher-value technological opportunities.

Figure VI: Private-Firm Entry and Non-Imputed Technology-Field Values



Notes: This figure plots annual estimates of the correlation between a technology field's innovation value and its private-firm share of patents. Field-level innovation value is measured as the ten-year moving average of non-imputed patent values based solely on public-firm patents. Correlations are estimated using year-by-year cross sections of technology fields and are weighted by the number of public and private patents granted in each field-year. Shaded bands denote 95% confidence intervals based on standard errors clustered at the technology-field level.

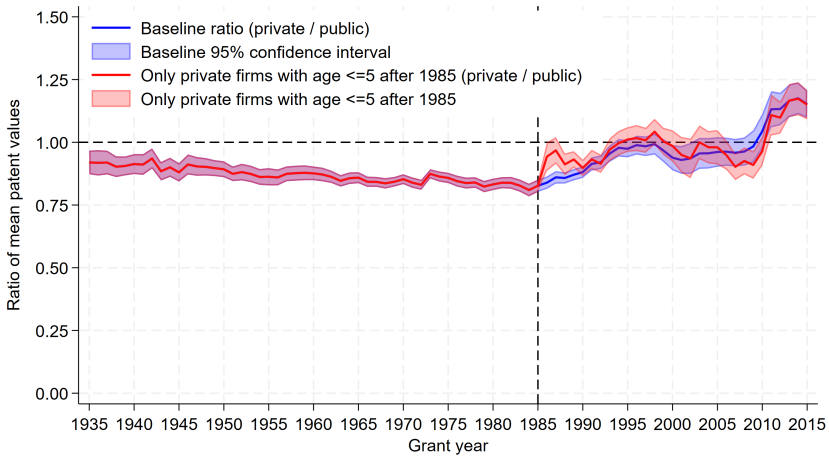
5.3. IPO Activity and Mechanical Explanations

A potential concern is that the reversal in relative innovation value we document reflects mechanical changes in firms' listing status rather than changes in innovative behavior. In particular, the well-documented decline in U.S. IPO activity since the late 1990s raises the possibility that high-quality innovative firms increasingly remain private, so that innovation that would previously have been attributed to public firms is mechanically reclassified as private. Under this view, the observed reversal would arise from shifts in the composition of public and private firms rather than from a change in how firms allocate innovative effort.

To address this concern, we construct a counterfactual that isolates innovation by firms for which IPO timing is unlikely to play a role. Specifically, we recompute the relative innovation value series restricting the private-firm sample to firms that are at most five years old at the time a patent is granted. These young firms are, by construction, too early in their life cycle for delayed IPO decisions to account for their classification as private, and they cannot represent mature public-firm substitutes that simply remain private for longer. The public-firm benchmark is unchanged.

Figure VII reports the results. The reversal in relative innovation value remains clearly visible, with timing and magnitude similar to the baseline series. If anything, the catch-up of private firms appears slightly sharper among young firms. This evidence rules out IPO-related mechanical explanations: delayed IPOs and changes in listing behavior operate through mature firms remaining private, whereas the reversal we document is already present at the point of entry. The findings therefore indicate that the rise of private-firm innovation value reflects changes in innovative behavior and opportunity allocation, rather than shifts in how innovation is classified across public and private firms.

Figure VII: The Relative Value of *Young*-Private- and Public-Firm Innovation



Notes: This figure compares the baseline measure of relative innovation value—the ratio of the geometric mean value of patents granted to private firms relative to public firms—with an alternative measure that restricts the post-1985 private-firm sample to firms that are at most five years old at the time of patent grant. Firm age is defined as the patent grant year minus the firm's self-reported founding year from the National Establishment Time Series (NETS) database. The 95% confidence intervals are based on standard errors clustered at the technology-field level.

With the reversal robust across a wide range of measures, and not mechanically driven by compositional changes, the next section examines its sources by asking whether it reflects changes in the characteristics of patented innovations, the valuation of those characteristics, or shifts in the technology fields in which firms choose to innovate.

5.4. Counterfactual Decomposition of the Reversal

The analysis so far establishes two facts. First, the relative value of innovation produced by private and public firms reverses sharply beginning in the mid-1980s. Second, this reversal is robust across a wide range of measures that do not depend on a particular valuation methodology. We now turn to the question of *why* this reversal occurs. In particular, we ask whether it reflects changes in the characteristics of patented innovations, changes in how markets value those characteristics, or changes in where firms choose to direct their innovative effort. To address this question, we exploit the structure of our patent valuation framework to decompose innovation value into distinct components and to assess their respective roles in generating the observed reversal.

Our approach is based on the observation that patent value can be decomposed into four elements: the characteristics of the patented invention (what firms patent), the valuation multiples attached to those characteristics (how markets price them), firms' technology-field choices (where firms innovate), and the underlying value of those technology fields (what those fields are worth). In our imputation model, patent value is expressed as a function of observable patent characteristics with time-varying coefficients, along with technology-field effects that capture differences in innovation value across fields. This structure allows us to construct counterfactual innovation value paths by holding one component fixed at its 1985 level while allowing the remaining components to evolve as observed in the data. The logic of the exercise is straightforward. If a counterfactual that fixes a given component closely tracks the observed reversal, then changes in that component cannot explain the reversal. Conversely, if fixing a component eliminates or substantially attenuates the reversal, then changes in that component are central to its emergence.

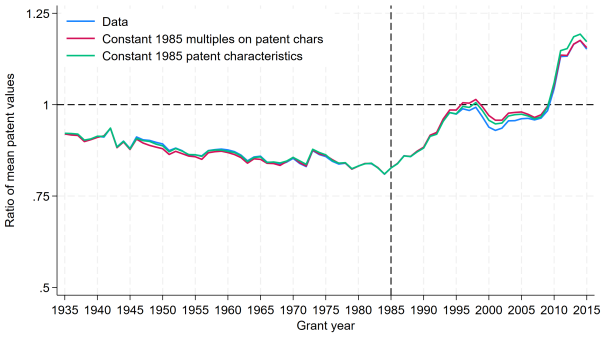
We implement a sequence of counterfactual exercises that use the structure of our valuation model to rule out candidate explanations for the reversal. We begin by examining whether changes in patent characteristics or in the pricing of those characteristics can account for the pattern. Specifically, we construct counterfactuals that hold fixed, at their 1985 levels, either

the valuation multiples attached to patent characteristics or the distribution of patent characteristics themselves, while allowing all other components of patent value to evolve as observed. As shown in Panel (a) of Figure VIII, both counterfactual paths closely track the data. This implies that neither changes in what firms patent nor changes in how markets price patent characteristics can explain the rising relative value of private-firm innovation. In both cases, the near coincidence of the counterfactual and observed series rules out patent characteristics and their pricing as primary drivers of the reversal.

