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ADB Working Paper Series

**MEASURING THE DEGREE
OF CORPORATE INNOVATION**

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Abstract

Corporate innovation propels both company performance and economic growth. Yet, measuring corporate innovation proves to be challenging, leading researchers to rely on a variety of different signals, such as reported R&D expenditures, patent citations and new product announcements. I posit that each of these signs of corporate innovation provides a noisy, biased signal of a firm's technological progress and capacity. Moreover, relying on a single indicator of an activity eliminates useful information, suggesting that all of the observable signals about corporate innovation should be included in measuring it. Using the annual survey of senior executives by BCG/*BusinessWeek* to identify the most innovative companies, I create two composite measures of corporate innovation. Finally, I evaluate how a common use of these individual, noisy signals of innovation to capture R&D productivity (patents scaled by R&D) influences studies on innovative efficiency. Simulation analysis shows that scaling one noisy, biased signal of innovation by another (e.g., R&D productivity) magnifies the noisy signal problem and leads to biased inferences. Arguably, the composite measures, based on multiple signals of corporate innovation, provide more reliable assessments of corporate innovation than any single indicator. Finally, I discuss the use of composite measures of innovation in empirical research on technological innovation and the implications for policy makers.

Keywords: innovation, R&D, patents, technological progress

JEL Classification: O30, O31, G31

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1. INTRODUCTION

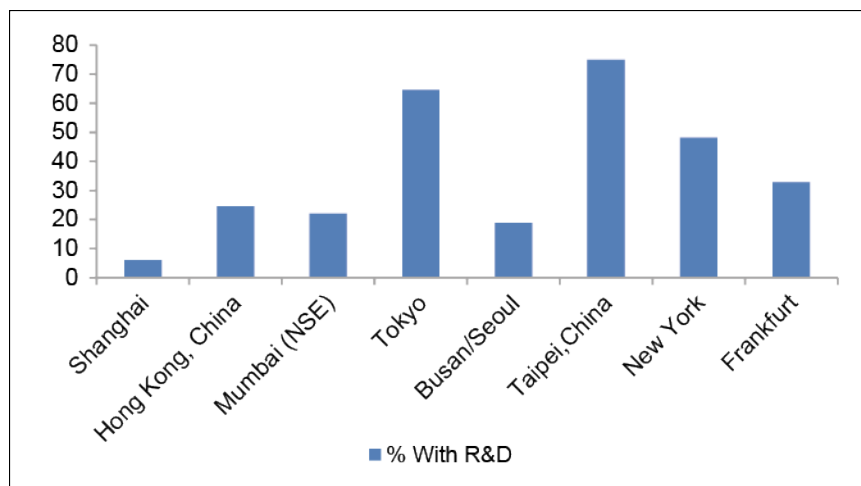
Researchers commonly view corporate innovation as a key foundation of economic growth. Scherer (1986) describes how technological progress disrupts industries and increases the per capita income in industrialized nations. Grossman and Helpman (1990) observe that successful research improves a firm's market power and profits. Audretsch and Feldman (1996) discuss the prevalence and magnitude of R&D spillovers, suggesting that corporate innovation exerts both direct and indirect influence on economic growth. More generally, researchers find that corporate innovation accelerates sales growth and increases a firm's profitability (Franco 1989). Others highlight, however, that these benefits and spillovers vary across ownership structures (Anderson et al. 2017). Koh, Reeb, and Zhao (2017) report that firms with cautious CEOs tend to engage in more innovation, while simultaneously failing to disclose their company's innovation activity. As a result, it is difficult to assess the determinants and impact of innovation because of the difficulty in measuring it. Research on corporate innovation often relies on firms' disclosure about their R&D activities. However, managers face a trade-off in disclosing their spending on innovation activities, garnering a benefit from sharing it with investors and customers but incurring a cost from informing competitors (Koh and Reeb 2015).

Academic research on innovation spans various business disciplines and also arises in economics and sociology. While the concept of innovation remains clear, measuring corporate innovation proves to be challenging and diverse. Accounting research regularly focuses on R&D expenditures, while economists and management scholars typically rely on patents and their citations. Others focus on new product announcements to capture the technological progress of a firm (Reeb and Zhao 2017). Unfortunately, none of these signals of corporate innovation fully capture the nature of innovation and knowledge creation in the firm. Unsurprisingly, these individual measures, such as R&D spending or patent citations, provide a noisy, imperfect signal of the technological progress and capacity of the firm. In addition, each of these signals of innovation depends on managerial disclosures about the company's research activities. Material R&D expenditures are a mandatory disclosure, while patents and new product announcements represent voluntary disclosures to investors that reinforce property rights and attract customers. Consequently, these noisy signals of corporate innovation also suffer from a series of selection processes within the firm and across markets.

These varying signals of innovation provide different snapshots or information about innovation in Asian markets relative to western economies. Figure 1 shows the percentage of innovative firms in selected stock exchanges, based on the proportion that report R&D. Using reported R&D, the stock exchange of Taipei, China (TPEX) appears to be one of the most innovative markets in the set, while the stock exchange of the Republic of Korea (KRX) lags behind the markets in Mumbai (NSE) and Hong Kong, China (HKEX). This metric indicates that over 70% of the firms in the stock exchange of Taipei, China are engaged in innovative activities. Nevertheless, relying on patents to signal corporate innovation provides a different view of innovative firms in these markets. Figure 2 again ranks markets by the proportion of companies engaged in innovation, using patents to capture or signal corporate innovation. Using this metric, the stock exchanges of Frankfurt; New York; Taipei, China; Tokyo; and the Republic of Korea all appear to exhibit similar magnitudes of corporate innovation, with roughly 15% to 25% of firms engaged in innovation. Figure 3 highlights the difference for each market resulting from measuring corporate innovation, using R&D relative to patents to signal corporate innovation activity. These separate signals provide the greatest

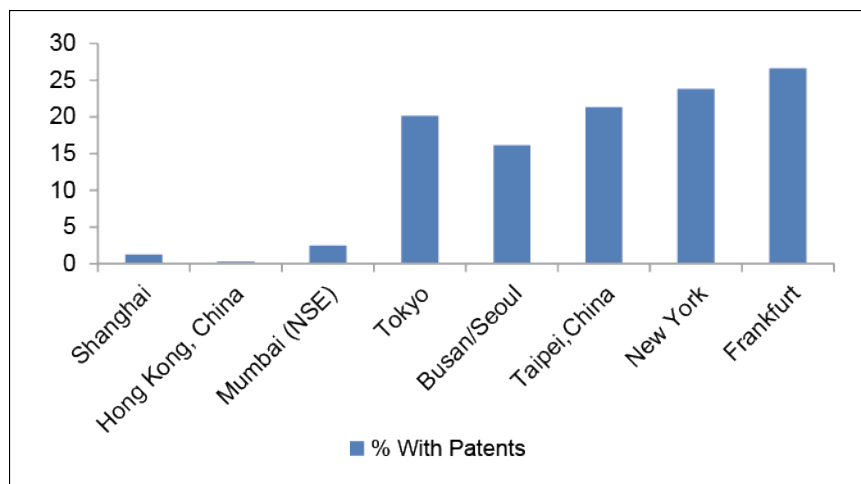
distortions in evaluating innovation activity on the stock exchanges of Taipei, China and Tokyo, arguably because the choice to disclose innovation via reported R&D spending, patenting activities, or product announcements differs across markets. For instance, firms in the Taipei, China market appear to be more willing to report their R&D spending relative to those in the stock exchange of the Republic of Korea. Relying on a single signal of corporate innovation potentially fosters complacency about innovation among policy makers in markets with fewer companies that fail to report R&D activities.

