

(Mis)Measuring Innovation around the World

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Abstract

Research on corporate innovation often focuses on firms with positive US patent activity and reported R&D, thereby excluding over 90% of the firms in Compustat. By exploiting data from 30 global patent offices, we investigate the nature of missing innovation data around the world. We find systematic and predictable patterns across firms and countries for missing patents and R&D. We then compare the empirical efficacy of excluding firms without US patents or reported R&D, to simple replacement methods, and to various econometric solutions for missing patent and R&D data. We further show how excluding or deleting firms without US patents or reported R&D provides biased coefficient estimates and standard errors in studies of innovation; this consequently leads to specific distortions in tests related to corporate growth and country level innovation capacity. Further analysis highlights a variety of problems with using partial sample methods to handle missing innovation data, underscoring the importance of full-sample approaches in studies of innovation.

Keywords: Mandatory Disclosure, Voluntary Disclosure, R&D Efficiency, R&D Bias, Patent Bias, Innovation, R&D Disclosure, Missing Data

1. Introduction

In an influential article in 1972, Edwin Mansfield, describes how research and development influences economic growth by increasing corporate productivity. Coe and Helpman, (1995) argue that commercially oriented innovation is a major engine of technological progress and domestic productivity. Investors, policy makers, and academics exhibit keen interest in evaluating and comparing innovation in different countries (Aoki, 1991; Scotchmer, 1991). However, measuring corporate efforts to create new knowledge remains difficult (Hall et al., 2014; Kogan et al., 2012). In empirical studies, researchers often use patent activity or R&D expenditures as proxy measures for innovation (Bloom and Van Reenen, 2002). Scholars in economics and business routinely report a substantial number of firms without any patent activity or reported R&D; which leads them to exclude these firms or to treat them as developing zero innovation (Lychagin et al., 2010). Missing innovation data could arise because of no innovation, unsuccessful R&D, as a disclosure choice (e.g. trade secrets), or because firms file patents in alternative patent offices.

By exploiting data from 30 global patent offices, we explore the nature of missing patents and R&D data in firms around the world. Our central research question is how studies of innovation, or those that rely on measures of innovation as a control variable, should assess firms without reported R&D or patent activity. While simply deleting firms without United States Patent and Trademark Office (USPTO) patents or reported R&D provides a quick solution to the missing data problem, the efficacy of this approach depends on the nature of the missing data. To investigate the nature of missing innovation data, we start with a simple preliminary question: do missing patents or R&D indicate the same level of innovation *inactivity* in different countries? Our formal analysis begins with tests on the predictability of missing patents and reported R&D. We then evaluate the empirical efficacy of excluding firms without USPTO patents or reported R&D, comparing the practice to simple replacement methods, and to various econometric solutions for missing data. We also demonstrate how different approaches to handling missing innovation data markedly affect tests related to corporate growth and country level innovation capacity.

Our primary analysis relies on data from the 29 countries with at least 100 equity-market listed firms. We use the EPO (European Patent Office) Worldwide Patent Statistical Database (PATSTAT) for data on patents and obtain financial statement information from the Compustat

Global database. The sample encompasses 37,272 unique firms from the period 1999–2012, comprising 85% of the universe of unique firms in Compustat. Over 83% of the observations in our sample fail to seek patent protection. Roughly two-thirds of the observations in our sample do not provide R&D expenditure data. Of those that report positive R&D, 69.7% do not file for patents, while 30% of firms with patents do not report R&D. Non-patenting and non-reporting R&D firms potentially include those without any innovation and those with positive but undisclosed innovation (Bound et al., 1982).