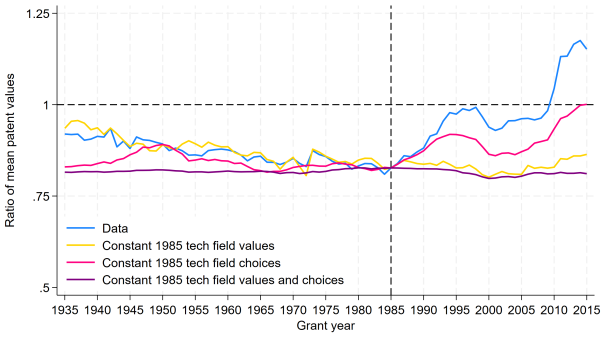
We next turn to counterfactuals that isolate the role of technology fields, shown in Panel (b) of Figure VIII. This panel reports three counterfactual paths: the yellow path holds technology-field values (multiples) fixed at their 1985 levels while allowing firms to reallocate across fields; the red path holds firms' technology-field choices fixed at their 1985 levels while allowing field values to evolve; and the purple path holds both field values and field choices fixed at their 1985 levels. The comparison between these paths is informative. Holding technology-field values fixed largely eliminates the post-1985 increase in the relative value of private-firm innovation, indicating that rising dispersion in field-level opportunities is essential for the reversal. Holding firms' field choices fixed, by contrast, attenuates (but does not eliminate) the reversal, implying that changes in where firms innovate also play a central role. When both field values and field choices are fixed at their 1985 levels, the relative value of private- and public-firm patents remains essentially flat, closely resembling the pre-1985 period. Taken together, these counterfactuals show that the reversal cannot be explained without technology-field dynamics: it arises from the interaction between increasingly valuable fields and differential reallocation toward those fields.

Panel (c) of Figure VIII disaggregates these technology-field counterfactuals by firm type, allowing us to attribute the reallocation underlying the reversal. Specifically, we separately hold fixed the 1985 technology-field distribution of public firms and that of private firms, while allowing field values to evolve as observed. Holding constant the field distribution of public firms has little effect on the relative innovation value series, which closely tracks the data through the late 2000s. By contrast, holding constant the 1985 field distribution of private firms largely

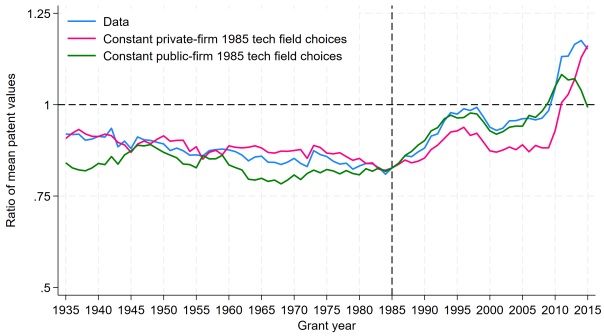
Figure VIII: Counterfactual Decompositions



Panel (a) Patent Characteristics Counterfactuals



Panel (b) Technology-Field Values and Reallocation



Panel (c) Attribution of Reallocation: Private vs. Public Firms

Notes: This figure presents counterfactual paths for the ratio of mean patent values of private firms relative to public firms. Counterfactuals are constructed using the patent valuation model described in Section 2.3, which decomposes patent value into patent characteristics, time-varying valuation multiples, and technology-field effects capturing field-level innovation value. Panel (a) presents two counterfactuals that hold fixed, at their 1985 levels, either the valuation multiples attached to patent characteristics or the distribution of patent characteristics themselves, while allowing all other components of patent value to evolve as observed. Panel (b) reports counterfactuals that hold fixed technology-field values, technology-field allocations, or both at their 1985 levels. Panel (c) separately holds fixed the 1985 technology-field allocations of public firms and of private firms, allowing field values to evolve in both cases.

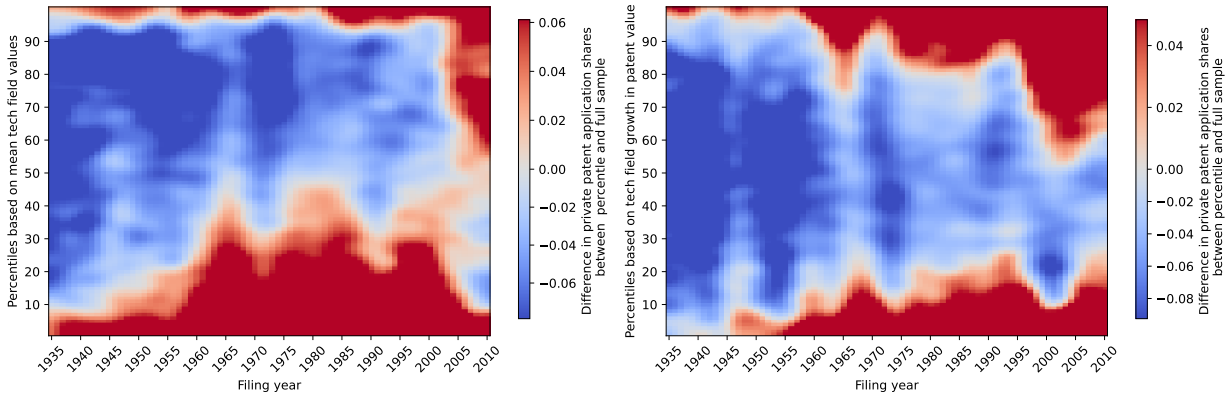
eliminates the post-1985 increase in relative innovation value. This asymmetry indicates that the reversal is driven primarily by changes in where private firms choose to innovate, rather than by public firms exiting high-value fields. In other words, private firms actively reallocate toward increasingly valuable technologies, while public firms' field composition plays a comparatively minor role.[12]

The counterfactual exercises summarize technology-field reallocation through changes in

[12]To further examine the timing of private firms' reallocation, Figure IA.6 in the Online Appendix reports counterfactuals that hold fixed private firms' technology-field distributions at different benchmark years. These results show that the most consequential reallocations occurred between the late 1980s and late 1990s.

average field exposure. We now complement this analysis with a nonparametric visualization that illustrates how private and public firms' patenting shifts across the *distribution* of technology-field opportunities. Figure IX presents heatmaps of firms' relative representation across technology fields ranked by value, allowing us to trace how innovative effort is reallocated over time without imposing parametric structure or aggregating across fields.

Figure IX: Private-Firm Innovation Across Technology-Field Opportunities



Panel (a) Private Innovation Share by Technology-Field Value

Panel (b) Private Innovation Share by Technology-Field Value Growth

Notes: This figure presents nonparametric evidence on the relationship between technology-field opportunities and private firms' innovation activity. Each panel displays a heatmap showing how the private share of patenting varies across technology fields over time. The x-axis reports patent filing (rather than grant) years, to more closely capture the point in time when a firm might pivot. Each cell reports the difference between the private share of patents in a given technology-field percentile and the private share in the full sample in that year. In Panel (a), technology fields are ranked by their mean patent value; in Panel (b), fields are ranked by the subsequent five-year growth rate of mean patent value. Field rankings are based on non-imputed patent values estimated for public firms following Kogan et al. (2017). Warmer colors indicate fields in which private firms are overrepresented relative to the aggregate, while cooler colors indicate underrepresentation. The color scale is truncated at the 25th and 75th percentiles, and the heatmaps are smoothed using a two-dimensional Gaussian filter with bandwidth $\sigma = 2$. The sample covers patent applications filed between 1935 and 2010, reflecting incomplete coverage of patent filings in later years.