Figure 1: Ranking By Innovation: Proportion of Firms Reporting R&D*
(%)



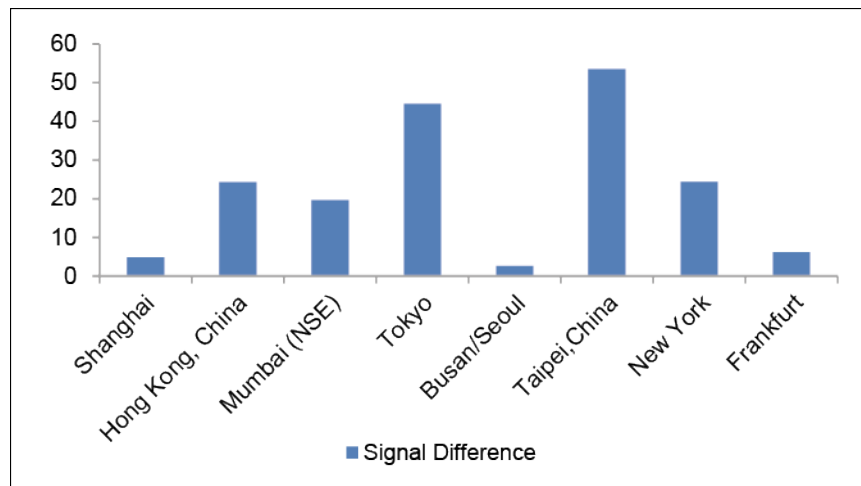
* Derived from Koh et al. (2015).

Figure 2: Ranking By Innovation: Proportion of Firms Seeking Patents*
(%)



* Derived from Koh et al. (2015).

Figure 3: Difference in Market Ranking: Using R&D versus Patents*
(%)



* Derived from Koh et al. (2015).

To formally assess the measurement of corporate innovation, I begin with an analysis of the importance of innovation and the types of questions that interest academics and policy makers. In section 3, I discuss the nature of the noise in the three signals of innovation most commonly used by empirical researchers in the social sciences. Next, I focus on the selection biases in these measures and the nature of the managerial choice to provide this information. The impact of signal noise and selection bias when using a single signal of innovation then forms the motivation in section 4 to assess the ability of these indicators of technological progress to capture or measure corporate innovation. Relying on the annual survey of senior executives by BCG/*BusinessWeek* to identify the most innovative companies, I then evaluate how well these signals identify corporate innovation. I contend that employing multiple signals provides a broader measure of corporate innovation. Arguably, the resulting factor-analysis-based measure of corporate innovation and the weighted-index of corporate innovation each provide a more reliable assessment of technological capacity than using a single signal of innovation (Kline 2015).

In further analysis, I explore a common dual-signal approach to measuring innovation, patents scaled by reported R&D (R&D productivity). I develop a simple simulation analysis to gauge the effect of scaling one noisy, biased signal innovation by another noisy, biased signal of innovation. I simulate both R&D spending and innovation success and then create noisy signals of the true values (reported R&D and patents). Analyzing both true R&D productivity and noisy R&D productivity reveals that the mean and variance of reported R&D productivity are downward biased. Thus, even without bias, scaling one noisy signal by another creates biased estimates of true R&D productivity. Using noisy R&D productivity in growth regressions, I find that it provides biased coefficient estimates and standard errors. Unsurprisingly, these problems are even greater once biased signals are introduced into the analysis. In short, scaling patents by reported R&D appears to intensify the problems in using these noisy, biased signals of corporate innovation. Finally, in the conclusion section, I discuss how to apply and use a multiple signal measure of corporate innovation in empirical research on technological innovation and how this affects policy makers in Asia.

2. CORPORATE INNOVATION AND GROWTH

2.1 Why Innovation?

Economic research highlights the role of Schumpeter in defining or describing the impact of innovation on economic growth and development (Ruttan 1959). This literature builds on the notion that corporate innovation creates new products and processes that antiquate existing products and firms. Tufano (1989) describes how firms exploit new products to capture a greater market share. Research on pharmaceutical firms, for instance, reveals that private-sector drug development can add substantial value to a firm (DiMasi, Hansen, and Grabowski 2003). Other studies emphasize that corporate innovation improves market competitiveness and leads to persistent economic growth (Raymond et al. 2010). Aghion and Tirole (1994) show how the allocation of property rights affects the frequency and magnitude of corporate innovation. There is a strong consensus among both academics and practitioners that corporate innovation drives firm performance and ultimately market capabilities and success (Cantwell 2014).

Operationally, corporate innovation captures firms' attempts to develop new products or new methods to reduce the costs of goods sold or to improve the quality of existing products (Grossman and Helpman 1990). Academics thus define innovation as inventing a process or object, using it to develop a product or service for the market and working to improve it in the future. Thus, innovation encompasses a variety of different tasks. How should we then identify innovative firms? Presumably, innovative firms are those that develop breakthrough products, innovative processes, unique customer experiences and/or new business models (Yoon and Deeken 2013). By definition, innovation is therefore a concept that covers multiple aspects or types of corporate activities. Perhaps the easiest innovation to identify is a new product, while more difficult innovations range from reductions in manufacturing costs to the development of new applications for an existing problem. Part of the issue of identifying innovation depends on the context of the analysis.

2.2 The Economics of Innovation

Research on the economics of innovation spans developmental economics, public economics and industrial organization (Hall and Lerner 2010). Two common themes in this body of research focus on determining how to encourage corporate innovation and how to gauge the impact of this innovation on economic growth. Some of the earliest research, such as that by Marshall (1890), emphasizes that knowledge growth occurs in clusters and requires specialized labor pools. Hicks (1932) argues that high labor costs spur the development of labor-saving inventions. Consistent with this notion, Acemoglu (2010) finds that labor scarcity encourages innovation in labor-saving devices. Building on this literature, Asheim and Coenen (2006) argue that spatial proximity and concentration are key issues in knowledge production. Duranton and Puga (2001) posit that innovation arises in diversified metropolitan areas and that, once perfected, mass production moves to lower-cost, specialized cities.

Png (2017) reports that legal protection of a firm's intellectual property spurs greater investment in innovation. Aghion, Van Reenen, and Zingales (2005) describe how product market competition increases the incremental profits from corporate innovation, especially among more competitive firms. Thus, the literature on the determinants of innovation focuses on the entirety of the innovation process. Gauging the degree of corporate innovation to investigate its determinants requires a broad measure

that captures the various activities among firms. The spillover literature provides a good example. The literature discussing the impact of corporate innovation on growth focuses on both firm-specific and spillover effects from corporate R&D. Griffith, Redding, and Van Reenen (2004) discover that a firm's ability to absorb technology transfers from others is a key determinant of success. Okamuro (2007) reports that successful innovation depends on the coordination costs of the research project. Nicholas (2008) finds that the valuation of knowledge capital depends on the quality of the underlying technological inventions. Thus, the literature on innovation and growth requires a comprehensive measure of innovation that includes both input and output measures.