The chart below shows the relative distribution of firms without reported R&D or patents in both the US and global data sets. For instance, studies that exclude firms without reported R&D and patents (Q1) essentially discard 90% (82%) of the Global (North American) Compustat sample. Similarly, studies that focus on measures of R&D efficiency (usually patents divided by R&D) effectively count 25% of Global Compustat firms as innovation failures (Q2), and 4% of them as almost infinite successes (Q3). In addition, studies that focus on firms with reported R&D and patents (Q1) exclude almost five times as many Q2 firms as Q3 firms, both of which contain firms with positive information about corporate innovation activity. We also observe that non-reported patent data is substantially more prevalent than non-reported R&D data. In this context, patent data arguably suffers from a more severe missing data problem than R&D.

Chart 1: Distribution of Missing Innovation

<p>Q1: Report R&D and Positive Patents</p> <p>(10%) Global Compustat/Patents</p> <p>(18%) North America Compustat/Patents</p>	<p>Q2: Report R&D and No Patents</p> <p>(25%) Global Compustat/Patents</p> <p>(28%) North America Compustat/Patents</p>
<p>Q3: Non-report R&D and Positive Patents (Missing R&D)</p> <p>(4%) Global Compustat/Patents</p> <p>(5%) North America Compustat/Patents</p>	<p>Q4: Non-report R&D and No Patents</p> <p>(61%) Global Compustat/Patents</p> <p>(49%) North America Compustat/Patents</p>

To evaluate “missing patents”, we focus on firms that do not obtain patents with the USPTO but instead seek patents in one of the other 29 patent offices in our sample. For instance, among US firms, 69% of positive R&D firms never file for patents using the USPTO data, while

only 43% never file patent applications using the 30 global patent offices. Thus, without even considering the role of trade secrets in protecting innovation, this 26% wedge provides clear evidence of missing patents in US firms for the econometrician relying only on USPTO data. In this context, our measurement of missing patents provides only a conservative estimate of the magnitude of the problem. The percentage of firms with missing patent activity varies substantially across the 29 countries in our sample. In Korea, Taiwan, and China, for instance, only 2%-3% of the firms file US patents without ever seeking domestic patents, while around 32% of firms in Italy seek US patents and forego domestic patents. Similarly, using any single domestic patent database to capture either domestic or foreign firms in any market creates missing data problems. These results imply that patents are not *missing completely at random*.¹

To gauge “missing R&D” around the world, we concentrate on non-reporting R&D firms with positive patent activity (Koh and Reeb, 2015). In our sample, these missing R&D firms average 23.69 patents per year. Firms with positive R&D expenditures average 25.73 patents per year, and firms that report zero R&D average less than one patent per year (0.10). Our cross-country comparison indicates that the proportion of missing to positive R&D observations varies significantly around the world, ranging from a high of 88% in Brazil to a low of 0% in Hong Kong. In several countries, such as Italy and Korea, missing R&D firms average more patents per firm than their positive R&D counterparts. In short, missing R&D does not appear to equate to zero R&D in most countries; in fact, missing R&D varies substantially across countries and does not represent the same level of innovation *inactivity* across different countries, thus, providing evidence to suggest that R&D expenditures are not *missing completely at random*.

To formally test the notion that missing innovation data randomly occurs across countries, we explore the predictability of missing patents and R&D. Specifically, we investigate multivariate correlations among country characteristics in studies of innovation, missing R&D and missing patents across the 29 countries. We choose variables based on the literature on innovation but do not make or infer any causal relations. Instead, our question centers on the potential for predicting missing R&D using country-level institutional factors in order to

¹ Terminology in statistics, while awkward, differentiates between three types of missing data. *Missing Completely at Random* occurs when neither observables nor unobservables can predict missing observations. *Missing at Random* occurs when observables can predict missing observations, while *Missing Not at Random* occurs when missing observations are related to values of unobserved data. More generally, the appropriate techniques for the econometrician in dealing with missing innovation data depend on the type of missing data.

determine whether they are *missing completely at random*. Our multivariate results indicate that missing R&D is related to several measures of government subsidies, labor regulations, and skilled labor. In contrast, missing patents occur more readily in non-commonwealth countries and in those with high levels of manufacturing intensity. These correlation results are inconsistent with the notion that R&D and patents are *missing completely at random*. Instead, missing R&D and missing patents are systematically related to several proxies of market development, suggesting that there are selection biases in firms that report R&D or file for patents across countries. To mitigate the cross-country industry differences we repeat the analyses on missing patents and R&D in two specific industries with substantive innovation, namely Industrial and Commercial Machinery (SIC 35) and Chemical and Allied Products (SIC 28) reaching similar conclusions.