Panel (a) ranks technology fields by their contemporaneous innovation value and shows the relative over- or under-representation of private firms across the distribution. Prior to the mid-1980s, private firms are disproportionately concentrated in lower-value fields and underrepresented in the upper tail of the field-value distribution. Beginning in the mid-1980s, this pattern reverses sharply. Private firms become increasingly overrepresented in the highest-value fields and underrepresented in the lowest-value fields, consistent with a broad re-sorting

of innovative activity across the technological landscape. This shift mirrors the timing of the reversal in relative innovation value and provides a distributional counterpart to the average reallocation identified in the counterfactuals.

Panel (b) focuses on a forward-looking measure of innovation opportunities by ranking technology fields based on subsequent growth in innovation value. Here again, private firms' patenting tilts increasingly toward fields that experience higher future value growth, particularly after the mid-1980s. This pattern indicates that private firms' reallocation is not limited to avoiding declining technologies but reflects a systematic shift toward emerging, high-growth areas of the frontier. Together, these visualizations reinforce the conclusion that the reversal in relative innovation value is driven by active reallocation across technology fields, with private firms increasingly positioning their inventive activity in the upper tail of the opportunity distribution.

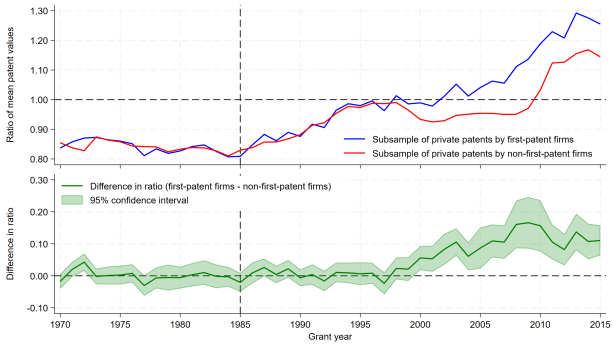
5.5. Cross-Sectional Evidence

We next examine which private firms drive the reallocation toward high-value technology fields documented above. Figure X reports the relative innovation value of private firms across several dimensions that proxy for organizational flexibility and exposure to frontier innovation environments.

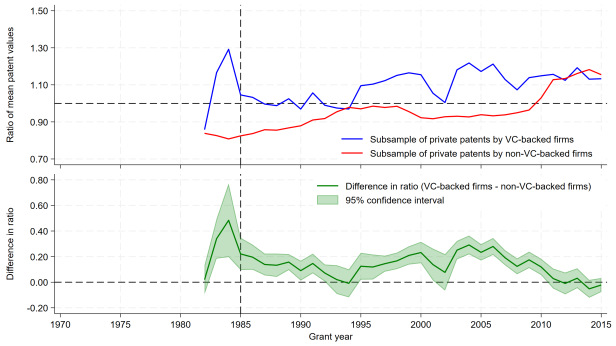
The reversal is concentrated among first-time patenters (many of which are presumably startups). Panel (a) shows that private firms patenting for the first time move from clear laggards to clear leaders relative to public firms beginning in the mid-1980s. This pattern indicates that entry and early-stage experimentation play a disproportionate role in the rise of private-firm innovation value, consistent with lower adjustment frictions among firms without legacy technology portfolios.

Panels (b) through (d) highlight the importance of financing and geography. VC-backed private firms outperform public firms earlier and by a wider margin than the average private firm, suggesting that access to risk-tolerant capital amplifies the ability to pursue high-value

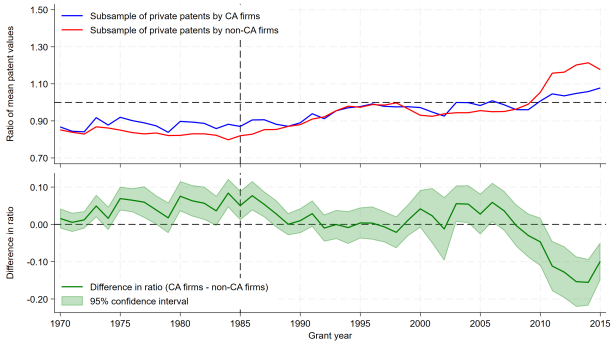
Figure X: Cross-section of Private Firms: Who Drives the Reversal?



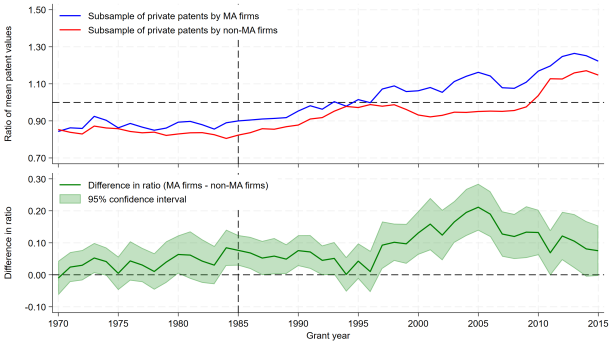
Panel (a) First-time



Panel (b) VC-backed



Panel (c) California



Panel (d) Massachusetts

Notes: This figure presents the evolution of the relative innovation value of private firms across subsamples defined by firm characteristics and location. Each panel plots the ratio of the mean patent value of private firms to that of public firms for two mutually exclusive subsamples (top), along with the difference between the two ratios (bottom). Panel (a) compares first-time private patenters to repeat private patenters. Panel (b) compares VC-backed and non-VC-backed private firms. A firm is classified as VC-backed if it received venture capital financing on or before the patent grant date, based on VentureSource or VentureXpert. Panels (c) and (d) compare private firms located in California and Massachusetts, respectively, to private firms located elsewhere in the United States. Shaded areas in the lower sub-panels indicate 95% confidence intervals. Patent values are constructed as described in Section 2.

technological opportunities. Similarly, private firms located in California and Massachusetts—regions characterized by dense scientific infrastructure and active VC markets—exhibit especially strong gains in relative innovation value, with California-based private firms losing their edge after 2010.

Taken together, the cross-sectional patterns reinforce the interpretation that the reversal is driven by a subset of private firms that are particularly nimble: young entrants operating in frontier innovation ecosystems and supported by specialized finance. These firms are best positioned to respond when technological opportunities become more dispersed, completing the

link between the aggregate reversal and the underlying reallocation mechanism.

Summary. Taken together, the evidence in this section supports the model's central mechanism: once dispersion in technology-field values rises, private firms—especially young and VC-backed entrants—reallocate more nimbly toward high-value opportunities, generating the observed reversal.

6. Macro Implications

The rise in the relative value of private-firm innovation would be of limited economic importance if it did not translate into a meaningful reallocation of aggregate innovation-value creation. We therefore examine whether the micro-level reversal we document has macroeconomic consequences.

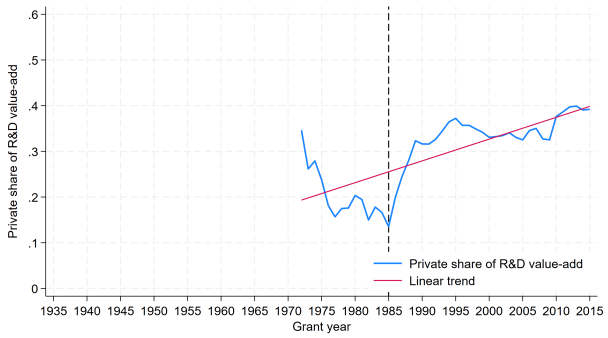
Figure XI, panel (a) shows that the shift in innovation leadership extends to the aggregate level. It plots the private-firm share of aggregate R&D value-add, defined as the value of patented innovation net of R&D expenditures. Since the mid-1980s, this share has more than tripled. The timing of this increase closely mirrors the reversal in relative patent values documented earlier.