2.3 Management Research on Innovation

Building on industrial organization research, management scholars study how managers set their innovation strategy, the types of organizational structures that are the most effective and the way in which their innovation influences their rivals. Cohen and Levinthal (1990) argue that innovation activity enhances a firm's ability to assimilate and exploit information from external sources. Moving beyond firms, others suggest that research and development alliances represent a critical component in developing successful innovation in industries with complex and diverse sources of expertise (Powell, Koput, and Smith-Doerr 1996; Phelps 2010). Another stream of this innovation literature centers on the ability of firms to fast-track their innovation process. Eisenhardt and Tabrizi (1995) observe that firms can accelerate their innovation either by compressing the sequential steps or by following an experiential model that relies on improvisation and flexibility. Boudreau, Lacetera, and Lakhani (2011) find that increasing the number of researchers reduces the incentives to exert effort but increases the odds of finding an extreme-value solution. Koh, Reeb, and Zhao (2017) document that cautious CEOs seek to speed up their innovation activities and aggressively seek to keep this information from their competitors. Williamson and Yin (2014) describe how firms in the People's Republic of China fast-track innovation by breaking the process into small components with multiple teams. These studies often focus on innovation outcomes as a function of strategic decisions by top management. Thus, the management innovation literature needs a measure of innovation that incorporates both inputs and outputs of technological progress.

2.4 Financing Innovation

Accounting and finance research focuses on motivating and financing corporate innovation. Dutta and Fan (2012) show that delegated R&D investment decision making improves innovation output. Manso (2011) highlights that managerial compensation contracts that allow for early failure and reward long-term success facilitate the innovation process. Cheng (2004) describes how boards design compensation contracts to minimize opportunistic reductions in R&D spending by corporate managers. Others focus on financing's potential to influence the creation of new technological capabilities and products. Lerner, Sorensen, and Stromberg (2011) report that LBO transactions do not appear to influence the innovation activities within the firm. Fang, Tian, and Tice (2014) argue that greater stock market liquidity causes a reduction in future innovation. Without the threat of a takeover, managers arguably reduce their investments in research and development (Atanassov 2013). In contrast, Cornaggia et al. (2015) argue that banking competition reduces corporate innovation by public companies. In sum, the finance innovation literature appears to require a measure of innovation that captures inputs and observable outputs to investors.

3. INNOVATION DATA

3.1 R&D Expenditures

R&D spending is arguably the most widely used measure of corporate innovation activity. This mandatory disclosure provides a quarterly update on how much the firm invested in R&D over the prior 3 months. Prior to 1974 firms often treated R&D much like capital expenditures, placing this investment on the balance sheet (Lev and Sougiannis 1996). However, accounting policy makers argued that R&D, while focusing on generating future cash flows, is intangible and difficult to verify. Consequently, corporate R&D began to be expensed under *Generally Accepted Accounting Principles*. These disclosure regulations, SFAS 2 *Accounting for Research and Development Costs*, require managers to report material R&D expenditures, providing clear guidelines for managerial compliance. Specifically, managers must report all relevant information and exclude trivial information to limit concerns about shrouding (Koh, Reeb, and Zhao 2016). The Supreme Court provided guidance in 1976, deciding that materiality occurs when a “reasonable investor” views the information as price sensitive (Sauer 2007).

Firms spend a considerable amount on R&D, with the largest 1,000 firms spending over \$638 billion in 2016. Bushee (1998) argues that investments in research and development constitute an essential factor of a firm’s market value. Kothari, Laguerre, and Leone (2002) emphasize that both capital expenditures and R&D spending deliver measurable market value benefits to the firm. R&D spending provides a signal about the inputs into the innovation process. For questions or concerns about motivating corporate innovation, this is an especially intuitive signal. Research in industrial organization often stresses the importance of analyzing inputs in a variety of settings. Athey and Bagwell (2008) stress that observing the costs of competitors can facilitate collusion within an industry. Similarly, the competitive strategy emphasizes that monitoring input prices allows investors and firms to assess the threats that current and future rivals pose (Miller and Waller 2003). While competitive intelligence may provide a range of R&D estimates about competitors, reported R&D provides a concise point estimate.

One of the primary advantages of using R&D spending as a signal of innovation activity is that a substantial number of firms provide this mandatory disclosure. For instance, almost two-thirds of S&P 1500 firms report R&D. However, this signal of innovation contains two sources of noise. First, managers must determine which activities constitute research and development. An engineer who expends part of her effort on innovation and part on quality control requires some system or decision about the relative allocation of her time. Thus, the decision about classifying specific spending as R&D outside of subunits that specialize in R&D is a discretionary choice of the manager (Horwitz and Kolodny 1980). Sougiannis (1994) describes the second concern for investors: does R&D spending today reflect benefits from prior R&D investments? In other words, does the past success of R&D translate into future success of today’s R&D spending? Any signal about innovation inputs provides a noisy signal about future payoffs from this investment. Thus, R&D spending contains two well-known sources of noise, one stemming from managerial discretion in categorizing R&D and the other from the potential disconnection between innovation inputs and innovation outputs.

The greatest challenge in using R&D to capture corporate innovation, however, arises from the large number of firms that do not report any information about R&D. R&D frequently requires specialized machinery, buildings, employees, computers and assorted other items, suggesting that the classification decision for these expenses can be subjective. Koh and Reeb (2015) argue that managers exploit this discretion not to report R&D, resulting in a large number of firms with blank or missing R&D data. Conceivably, managers consider the strategic response of their competitors to their reported R&D and therefore choose not to report it to gain a competitive advantage over them (Scotchmer 1991). This potential failure to report R&D spending creates a selection bias in using R&D expenditures as a measure of innovation activity.

To assess whether firms without reported R&D actually do engage in innovation activities, Koh and Reeb (2015) undertake a series of tests. Their first set of tests compares patent activity between the firms that do not report R&D and those that report zero R&D, finding that non-reporting R&D firms file 14 times more patents than their zero R&D counterparts. Koh and Reeb (2015) also document significant differences in patent characteristics between zero and non-reporting R&D firms. Using patent citation data, they find that non-reporting R&D firms, relative to zero R&D firms, receive more influential patents that take longer for competitors to discover. Perhaps a more informative comparison is to compare patents in firms without reported R&D with patents in firms that do report R&D. Koh and Reeb (2015) discover that the top 5% of positive R&D firms receive substantially more patents than firms with missing R&D, yet they also find that missing R&D firms with patents correspond to the bottom 90th percentile of the patenting profiles of positive R&D firms. To investigate whether this reporting choice is deliberate, Koh and Reeb (2015) exploit the forced change in auditors following the collapse of Arthur Andersen. They find that this exogenous change in auditors led firms to begin reporting R&D, resulting in these firms disclosing R&D at the around the 26th percentile of all positive R&D firms.