Potential solutions for missing data involve excluding all firms with missing innovation data, substitution approaches that replace the missing values with zero or industry averages, and methods that model the missing process or variables. Empirical specifications often use innovation as an independent variable, while many of the common remedies seem more amenable to empiricists when the missing data stems from a dependent variable. Moreover, studies on innovation typically confront missing data in two variables, namely R&D and patents, which further exacerbates the tractability of techniques such as Heckman models or inverse probability weighting. Encountering missing innovation data as the independent variable, as a dependent variable, and as dual dependent variables, research in the economics of innovation routinely excludes observations with missing R&D data and/or those without patents (Brown et al., 2013).² We show that, analytically, excluding firms without observable R&D or patents can heighten the potential bias with data *missing at random* (see Appendix 1). The empirical implications of this analysis are that excluding firms without USPTO patents or reported R&D in

² Business research commonly uses substitution methods for firms without reported R&D or patents. Koh and Reeb (2015) compare various substitution methods and find that including a dummy variable for missing R&D improves these simple substitution models. Lerner and Seru (2015) observe that missing patents vary across states in the US. Bound et al. (1982) suggest that non-patenting firms average about half a patent per year. Beyond deleting missing patents or R&D, research in economics often seeks to interpolate missing R&D using historical data in the firm. Extrapolation using historical data will fare similarly to other single imputation models, by providing reliable coefficient estimates but biased standard errors. We discuss these issues in greater detail in the formal analysis in Appendix 1.

studies that focus on innovation or use it as control variable yield biased coefficient estimates and standard errors. These implications hold for single-country and cross-country studies.

To evaluate the different approaches available to the econometrician handling missing innovation data, we simulate missing patents and R&D. Although, our empirical analysis suggests that innovation data is *missing at random*, simulation analysis enables us to consider the case of *missing not at random*. In our simulation analysis, we find that the direction of the bias for both patents and R&D could go either way depending on the context of the investigation. Moreover, our simulations suggest that simple substitution models fare poorly relative to methods that model the selection process or the missing innovation variables. Allowing for the greater proportion of “missingness” in patent data relative to R&D data, our simulation also indicates a larger bias in studies using patents to measure innovation relative to those measuring innovation with R&D. One caveat is that our simulated measures of missing R&D and patents understate the true level of missingness, because we cannot capture trade-secret related non-disclosures. As such, our analysis arguably provides a lower bound for the potential problem of missing innovation data.

To illustrate how the treatment of missing patents and R&D affects the results of innovation research, we compare firm characteristics of our complete sample to samples that only include observations with either positive R&D or patents (partial deletion) and to those that only include firms with both positive R&D and patents (full deletion). The full sample contains 333,920 firm-year observations. In contrast, the partial deletion sample contains 122,546 firm-year observations, while the full deletion approach contains only 26,273 observations. Studies that use partial deletion approaches typically exclude firms missing the variable of interest (for example R&D) and set the other variable to zero if it is missing (e.g. firms without USPTO patents are set to zero). It is noteworthy that observable characteristics, such as profits, leverage, and capital intensity, vary substantially between the three samples. For instance, profits among the full deletion sample firms are 400% lower than in the full sample. Our perusal of the literature on the economics of innovation suggests that most studies use either partial or full deletion to handle the problem of missing innovation data.