Panels (b) and (c) clarify the source of this macro reallocation. Panel (b) shows that the private-firm share of patenting remains relatively stable over time. Public firms continue to account for the majority of patents granted throughout the sample. The growing contribution of private firms is therefore not driven by an increase in the quantity of innovation.

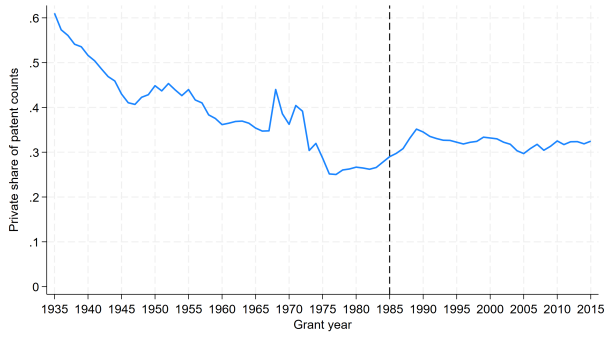
Panel (c) shows that the private-firm share of aggregate R&D spending declines sharply beginning in the mid-1980s. Public firms account for an increasing fraction of total corporate R&D expenditures over time. The rise in the private-firm share of R&D value-add therefore reflects a pronounced divergence between innovative inputs and innovative outputs: private firms generate a growing share of innovation value while accounting for a shrinking share of R&D spending.

Taken together, these patterns point to a macro reallocation of innovative value rather than innovative effort. As technological opportunities become more dispersed, private firms—particularly those able to pursue opportunities nimbly—generate substantially more value per dollar of R&D. A rising share of innovation-driven value creation thus originates outside public equity markets. This shift has implications for how innovation-driven growth is measured (as the behavior of private firms is relatively opaque and thus understudied) and how it is understood (as private firms are not widely investible).

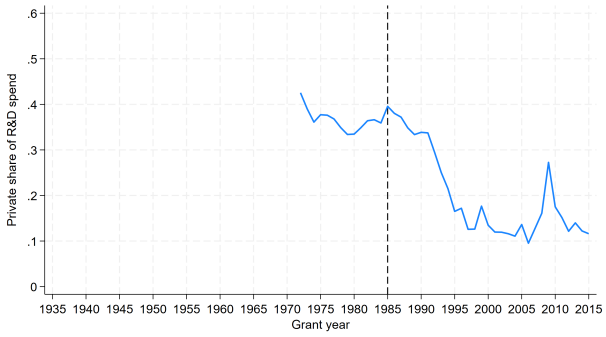
Figure XI: Private Firms and the Aggregate Value of Innovation



Panel (a) Private share of R&D value-add



Panel (b) Private patent share



Panel (c) Private share of R&D

Notes: This figure reports the aggregate implications of the rise in private-firm innovation value. Panel (a) shows the private-firm share of aggregate R&D value-add, defined as the total value of patented innovation net of R&D expenditures. Panel (b) shows the private-firm share of total patents granted. Panel (c) shows the private-firm share of aggregate corporate R&D spending. Patent values are constructed as described in Section 2. Aggregate R&D spending for public firms is obtained from Compustat beginning in 1972, following the introduction of mandatory R&D disclosure and expensing requirements. Aggregate R&D spending for private firms is estimated as total corporate R&D spending reported by the National Science Foundation minus aggregate R&D spending by public firms.

7. Conclusion

This paper documents a long-run reversal in the relative value of innovation produced by private and public firms in the United States. After lagging public firms for much of the twentieth century, private firms have emerged since the mid-1980s as the leading producers of high-value patented innovation. We show that this shift is not driven by changes in patent characteristics, by how markets price innovation, or by greater innovative scale. Instead, it reflects differences in how firms reallocate innovative effort across technology fields as the opportunity landscape evolves.

To interpret these patterns, we develop a simple model in which firms differ in their ability to adjust innovative activity across technologies. The model highlights a key interaction: when technological opportunities are relatively uniform or short-lived, organizational nimbleness confers little advantage; when opportunities become more dispersed and persistent, rapid reallocation generates higher innovation value. Consistent with this mechanism, we document a sharp increase in the dispersion of technology-field values beginning in the mid-1980s, alongside high and rising persistence. Private firms respond more quickly to these shifts, reallocating toward higher-value fields and generating greater value per dollar of R&D.

The consequences of this reallocation extend beyond individual patents. While accounting for a stable share of corporate patenting, private firms now generate a growing share of aggregate R&D value-add through a combination of producing more valuable inventions and doing so at lower R&D cost. The rise of private-firm innovation is therefore not merely a micro-level reordering of innovators, but a macro-level shift in where economically valuable technological progress originates.

Our findings speak to a growing literature documenting rising dispersion in economic outcomes and its implications for innovation and growth. A growing body of work emphasizes that technological change since the late twentieth century has become increasingly uneven, generating large gains in some domains while leaving others relatively unaffected (e.g., Autor et al. 2020; Gordon 2016). While much of this literature focuses on firm-level outcomes such as con-

centration, productivity, or market power, our evidence highlights a complementary dimension of unevenness operating at the level of technological opportunity. We show that the dispersion of innovation value across technology fields increases sharply beginning in the mid-1980s, raising the stakes associated with where firms choose to innovate. In this environment, firms that can reallocate innovative effort more rapidly toward high-value fields gain a systematic advantage. Viewed through this lens, the rise of private-firm innovation reflects not only changes in firm behavior, but a shift in the technological landscape itself—one in which organizational flexibility translates into persistent differences in innovation value.

More broadly, our findings underscore that innovation outcomes depend on the interaction between organizational form and the technological environment. Who innovates matters—but when it matters depends on the nature of the technology frontier. As scientific and technological opportunities continue to evolve, understanding how institutions shape the allocation of innovative effort will remain central to understanding long-run economic growth.

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A. Proofs

A.1. A Simple Model of Technological Reallocation

We develop a minimal model that captures the mechanism suggested by our empirical results: private firms adapt their innovative portfolios to changing technological opportunities more rapidly than public firms. There are two technology fields $j \in \{A, B\}$ with period-t values $v_{j,t}$, where

$$v_{A,t} = \mu + \epsilon_t, \qquad v_{B,t} = \mu - \epsilon_t,$$

and ϵ_t is persistent over short horizons.[13] Two types of firms—private (P) and public (U)—allocate innovative effort shares $s_{i,j,t}$ with $\sum_j s_{i,j,t} = 1$.

Following partial-adjustment models of investment and R&D, firms face adjustment costs when shifting their innovative focus:

$$\Pi_{i,t} = \sum_j s_{i,j,t} v_{j,t} - \frac{\kappa_i}{2} \sum_j (s_{i,j,t} - s_{i,j,t-1})^2,$$

where $\kappa_i > 0$ measures organizational inertia. Motivated by evidence on internal rigidities and disclosure frictions, we assume $\kappa_P < \kappa_U$. (See Appendix B for microfoundations.)