Extending this line of research, Koh, Reeb, and Zhao (2016) assess whether this missing R&D is material. Focusing on firms that switch from missing to positive R&D, they find that these firms often report comparative figures for prior years (years that were previously blank). Koh, Reeb, and Zhao (2016) document that the unreported R&D numbers correspond to about the 55th percentile of their positive R&D peers. Using stock returns, they also find that missing R&D firms co-move nearly 1,300% more with positive R&D firms than with zero R&D firms. Turning to financial analysts, Koh, Reeb, and Zhao (2016) report that analysts following missing R&D firms are over five times more likely to cover a positive R&D firm than zero R&D firms. Moreover, they report that an exogenous loss in analysts' coverage leads missing R&D firms to begin reporting R&D. Perhaps more importantly, Koh, Reeb, and Zhao (2016) document that opportunistic insider trading in missing R&D firms allows managers to obtain substantial rents relative to those found in positive R&D firms. Thus, withholding R&D expenditures allows insiders of missing R&D firms to obtain private benefits. In short, firms without reported R&D often engage in substantial R&D activities with the opacity from not reporting, benefiting the managers of the firm.

Empirical innovation research typically handles the missing R&D problem in one of two ways, either classifying these firms as zero R&D or discarding these observations. If these missing observations simply result from noise, then either of these approaches has potential merit (Koh et al. 2015). In contrast, if missing R&D represents a selection bias or disclosure choice of the managers, it could influence the results of tests that use it as a measure of innovation. Koh et al. (2015) investigate how these treatments potentially influence research on corporate innovation. They focus on the research in finance and management that explores how managerial overconfidence influences

corporate innovation. Specifically, Galasso and Simcoe (2011) and Hirshleifer et al. (2012) document that overconfident managers, relative to their cautious peers, lead their firms to participate in greater corporate innovation. Koh, Reeb, and Zhao (2017) show that cautious CEOs are substantially less likely to report their R&D or seek patents for their corporate innovation due to their concerns that their competitors will learn from this information. Since cautious CEOs show a lower tendency to report their R&D expenditures or file patents, the standard approach of excluding missing R&D firms will lead to biased results. After adjusting for the propensity to disclose corporate innovation, Koh et al.'s (2017) results suggest that cautious CEO firms are the ones that engage in more corporate innovation.

R&D spending is an important, mandatory signal about corporate innovation. However, it suffers from concerns about the noise in the signal and about managers' potential selection bias. The noise in this signal arises because it only captures inputs (rather than outputs) and because of the managers' discretion in classifying R&D activities. The bias in this signal stems from the managers' choice to report or not to report the R&D, depending on their own assessment of materiality. Recent literature shows that non-reporting R&D firms often have substantial R&D expenditures. Consequently, strictly relying on R&D spending to measure or capture the innovation activities of a firm can lead to biased and misleading results.

3.2 Patents

Recognizing these problems with R&D spending data, empirical research on corporate innovation often relies on patent data. Griliches (1981), focusing on market value, argues that patents provide a good measure of the intangible capital or innovation capabilities of a firm. Jaffe (1986) reports that patents capture the technological position of the firm. Predicated on the notion that patents provide an indicator of successful innovation, Pakes and Griliches (1984) investigate the productivity of innovation across firms (typically researchers compute productivity as patents per R&D). More generally, researchers consider firms with large numbers of patents, across a wide spectrum of technological classes, to contain the greatest innovation. Patents, like academic articles, receive citations, which are also used to capture corporate innovation. Trajtenberg (1990) advocates the use of patents, weighted by their citations, to capture the value of a firm's innovations. Exploiting the citation data further, two other common measures of innovative capacity based on citations are the originality and generality of the patent (Koh and Reeb 2015). These measures capture the heterogeneity of the references in the patent and the width of the future citations across technological spaces (Hall, Jaffe, and Trajtenberg 2001). Conceptually, these measures build on the notion that patents and their citations represent an output measure of successful, corporate innovation.

Developing new technologies and knowledge capacity inherently involves spillovers and mimicking activity. One major stream of literature on innovation highlights the role of a firm's ability to protect its knowledge generation. Several firms can use knowledge simultaneously, which provides benefits to the firms and improves the stock of general knowledge capital in the region (Romer 1990). To limit these spillovers, firms rely on both trade secrets and patents. Focusing on the mix of patents and trade secrets, Mansfield (1986) reports that pharmaceutical firms view patents as an important tool, while most other firms use them less than 20% of the time. Nevertheless, patents provide an observable and measurable approach for firms to protect their innovation. Moser (2005) finds that most inventions remain unpatented, but those that are patented are some of the most successful. Early literature in the field of economics highlights

several benefits of using patents to measure innovation. For instance, patents and their citations allow the researcher to investigate the number of successes, the depth of the patent citations, the spread of the citations across other industries and the reliance of the innovation on prior research in the same technological class (Jaffe 1986; Trajtenberg 1990). Other studies emphasize how patents and their citations provide an indicator of technological output and knowledge generation (Hall, Jaffe, and Trajtenberg 2005).

One primary challenge in using patents or patent citations to measure innovation is their relative scarcity. While R&D data may only be available for 58% of the Compustat universe of firms, patents are even scarcer. Among the Compustat-listed firms, only 23% file patent applications (Koh et al. 2015), suggesting that the non-patenting R&D firms are failed innovators (Reeb and Zhao 2017). Business research typically treats these as zero patent firms, while economists simply tend to exclude them from the analysis. Recent studies emphasize the common view that patents capture innovative success, documenting that stock market liquidity, institutional ownership and acquisition activity cause significant reductions in corporate innovation (Atanassov 2013; Fang, Tian, and Tice 2014; Bernstein 2015).

Firms potentially weigh the cost of filing a patent against the expected value of the property rights protection (Evenson 1984). Of course patents also provide detailed plans and schematics about the underlying technological innovation, which may benefit competitors, yet the typical interpretation of this trade-off is that non-patenting firms possess unimportant innovations. Moser (2012) provides empirical support for this interpretation based on data from the world's fairs from 1851 to 1915. She documents that these inventors more frequently patented the inventions that ultimately proved to be more valuable. Using a survey of Canadian firms, Hanel (2008) discovers that patent-reliant firms exhibit higher profits than their non-patenting peers. Others indicate that non-patenting firms, based on subsequent sales revenues, suffer from inefficient R&D investments (Hussinger 2006). More generally, the cross-disciplinary literature on patents and their citations depicts non-patenting R&D firms as failures. Building on this notion, the previously noted approach to capturing R&D productivity relies on scaling R&D by patents, which explicitly depicts non-patenting R&D firms as innovation failures.

In contrast, other researchers highlight that patents help firms to secure their property rights and that successful innovation is often kept as trade secrets. Cohen, Nelson, and Walsh (2000) argue that firms appear to garner patents for strategic reasons instead of simply seeking to secure their property rights. More specifically, these authors suggest that firms seek patents to block competitors or as a way of advertising their technological prowess. Firms have a choice between patenting their successful innovations and keeping them as trade secrets (Horstmann, MacDonald, and Slivinski 1985). Survey evidence, across different time periods and locations, suggests that firms use trade secrets more commonly than patents to protect successful innovation (Levin et al. 1987; Cohen, Nelson, and Walsh 2000). A 2008 survey reveals that firms choose to use trade secrets instead of seeking patent protection roughly two-thirds of the time. Highlighting the value of trade secrets, Younge and Marx (2012) report that non-compete agreement changes provide evidence of their widespread appeal and value.