The first-order condition yields

$$s_{i,j,t} - s_{i,j,t-1} = \frac{1}{\kappa_i}\big(v_{j,t} - \bar{v}_t\big), \quad \bar{v}_t = \tfrac{1}{2}(v_{A,t} + v_{B,t}),$$

so firms increase effort in fields whose value is above average. Lower κ_i implies faster response to changes in technological opportunities. Expected innovative output is

$$V_{i,t} = \sum_j s_{i,j,t} v_{j,t},$$

[13] While econometricians proxy ϵ using stock-market reactions observed at the time of patent grant, researchers and engineers working at the technological frontier often receive earlier signals about these technological opportunities (for example, through scientific breakthroughs).

and is increasing in the covariance between $(s_{i,j,t})$ and $(v_{j,t})$. Because $1/\kappa_P > 1/\kappa_U$, private firms align their portfolios more closely with high-value fields and therefore generate higher-value innovations whenever technological opportunities differ meaningfully across fields.

To explain the long-run reversal we document empirically, we allow the variance and persistence of $v_{j,t}$ to differ across regimes. When technological opportunities were relatively uniform and short-lived (mid-20th century), nimbleness was not highly rewarded. As dispersion and persistence increased with the rise of ICT and frontier scientific domains (post-1980s), a lower κ_P became more advantageous, making private firms the leaders in innovation value.

A.2. Formal Propositions and Proofs

We provide formal statements and proofs for the key results in Section 3.

Let

$$v_{A,t} = \mu + \epsilon_t, \quad v_{B,t} = \mu - \epsilon_t,$$

and let $\bar{v}_t = \frac{1}{2}(v_{A,t} + v_{B,t}) = \mu$. Firm type i chooses $s_{i,t} = (s_{i,A,t}, s_{i,B,t})$ subject to $\sum_j s_{i,j,t} = 1$.

Adjustment cost parameters satisfy $\kappa_P < \kappa_U$.

Proposition 1. ***Optimal adjustment rule***

The optimal innovative-effort adjustment satisfies

$$s_{i,j,t} - s_{i,j,t-1} = \frac{1}{\kappa_i}\left(v_{j,t} - \bar{v}_t\right).$$

Proof:

The Lagrangian is

$$\mathcal{L} = \sum_j s_{i,j,t} v_{j,t} - \frac{\kappa_i}{2}\sum_j (s_{i,j,t} - s_{i,j,t-1})^2 + \lambda_t\Big(1 - \sum_j s_{i,j,t}\Big).$$

The first-order condition is:

$$v_{j,t} - \kappa_i(s_{i,j,t} - s_{i,j,t-1}) - \lambda_t = 0.$$

Subtract the analogous condition for field k and use $\sum_j s_{i,j,t} = 1$. Because the multiplier λ_t equals $\bar{v}_t$, the stated expression follows. □

Proposition 2. ***Innovation value advantage***

If $\mathrm{Var}(v_{A,t} - v_{B,t}) > 0$, *then*

$$\mathbb{E}[V_{P,t}] > \mathbb{E}[V_{U,t}] \quad \textit{whenever } \kappa_P < \kappa_U.$$

Proof:

Expected innovation value can be decomposed as

$$\mathbb{E}[V_{i,t}] = \mu + \mathrm{Cov}(s_{i,j,t}, v_{j,t}).$$

Using Proposition 1, $s_{i,j,t}$ is a linear filter of $v_{j,t}$ with gain $1/\kappa_i$. Lower κ_i therefore produces a larger covariance with $v_{j,t}$. The result follows. □

Proposition 3. ***Reversal across regimes***

Let Regime R have field-value process characterized by variance σ_R^2 *and persistence* ρ_R. *Then:*

• *If* σ_0^2 *and* ρ_0 *are sufficiently low,*

$$\Delta_0 \equiv \mathbb{E}[V_{P,t}|R = 0] - \mathbb{E}[V_{U,t}|R = 0] < 0.$$

• *If* $\sigma_1^2 > \sigma_0^2$ *and* $\rho_1 > \rho_0$ *are sufficiently high,*

$$\Delta_1 > 0.$$

Proof:

From Proposition 2, the private-firm advantage is increasing in the covariance between $(s_{P,j,t})$ and $(v_{j,t})$, which grows in (σ_R^2, ρ_R). In low-dispersion environments, the benefit is small

and adjustment costs can dominate. In high-dispersion, high-persistence environments, the benefit dominates. □

B. Microfoundations for the Adjustment-Cost Asymmetry

This appendix provides three complementary microfoundations for the assumption that public firms face higher effective adjustment costs than private firms, $\kappa_U > \kappa_P$. Each microfoundation produces a reduced-form adjustment-cost term of the form

$$\frac{\kappa_i^{\text{eff}}}{2} \sum_j (s_{i,j,t} - s_{i,j,t-1})^2, \quad \kappa_U^{\text{eff}} > \kappa_P^{\text{eff}},$$

consistent with the main model in Section 3.

B.1. Arrow's Information Paradox and Appropriation Losses

To convince outside investors and analysts that a pivot to a new technology field is worthwhile, a public firm has to disclose more about what it has learned about emerging technological opportunities. By Arrow's (1962) classic paradox, that disclosure (a) makes the information more valuable to others and (b) less appropriable by the disclosing firm. For a private firm with concentrated owners and no need to persuade anonymous investors, disclosure can be kept internal, so this "leakage" cost is much smaller. We capture this by adding to the firm's payoff an Arrow-type appropriation loss that is increasing in how much the firm changes direction and that is steeper for public firms.

Formally, let a firm reveal an information set $\mathcal{I}_{i,t}$ to external investors when adjusting its R&D portfolio. Let the fraction of information lost through disclosure be $\alpha_i \in (0, 1)$, with

$$\alpha_U > \alpha_P,$$

capturing that public firms lose more informational advantage.

Suppose that losing information reduces the expected surplus from the pivot by

$$L_i = \frac{\alpha_i}{2} \sum_j (s_{i,j,t} - s_{i,j,t-1})^2.$$

Then the firm's objective becomes

$$\Pi_{i,t} = \sum_j s_{i,j,t} v_{j,t} - \frac{\kappa}{2} \sum_j (s_{i,j,t} - s_{i,j,t-1})^2 - L_i.$$

The effective adjustment cost is therefore

$$\kappa_i^{\text{eff}} = \kappa + \alpha_i, \qquad \kappa_U^{\text{eff}} > \kappa_P^{\text{eff}}.$$

where κ is a "technological" adjustment cost (reassign people, labs, etc.), common to both firm types. A public firm's pivot is doubly costly: the firm has to reorganize, and it also bleeds some of its informational advantage when it explains the pivot to the market. A private firm only pays the first part. Arrow's (1962) information paradox therefore provides a natural foundation for higher adjustment frictions in public firms.

B.2. Governance, Verifiability, and Soft vs. Hard Information

Public firms have dispersed shareholders, independent boards, committees, analyst coverage, etc. A big change in R&D direction typically requires more formal approval, more meetings, more documentation, and more career risk for managers. Private firms with concentrated owners can act on soft information (an internal signal that "field A is hot") quickly. We implement this microfoundation by drawing on the literature on verifiability in contracting (Holmström 1979, 1982) and on the economics of hard versus soft information (Stein 2002).

Specifically, we assume that public firms must obtain approval for major strategic pivots from independent boards, which rely on verifiable, "hard" information. Private firms can instead act on "soft" internal information, such as engineer intuition or preliminary scientific feedback.

This creates differences in the precision of the effective signals used for reallocation decisions. Let firms observe imperfect signals of technology field values:

$$\tilde{v}_{i,j,t} = v_{j,t} + \eta_{i,t},$$

where $\eta_{i,t}$ is noise. Suppose public firms must rely on hard, verifiable signals and therefore have

$$\mathrm{Var}(\eta_{U,t}) > \mathrm{Var}(\eta_{P,t}).$$

Optimal partial-adjustment yields

$$s_{i,j,t} - s_{i,j,t-1} = \frac{\lambda_i}{\kappa}\big(\tilde{v}_{i,j,t} - \bar{\tilde{v}}_{i,t}\big),$$

where λ_i is a Kalman-gain-type responsiveness parameter increasing in signal precision. Public firms have lower λ_U because the board only acts when signals are very strong (and verifiable), effectively dampening responsiveness.

Define the reduced-form effective adjustment cost as

$$\kappa_i^{\text{eff}} \equiv \frac{\kappa}{\lambda_i}.$$

Because $\lambda_P > \lambda_U$, we have

$$\kappa_U^{\text{eff}} > \kappa_P^{\text{eff}}.$$

Thus governance constraints and reliance on hard information (Holmström 1979, 1982; Stein 2002) generate slower responsiveness for public firms.

B.3. Stock-Market Penalties, Downside Risk, and Cautious Reallocation

A pivot that doesn't work out is more painful for a public firm: the stock price drops, managers face career risk, covenants may bite, activists may show up. Private owners can

tolerate more variance in outcomes and are less exposed to noisy short-term market reactions. So public firms have stronger ex ante aversion to big reallocations. The idea that public firms face strong stock-price, financing, and managerial-career penalties for failure is central in Stein (1989), Holmström (1999), and Gibbons and Murphy (1992).

We model these mechanisms as a mean–variance decision problem, where pivot failures increase payoff variance. Let innovative payoff be

$$\Pi_{i,t} = \sum_j s_{i,j,t} v_{j,t} + \varepsilon_{i,t},$$

where $\varepsilon_{i,t}$ captures pivot-specific risk, with variance

$$\mathrm{Var}(\varepsilon_{i,t}) = \sigma^2_{\text{pivot}} \sum_j (s_{i,j,t} - s_{i,j,t-1})^2.$$

Suppose public managers solve a mean–variance problem:

$$U_U = \mathbb{E}[\Pi_{U,t}] - \frac{\gamma_U}{2} \mathrm{Var}(\Pi_{U,t}), \qquad \gamma_U > \gamma_P,$$

while private owners have a lower risk penalty γ_P.

A quadratic approximation yields the objective

$$U_i \approx \sum_j s_{i,j,t} v_{j,t} - \frac{1}{2} \left(\kappa + \gamma_i \sigma^2_{\text{pivot}}\right) \sum_j (s_{i,j,t} - s_{i,j,t-1})^2.$$

Thus, the effective adjustment cost is

$$\kappa_i^{\text{eff}} = \kappa + \gamma_i \sigma^2_{\text{pivot}}, \qquad \kappa_U^{\text{eff}} > \kappa_P^{\text{eff}}.$$

Intuitively, because public firms internalize stronger stock-market and career penalties for failed pivots, they act as if they face higher adjustment costs, reoptimizing their R&D portfolios more slowly than private firms. Stock-market discipline, career concerns, and downside-risk exposure

(Stein 1989; Holmström 1999; Gibbons and Murphy 1992) therefore imply greater sluggishness for public firms.

B.4. Summary

Each microfoundation—appropriation losses from disclosure, governance-induced signal attenuation, and differential downside-risk penalties—generates a reduced-form adjustment friction that is higher for public firms than for private firms. The core implication of the main text, $\kappa_U > \kappa_P$, is therefore consistent with multiple economic primitives.

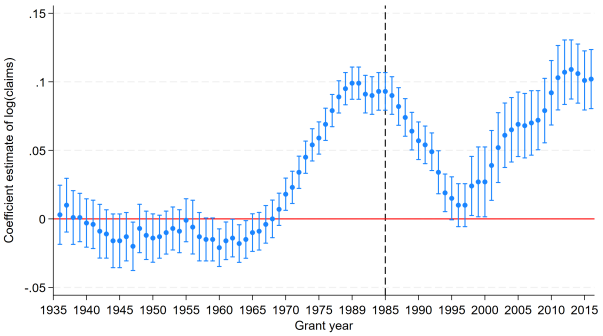
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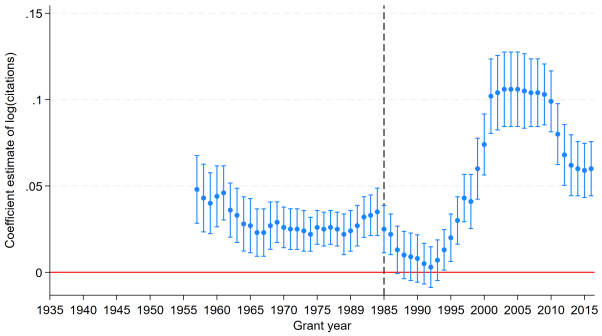
Quietly Ahead: The Diverging R&D Productivity of Public and Private Firms

(NOT INTENDED FOR PUBLICATION)

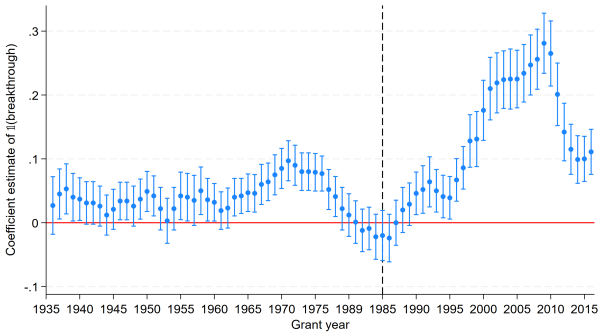
Figure IA.1: Patent-Value Imputation Model Coefficient Estimates