To investigate this issue, Reeb and Zhao (2017) report that both patenting and non-patenting firms introduce valuable new products. Their analysis suggests that innovation in patent-seeking firms focuses on product efficiency while non-patenting R&D firms tend to concentrate on cost-efficiency improvements. Interestingly, Reeb and Zhao (2017) document that executives in non-patenting R&D firms participate in

substantial opportunistic insider trading, which account for the findings in prior studies of excess insider trading in innovative firms. They suggest that their results indicate that findings that stock market liquidity, institutional ownership and acquisition activity influence corporate innovation are misleading. Instead, Reeb and Zhao (2017) document that intermediary coverage or firm characteristics influence the choice between patenting and keeping an innovation a trade secret. Citations depend on the firm filing a patent; therefore, they suffer from the same problems as patent counts (Lerner and Seru 2015).

Patents and their citations are important signals about corporate innovation. Nonetheless, they suffer from concerns about the noise in the signal and about managers' potential selection bias. The noise in these signals arises because patent counts and their citations only provide a rough proxy for the innovation occurring in the firm. Patents are a voluntary disclosure of the firm that potentially secures property rights. However, these signals of corporate innovation, patents and citations, are available for a much smaller segment of the population than R&D spending. The bias in these signals stems from the managers' choice to seek or not to seek to patent an innovation, depending on their own assessment of the firm's ability to keep the information a trade secret. Recent literature shows that non-patenting firms often make substantial innovations in cost efficiency relative to product quality. Consequently, strictly relying on patents or their citations to measure the innovation activities of a firm can lead to biased and misleading results. Turning to R&D productivity, this formulation relies on scaling one noisy, biased measure of innovation by another noisy, biased measure of innovation.

3.3 New Product Announcements

Another, less common, approach to measuring innovation centers on new product announcements. New product announcements provide a potential signal about the output of the firm's R&D. Eddy and Saunders (1980) argue that new products capture the output of technological innovation and investigate stock market reactions to new product announcements. Consistent with this output perspective, Chaney, Divenny, and Winer (1991) document substantive increases in firm value with new product announcements for technological firms. Lee et al. (2000) find that new product announcements are especially valuable for first movers but less so for slow movers. Importantly, first movers suffer when late entrants imitate their products, suggesting that the magnitude of the market reaction provides a potential gauge of innovation success. New products tend to increase firm profits and size but are also associated with decreases in company advertising (Bayus, Erickson, and Jacobson 2003). Finance research suggests that increased taxes lead to fewer new product announcements (Mukherjee, Singh, and Zaldokas 2017). More generally, researchers consider new product announcements to capture the successful innovation of the firm, with stock market reactions providing a gauge of the relative magnitude of the innovation.

New product announcements span small and large firms, with roughly 18% of the Compustat universe announcing new products (Reeb and Zhao 2017). Katila (2002) emphasizes that new product announcements provide a multi-layered measure of the innovativeness of the firm. However, new product announcements' effects differ across industries and firms (Chaney and Devinney 1992). Marketing research emphasizes that the industry characteristics and the firm's prelaunch activities explain some of the heterogeneity in the market reactions to new product announcements (Wind and Mahajan 1987). While new products capture the heart of what many consider to be the

outcome of corporate innovation activity (e.g. classic stories like Kodak and Xerox or more recent ones like Tesla and Facebook), they only provide a signal regarding the product side of corporate innovation. Thus, new product announcements provide a noisy signal of corporate innovation, failing to capture cost-reducing innovations.

New product announcements are a voluntary disclosure of firms. Management research indicates that the incentives to make new product announcements differ depending on the types of goods and customers (Porter 1976). Bayus, Erickson, and Jacobson (2003) suggest that firms trade off advertising and new product announcements. Firms with multiple new products in a given period face a choice between multiple new product announcements and greater paid advertising; they depend on their assessment of the greatest impact on potential customers (Hendricks and Singhal 1997; Rabino and Moore 1989). Thus, both firm and industry characteristics potentially influence the choice between advertising and new product announcements, suggesting selection issues in new product announcements.

New product announcements are an important, voluntary signal about corporate innovation. However, they also suffer from concerns about the noise in the signal and about managers' potential selection bias. The noise in this signal arises because it only captures product outputs (rather than cost outputs) and because of the difficulty in assessing the value of such announcements. The bias in this signal stems from the managers' choice regarding whether or not to announce new products, depending on their own assessment of paid advertising for this market or product. Consequently, strictly relying on new product announcements to measure the innovation activities of a firm can lead to biased and misleading results.

4. EVALUATING MULTIPLE SIGNALS

4.1 Composite Measures

Each of the various signals discussed above regarding corporate innovation provides a noisy and potentially biased indication of firms' innovation activities. Holmstrom (1989) argues that omitting informative signals about an activity eliminates useful information, making it difficult to assess performance. While his arguments are embedded in a model of incentivizing agents, the basic intuition for creating a measure of innovation is similar. The firm chooses an innovation strategy that has an impact on its performance, which managers may not fully reveal for both strategic and agency reasons. Shareholders and empirical researchers observe these noisy signals of the firm's innovation strategy. Business and economics research usually focuses on one of these signals and forms an opinion about the innovative capabilities of the firm. Marketing scholars suggest that all of the observable signals that contain information about a construct should be included in the measure (e.g., Gerbing and Anderson 1988).

Psychometrics research has dealt with noisy measures about an underlying issue that is coupled with selection bias for decades (Cronbach and Meehl 1955). The concern arose from seeking to incorporate multiple responses into a questionnaire to form a single measure (or construct as these researchers often call it) about a specific underlying issue or viewpoint in a subject (Nunnally 1978). Researchers face two problems in trying to compare individuals' beliefs or values with those of the general population. First, they usually use multiple questions to solicit signals about the subjects' underlying issue or viewpoint on a particular topic (Cautin and Lillienfeld 2015). Consequently, they have multiple, noisy signals that potentially capture an

underlying issue. Second, they also face a selection bias, because respondents often leave some of the questions blank (Kline 2015).

To develop a single scale or measure, with noisy signals that are also influenced by selection bias, clinical psychology research uses item–total correlations or a factor analysis approach to identify the set of signals to incorporate into the measure. Starting with Nunnally (1978), the item–total correlation approach investigates how well each of the signals correlates with the others in assessing corporate innovation. Specifically, this approach starts with several potential signals about corporate innovation and identifies the set of signals that best correlates with the total score of the item pool (Sullivan 1994). Although there is no complete solution to this problem, it is possible to assess the relative merits of combining several noisy, biased signals in a single measure of corporate innovation.

The sample for this analysis is based on the *BCG/BusinessWeek* senior executive survey regarding the most innovative companies. Starting in 2005, the *BCG/BusinessWeek* survey was conducted by the Boston Consulting Group, a management-consulting firm with offices in 37 countries when it began this initiative. The survey was conducted in conjunction with *BusinessWeek*, a weekly business magazine that began operations in 1929 and was purchased by Bloomberg in 2009. The first senior executive survey contained a total of 940 executives from 68 countries, ranking Apple, 3M, GE, Microsoft and Sony as the five most innovative firms (BCG Survey 2005). Overall, the survey names the most innovative companies each year, naming 10 for a few years and expanding the number to 50 in 2007. The survey respondents are primarily CEOs, presidents, strategy executives and brand managers. By 2010 the survey included 1,590 senior executives, over half of whom were listed as holding C-Suite positions (BGS Survey 2010). The top five firms in 2004 were Apple, Google, Microsoft, IBM and Toyota. Both the business press and the mainstream press generate substantial coverage of these annual reports, including Reuters, *The Telegraph* in the UK and *The Sydney Morning Herald*.

Interestingly, several firms, considered as some of the most innovative, exhibit missing or limited information in several of the commonly used signals of innovation. For instance, the 2010 list includes Coca-Cola, a firm that does not report R&D in its financial statements but has six R&D centers around the world. Wal-Mart is also listed in the 2010 report and is often described as an innovative leader in supply chain management because of its use of communication and computer technologies (Brunn 2006). However, Wal-Mart only averaged two patents per year from 2005 to 2009. Of course, firms like Pfizer, Boeing and Honda also appear on the lists, and these firms typically have substantial amounts of R&D, patents and new product announcements. The respondents to the *BCG/BusinessWeek* survey report that they measure innovation internally, focusing on profits, idea generation and revenue growth. Consequently, in addition to the measures noted above (R&D, patents, patent citations and new product announcements), I consider four firm characteristics in the analysis. Specifically, I incorporate revenue, revenue growth, advertising and profitability as potential signals of corporate innovation (BCG Survey 2005; Reeb and Zhao 2017).

I limit the sample to public firms listed in the years 2007–2010 to capture patents and their citations. This gives a sample of 63 highly innovative firms during the period 2007 to 2010. The sample comprises large firms from several different countries and industries. I gather financial data from Global Compustat, patent data and citations from Noah Stoffman's website and new product announcements from Reeb and Zhao (2017). Patents are a simple, annual count measure of patent applications, while citations capture the number of citations that they receive in a given year. I combine these items to capture citation-weighted patents, which I compute as the product

of patents plus one and citations plus one. New products are the number of announcements about the firm's new products. R&D spending and advertising are simply the reported R&D and advertising, scaled by total assets. Sales and sales growth are also based on annual income statement data. I use the log of sales.

My analysis starts with all seven potential signals (sales, sales growth, weighted patents, new products, R&D, advertising and profits). Table 1 provides descriptive statistics and correlations for these seven variables. Weighted patents, profits, R&D and new product announcements are all highly correlated with each other. For instance, the correlation between weighted patents and new product announcements is .32. This preliminary analysis suggests that the three traditional signals of innovation (R&D, weighted patents and new product announcements) and firm profitability provide potential signals about corporate innovation.

Table 1: Descriptive Statistics

	Products	Growth	Advertising	Profits	WPatents	R&D	Sales
Products	1						
Growth	.04	1					
Advertising	.00	.02	1				
Profits	.09	.34	.14	1			
WPatents	.32	.05	.06	.22	1		
R&D	.13	.15	-.01	.33	.59	1	
Sales	.20	.03	-.13	-.11	.18	-.03	1

Item-total correlation analysis tests the reliability of each of the items against the set of the other items. I proceed in stages to identify the appropriate set of signals to include in a composite measure of corporate innovation. In the first stage, I apply item-total correlation analysis to all seven potential signals, which shows that these seven items do not appear to capture the same concept. Consequently, I drop the variable with the lowest item-rest correlation. In the first iteration, I drop advertising, as it has the lowest item-rest correlation (score of .002). I repeat this analysis and drop growth (item-rest correlation = .044) and profits (item-rest correlation = .099). The remaining signals (R&D, weighted patents, new products and sales) provide the final set of variables for a combined measure of corporate innovation.

Based on these results, I construct two composite measures of corporate innovation using factor analysis and index-ranking analysis to reduce these four signals of innovation into a single measure. Factor analysis requires the signals to be highly correlated and load on a single factor (Duru and Reeb 2002). This dovetails nicely with the requirement from item-correlation analysis that the signals capture some common, underlying construct. Table 2 provides the results of the factor analysis, showing that these innovation signals load on a single factor that explains 75.56% of the cumulative variance. Weighted patents and R&D spending have the highest factor loadings of the four potential signals of innovation. Taken as a whole, these results suggest that factor analysis with the four variables provides a potentially useful measure of corporate innovation. Table 3 provides the average predicted factor score for each firm in the analysis.¹

¹ To create a factor score centered on 100, I scale each predicted value of factor 1 by the standard deviation of the factor, multiply it by 10 and add 100. The Stata code for this analysis is available on request.

Table 2: Factor Analysis and Measuring Innovation

Panel A: Total Variance Explained

Component	Eigenvalue	Proportion	Cumulative
Factor 1	1.63598	.4090	.4090
Factor 2	0.16905	.0423	.4513
Factor 3	−0.17501	−.0438	.4075
Factor 4	−0.20571	−.0514	.3561

* Component extracted: only one component has an eigenvalue greater than 1.

Panel B: Factor Loadings

Variable	Loading
R&D	.6289
Citations	.6846
Patents	.3942
New Product Announcements	.7851

Table 3: Composite Measures of Corporate Innovation

Company Name	Factor Measure	Index Measure	Company Name	Factor Measure	Index Measure
3M	108.7	91.8	Johnson and Johnson	105.4	114.8
Amazon	105.6	114.8	JP MorganChase	93.7	114.8
Amgen	105.7	80.3	LG	108.1	91.8
Apple	104.9	114.8	Marriott	90.1	57.4
ArcelorMittal	90.7	68.9	McDonalds	91.1	57.4
AT&T	104.4	149.2	Merck and Co	109.6	103.3
Banco Santander	88.45	34.42	Microsoft	125.3	160.7
Best Buy	91.0	80.3	Nestle	92.2	80.3
Boeing	111.9	149.2	Nike	99.4	91.8
BP	91.7	80.3	Nintendo	92.2	68.9
Caterpillar	104.0	114.75	Nokia	121.6	172.1
China Mobile	90.6	68.8	Nordstrom	89.6	45.9
Cisco	115.9	160.7	Oracle	110.8	137.7
Citigroup	91.3	103.3	Pfizer	104.5	126.2
Coca Cola	89.9	45.9	Proctor and Gamble	105.0	137.7
Daimler	100.6	103.3	Reliance Industries	89.4	34.4
Dell	104.4	114.8	Royal Dutch Shell	91.9	91.8
Duke Energy Co	89.8	34.4	Siemens	111.1	137.7
ExxonMobil	103.0	126.2	Sony	112.8	137.7
Facebook	93.2	57.4	Southwest Airlines	90.7	57.4
Fiat	92.9	80.3	Starwood Hotels	89.7	57.4
Fidelity	89.3	34.4	Target	90.1	91.8
Ford	108.9	172.1	Telefonica	91.2	91.8
GE	109.9	91.8	Toyota	97.7	126.2

continued on next page

Table 3 *continued*

Company Name	Factor Measure	Index Measure	Company Name	Factor Measure	Index Measure
Genentech	111.1	160.7	TwentyFirst Cent Fox	90.2	45.9
Goldman Sachs	95.4	80.3	Verizon	97.4	114.8
Google	106.6	103.3	Vodafone	92.7	114.8
HP	112.3	172.1	Volkswagen	94.2	103.3
Honda	113.3	126.3	Wal-Mart	94.6	126.2
HSBC	89.8	45.9	Walt Disney	91.3	68.9
Infosystems	92.6	68.8			
Intel	119.5	149.2	Correlation		.83
IBM	119.9	160.6			