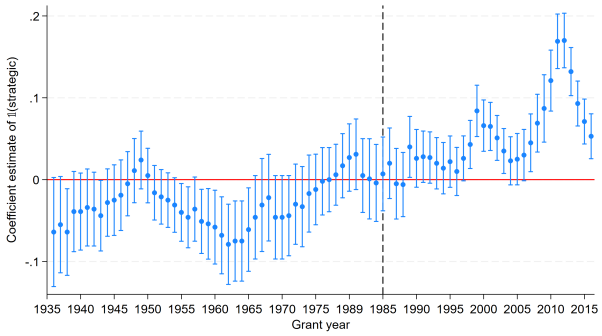
Panel (a) Claims



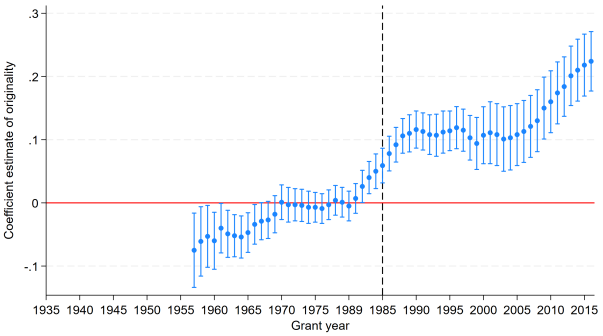
Panel (b) Citations



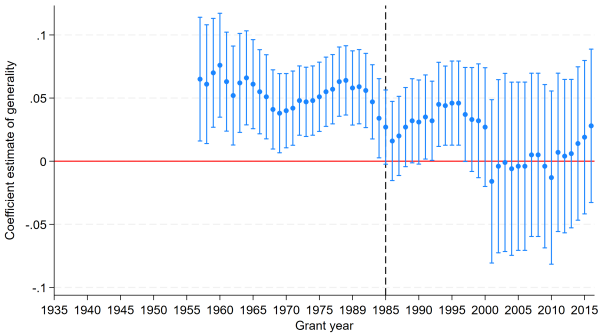
Panel (c) Breakthroughs



Panel (d) Strategic patents



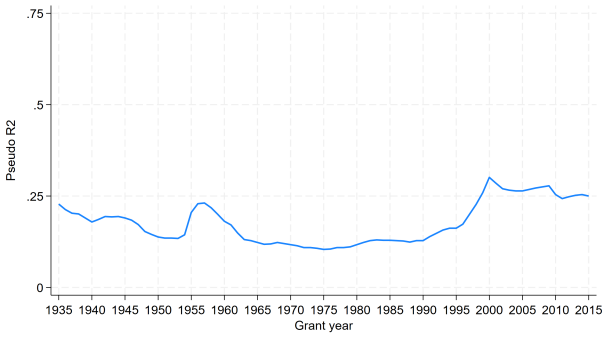
Panel (e) Originality



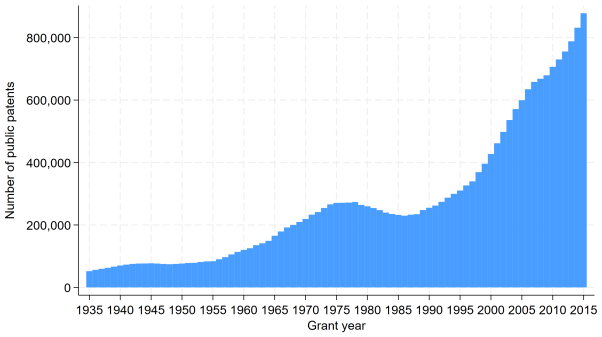
Panel (f) Generality

Notes: This figure plots annual coefficient estimates from the patent-value imputation model in equation 1, estimated using rolling ten-year windows. Data on citations, originality, and generality are unavailable prior to 1947, when the USPTO began reporting citations to prior art on the front page of patents. The blue bars indicate 95% confidence intervals based on standard errors clustered at the technology-field level.

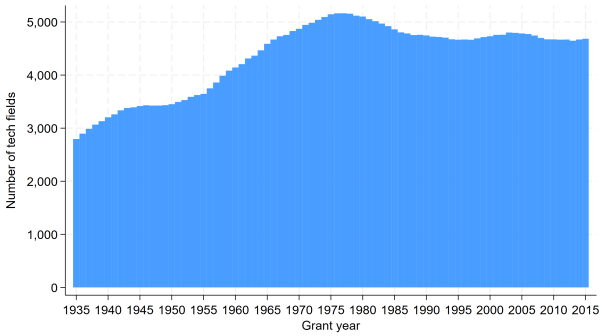
Figure IA.2: Patent-Value Imputation Model: Diagnostics