I also compute a composite measure of innovation based on an index-ranking method and the same for four signals of corporate innovation. In contrast to factor analyses, index ranking equally weights each of the four variables to create the composite measure of corporate innovation. In this approach each firm in the sample is ranked along each of the four signals of corporate innovation. The firms are ranked by quintile along each of the four dimensions, with the firms in the bottom 20% ranked in the lowest quintile (1) and those with the highest signals ranked in the top quintile (5). The four scores are then added together to give the Innovation Index; the higher the score, the more innovative the firm. Column 2 of Table 4 provides the Innovation Index score for each firm.² The two composite measures of corporate innovation are correlated at .83. Importantly, neither composite measure relies on a single signal of corporate innovation.

Table 4: Simulation Analysis

Panel A: Mean Analysis

	True	Noisy	Noisy–Biased	Diff. 1–2	Diff. 1–3
	1	2	3	4	5
Spend/R&D	10.05	10.08	12.08	–0.48	–28.69***
Success/Patents	15.28	15.33	27.41	–0.68	–114.03***
Productivity	1.58	0.70	2.45	40.26***	–36.95***

Panel B: Standard Errors

	True	Noisy	Noisy–Biased
	1	2	3
Spend/R&D	0.063	0.089	0.096
Success/Patents	0.095	0.112	0.127
Productivity	0.015	0.009	0.029

² To create an index score centered on 100, I multiply the raw index scores by 11.475. In a larger sample, I would use deciles or vigintiles.

Table 4 *continued*

Panel C: Multivariate Analysis

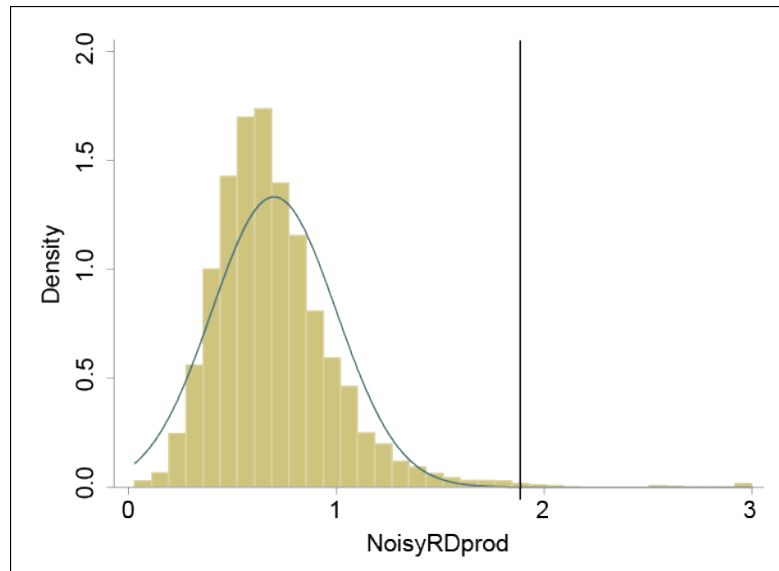
	<i>Dependent Variable = Growth</i>					
	True Values		Noisy Signals		Noisy-Biased	
Constant	.704 (0.30)	3.940*** (4.99)	1.225 (0.80)	4.466*** (5.68)	−1.914 (−1.11)	4.912*** (6.31)
Firm Size	.289 (0.84)	−0.374** (−2.20)	0.193 (0.65)	−0.370** (−2.17)	0.378 (1.16)	−0.375** (−2.23)
Spending or R&D	−0.865 (−0.51)		0.771 (0.59)		1.759*** (10.83)	
Success or Patents	4.116*** (3.38)		2.512** (2.43)		2.268*** (2.68)	
Productivity		0.237*** (2.72)		−0.241 (−1.61)		−0.241*** (−5.63)
R-Square	.02	.01	.01	.01	.11	.03

4.2 R&D Productivity

Factor analysis with different signals of innovation aims to uncover the underlying or latent technological capacity of a firm. However, another approach to combining innovation signals is popular in the academic literature, specifically scaling one signal of innovation by another. Typically, this approach focuses on scaling patents by corporate R&D expenditures, which are then labeled R&D productivity. To assess the impact of scaling one noisy, biased signal by another such signal of innovation, I undertake a simple simulation analysis. First, I simulate true R&D spending, true innovation success and firm size, which are labeled *spending*, *success* and *size*. To keep the simulation as simple as possible, I simulate all the values using the normal distribution. I next create noisy signals of these individual signals, reported R&D and patents, which have similar means to the true values but higher variances. The noise in each signal is also normally distributed with a mean of zero.

Second, I add selection bias to each of these signals to create noisy-biased signals of R&D and patents. I model disclosure bias as a function of firm size and a random variable, assuming that disclosure bias decreases with firm size. The noisy-biased signals of innovation have higher means and variances than true R&D spending and innovation success. R&D productivity is computed using the true values, the noisy signals and the noisy-biased signals of innovation.

Table 4 (Panel A) shows the mean R&D productivity for each of the three sets of innovation measures. Even without selection bias, the noisy measures of R&D and patents give a downward-biased estimate of true productivity. Panel B shows that the variance of R&D productivity is also downward biased when computed using the noisy signals. This finding arises across a variety of different assumptions about the nature of the noise in the measures (changing the scope of the noise or the distribution). The results in Table 4 stem from a 1,000-observation simulation. Figure 4 shows the mean R&D productivity with the noisy signals based on 5,000 simulations. Without any bias in the signals, the distribution of R&D productivity is well below the true R&D productivity.

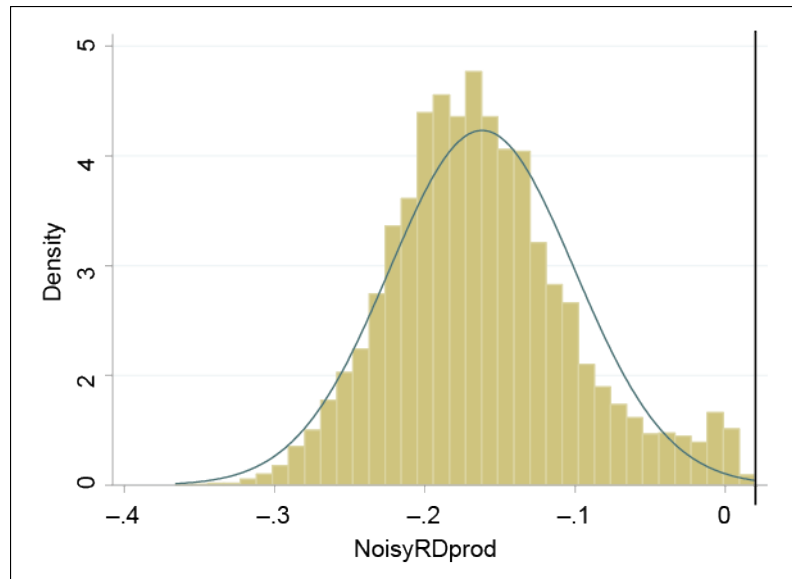
Figure 4: R&D Productivity with Noisy Signals

* The vertical line at 1.58 is the true R&D productivity of the population.

Panels A and B of Table 4 also show the results of R&D productivity using the noisy-biased signals of innovation. These estimates are consistently different from true R&D productivity. While the nature of the selection bias influences the direction of these results, the upward bias in R&D productivity occurs across a wide spectrum of potential modeling choices for selection bias.

Finally, I investigate how these three versions of R&D productivity perform in a multivariate setting. I simulate firm growth and make two assumptions about it. First, I assume that smaller firms exhibit higher growth rates than larger firms. Second, I assume that successful innovation leads to firm growth. Consistent with these assumptions, the Column 1 results in Panel C of Table 4 show that innovation success is correlated with firm growth. Column 2 shows that true R&D productivity is also associated with firm growth.

Columns 3–4 repeat these regressions using the noisy signals of reported R&D and patents to compute R&D productivity. The noisy signals of R&D and patents give similar inferences to the true measures in the base regression (comparing columns 1 and 3). However, using R&D productivity with these noisy signals gives a downward-biased coefficient estimate. R&D productivity does not appear to be a reliable measure of corporate innovation using the noisy signals of reported R&D and patents. Columns 5–6 repeat these regressions with the noisy-biased signals of innovation. In this setting the coefficient estimates and standard errors of R&D are biased upwards. Moreover, the coefficient estimates and standard errors of R&D productivity are also biased. Figure 5 shows the results of repeating this analysis 5,000 times. Rather than mitigating the problem of noisy-biased signals of innovation, the use of R&D productivity appears to magnify or intensify the problem.

Figure 5: Plot of the Beta Coefficient for R&D Productivity (Noise-Biased)

* The vertical line at 0.238 is the true beta coefficient for R&D productivity.

5. SUMMARY AND CONCLUSION

Innovative firms often exhibit stock market premiums, and both the academic and the business press suggest that they foster economic growth. Corporate innovation consists of several different tasks, including the development of new products and new production methods and the improvement of existing products (Grossman and Helpman 1990). Thus, innovation focuses on making something new, making it cheaper or making it better. Research on corporate innovation extends across several social science research streams, focusing on the encouragement and impact of corporate innovation. Studies on the determinants of innovation concentrate on the entire innovation process. However, measuring corporate innovation remains difficult, because it covers multiple tasks and types of corporate activities.

R&D spending, patent counts, patent citations and new product announcements are the most commonly used measures of corporate innovation. One challenge of these measures is the large number of firms without reported R&D, patents or new product announcements. While R&D spending is a mandatory disclosure, patents and new product announcements are voluntary disclosures with additional benefits (acquiring property rights and customers). R&D spending is only available for 58% of the Compustat universe; patents are available for 23% of the firms, while new product announcements only cover 18% of the firms (Reeb and Zhao 2017).

Firms potentially weigh the costs and benefits of disclosing innovation along each of these lines by trading off the potential costs and benefits. Each of these signals conveys information about corporate innovation, yet they all suffer from concerns about the noise in the signal and about managers' potential selection bias. The noise in these signals arises because they only capture a single component of firms' innovation process, such as inputs, intermediate steps or outputs. The bias in these signals stems from the managerial disclosure choices. Consequently, strictly relying on new product announcements to measure the innovation activities of a firm can lead to biased and misleading results.

Excluding informative signals about innovation discards useful information, making it difficult to measure the activity (Holmstrom 1989). Firms decide on their investments in innovation and, for both strategic and agency reasons, may choose to keep this information private. The econometrician observes several noisy and biased signals of the firm's innovation strategy. The ability to measure innovation, across a wide spectrum of activities and firm types, is a salient concern for research that seeks to understand and evaluate corporate innovation. My results imply that research on corporate innovation that relies on a single signal of innovation potentially leads to misleading conclusions. Instead, researchers should rely on multiple signals of corporate innovation to measure it. Using item-total analysis to identify common signals of innovation, I find four signals that are potentially important. I then develop both factor analysis and index-based composite measures of corporate innovation, relying on R&D, patent citations, new product announcements and profitability. Both approaches provide a composite measure of corporate innovation that incorporates multiple signals of innovation activity.

Using a composite measure of corporate innovation does not completely mitigate the concerns about measure noise. However, using a composite measure potentially reduces some of the concerns in using a single noisy, biased signal of corporate innovation. The factor analysis approach to measuring innovation in this study attempts to limit the impact of noise and selection bias by concentrating on the shared components of each signal that only captures one dimension of the firm's technological capacity. In contrast, the common practice of scaling one noisy and biased signal of innovation (such as patents) by another noisy, biased signal of corporate innovation (R&D) exacerbates the potential problems with these signals. Specifically, scaling one noisy signal by another noisy signal is likely to magnify the noise-to-signal ratio and lead to biased empirical results. Once selection bias is introduced into the signals, R&D productivity performs even more poorly than before.

The measurement of corporate innovation also affects policy makers. Both the academic and the popular press commonly reference corporate innovation as an important driver of national prosperity. Politicians often focus on inputs such as research and development expenditures, while organizations like the World Bank often discuss R&D productivity as they seek to capture returns to dollars spent on innovation. Others use this type of data to argue for policy changes, noting that companies in one market spend more on R&D than companies in another market. However, these comparisons are difficult to assess. The noise of these signals differs across markets, suggesting that such comparisons capture both differences in signal noise and differences in true innovation capacity. The nature of the noise in measures of innovation often stems from the type of innovation undertaken by the firms in that economy. Companies involved in process innovation are more willing to report their R&D expenditures, while companies engaged in new product development often seek to minimize information about their research and development outputs. Consequently, policy makers that rely on a single signal of corporate innovation to evaluate corporate innovation run the risk of making decisions based on biased inputs, suggesting that they should also seek to incorporate multiple signals of corporate innovation into their analyses.

Focusing strictly on patents to measure innovation in a cross-market setting is especially problematic, as firms differ in their use of trade secrets and patents to protect successful innovation. The ownership structure of the firm, the legal environment, the distance from competitors and a host of market characteristics potentially influence firms' decisions to patent their corporate activities. For instance, on the stock exchanges of New York and Taipei, China, roughly 19% of firms with R&D expenditures seek patents while the other 81% appear to rely more on trade secrets. In contrast, fewer than 4% of positive R&D firms in the stock exchange of the Republic of Korea seek patents. In fact, in the stock exchange of the Republic of Korea, firms without reported R&D often received more patents in a given year than firms with R&D expenditures. Similarly, the decision to report R&D expenditures appears to differ across markets in Asia. Relying on a single, noisy signal of corporate innovation to capture innovative capacity in a firm or market can therefore provide a distorted view of progress. These distortions can be especially pronounced when attempting to compare companies located in different economies. Assessing innovation in Asia and comparing it with innovation in western economies will be strongly influenced by the metric chosen to capture innovation. Ideally, we should use multiple signals of innovation to measure the degree of innovation in companies and markets across Asia.

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