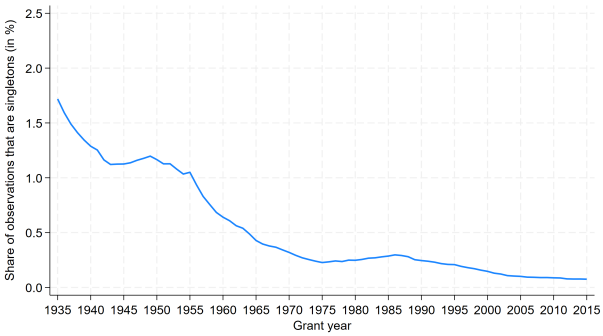
Panel (a) Pseudo $R2$



Panel (b) No. of public patents



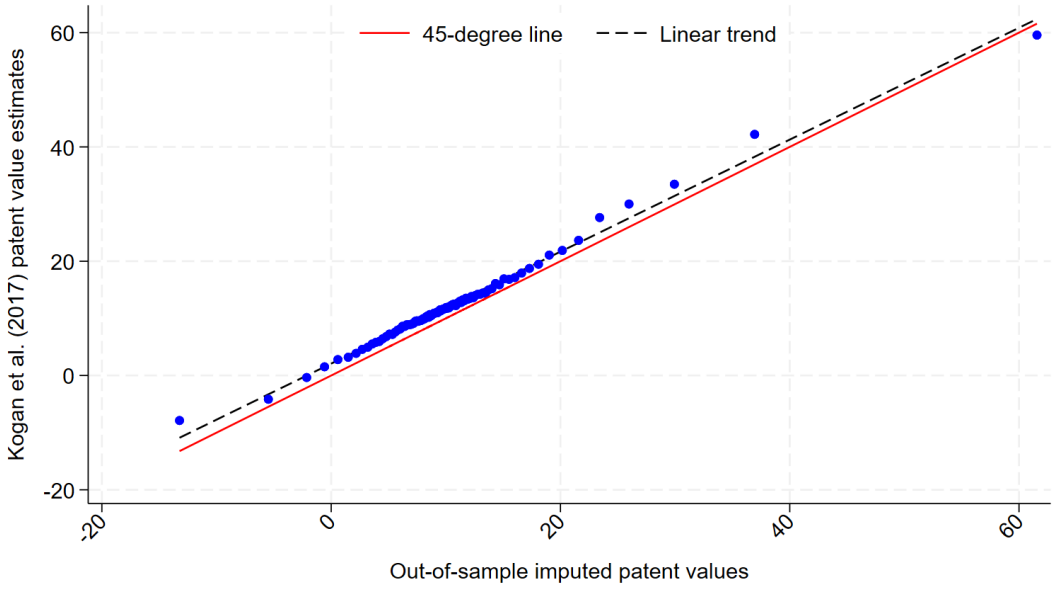
Panel (c) No. of tech fields



Panel (d) Share of singletons

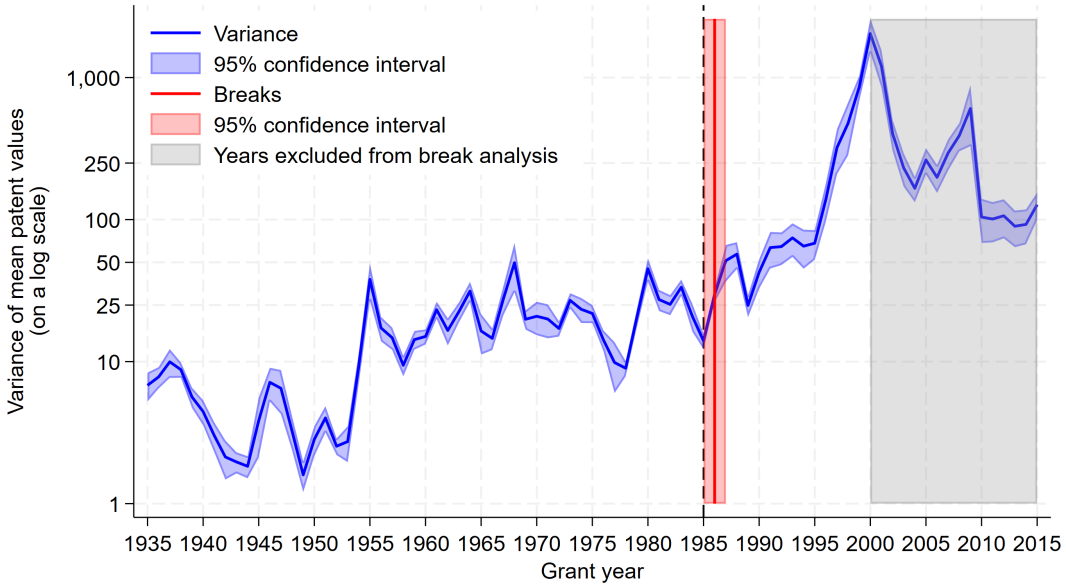
Notes: This figure presents diagnostics of the imputation models (equation (1)) estimated over rolling windows of ten years. Panel (a) presents the Pseudo $R2$ of the imputation models, Panel (b) the number of public patents used to estimate the imputation models, Panel (c) the number of distinct tech fields, and Panel (d) the number of patents that are singletons and therefore excluded.

Figure IA.3: Patent-Value Imputation Model:
Imputed vs. Kogan et al. (2017) Patent Values



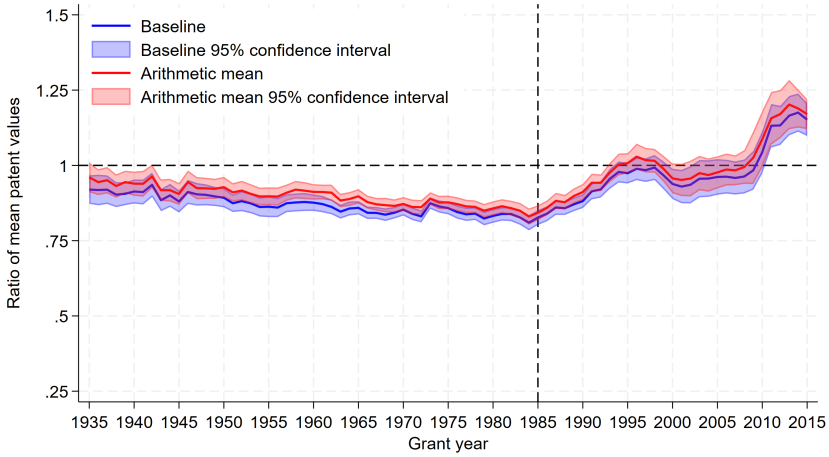
Notes: This figure presents a binned scatter plot comparing out-of-sample imputed patent values to the Kogan et al. (2017) patent-value estimates for public-firm patents. Imputed values are constructed using coefficients estimated from preceding rolling 10-year windows, ensuring that each observation is imputed out of sample with respect to its grant year. Both measures are residualized with respect to grant-year fixed effects, so the comparison reflects cross-sectional variation within year. Each point represents the mean of a bin of observations. The solid line denotes the 45-degree line, and the dashed line shows the fitted linear relationship. The slope of the fitted line is 1.01 using the binned data and 0.94 in the patent-level microdata.

Figure IA.4: Dispersion of Innovation Value Across Technology Fields: Excluding the Period After 1999



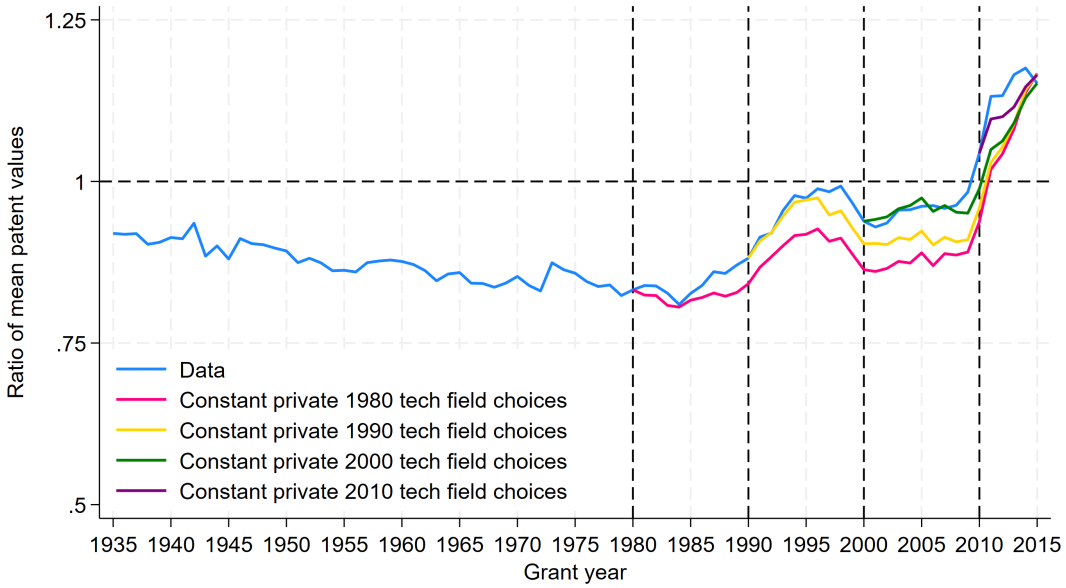
Notes: This figure plots the cross-sectional variance of technology-field innovation values over time. Field-level values are computed as the mean market value of non-imputed public-firm patents granted within a technology field in a given year. Shaded bands denote 95% confidence intervals, constructed using bootstrap standard errors clustered at the technology-field level. Vertical lines indicate estimated structural breaks in the variance series, identified by testing for one structural break using the methodology of Bai and Perron (1998) applied to an autoregressive specification estimated in first differences. Break dates are chosen to minimize the sum of squared residuals subject to a trimming factor of 20%, following Bai and Perron (2006). Unlike in Figure II in the text, the Bai and Perron test is instructed to ignore post-1999 observations to verify that the mid-1980s break is not mechanically driven by the dot-com period.

Figure IA.5: The Relative Value of Private- and Public-Firm Innovation: Geometric versus Arithmetic Means



Notes: This figure compares our baseline measure of relative innovation value—the ratio of the *geometric* mean value of patents granted to private firms relative to public firms—with an alternative version based on the *arithmetic* mean. Shaded areas indicate 95% confidence intervals based on standard errors clustered at the technology-field level.

Figure IA.6: Counterfactual Decompositions



Notes: This figure examines the timing of private firms' technology-field reallocation. Each counterfactual holds fixed the distribution of private firms' technology-field allocations at the beginning of a given decade (1980, 1990, 2000, or 2010), while allowing technology-field values to evolve. Public firms' technology-field allocations are allowed to evolve in all cases.