To further illustrate the problems with deleting firms with missing patents and/or R&D, we consider some simple rankings of country-level innovation capacity using both the partial and full deletion approaches. The partial and full deletion approaches provide substantially different

results regarding country innovation capacity. For instance, in Finland and Japan, the full deletion sample suggests that approximately 13% of firms engage in innovation activity, while the partial deletion sample indicates that around 67% of those countries' firms engage in corporate innovation. In contrast, in Australia and Canada, the full deletion sample indicates that 2%–5% of firms engage in innovation activity, but the partial deletion sample results suggest that both countries are around 18%–21%. The size of the discrepancy between the partial and full deletion samples varies substantively across countries. Ranking countries by their innovation capacity produces substantially different conclusions based on the partial and full deletion samples. Countries such as Taiwan, Austria, and Korea are substantially under-ranked when using the full deletion sample (relative to the partial deletion sample results). In contrast, countries such as Canada, Australia, and Denmark are substantially over-ranked in their innovation capacity when using the full deletion sample.

For a more complete examination of how different approaches to handling missing patents and R&D influence studies of innovation, we conduct simple regressions of firm growth on innovation. We consider several methods for handling missing innovation data, including deletion, substitution methods, inverse probability weighting, Heckman, and multiple imputation. We find that regressions that relate corporate innovation to sales growth provide upwardly biased estimates in the deletion samples relative to the multiple-imputed sample. Replacing missing data with zero or the industry average (and including a dummy variable) also provides substantively different results relative to the deletion specifications. Estimator based models (multiple imputation, inverse probability weighting, and the Heckman approach) provide different approaches to assess the impact of missing data problems in a given set. Importantly, we find that inverse probability methods seldom converge in this real world example, suggesting that methods that rely on partial or full deletion samples face severe hurdles in overcoming this selection bias.

Intuitively, using R&D efficiency to measure innovation provides an even more problematic approach to capturing innovation as it relies on deleting firms with missing patents and missing R&D. The most important take away from these specific findings is arguably that each of the different approaches yields a vastly different result. The coefficient estimates and standard errors have different magnitudes and signs. We interpret this evidence as suggesting that studies of innovation should rarely, if ever, simply exclude or delete firms without any

reported R&D or patents. Rather, studies on innovation should consider using several different approaches to model corporate R&D and patents in order to handle the missing data problem. Based on our results, both the Heckman and multiple imputation approaches seem potentially viable in this setting. Yet, implementing a Heckman model, especially when confronting both missing patents and R&D, is quite challenging. Studies that use R&D as a control variable, also suffer from this missing data bias, suggesting that full sample approaches that use a simple method to impute the missing variables are especially tractable in such a setting.

In summary, we document how the failure to disclose R&D or file patent applications implies different things across firms, countries, and time. While the missing innovation data problem in studies of innovation is well recognized, most common treatments implicitly assume that the data is *missing completely at random*. Our analysis suggests that undisclosed innovation systematically varies around the world. Rather than solving the problem, simply deleting or excluding these firms/observations can magnify the potential bias.³ Unfortunately, there is no single “correct” approach to solving this problem. Instead, our analysis suggests that the specific use of a variety of methods, such as multiple imputation, inverse probability weighting, and Heckman models, provides a more conservative approach to handling missing R&D and patent data. Given the substantive differences in sample statistics between the full sample and subsamples obtained after deleting missing observations, full sample approaches seem especially relevant.

2. Data and Sample

The sample of patents is derived from the EPO-OECD-PATSTAT database. This database, also known as the EPO Worldwide Patent Statistical Database, contains a snapshot of the European Patent Office (EPO) master documentation database with worldwide coverage. It has more than 20 tables with bibliographic data, citations, and family links for about 70 million applications from more than 90 countries, including the EPO and the USPTO.

Our sample selection begins with the October 2013 version of the PATSTAT data. It contains 44,730,405 observations, including patentees who are individuals, governmental

³This bias might intuitively explain why the effect of patent applications on firm value becomes subsumed by the R&D variable in standard empirical tests. Specifically, if the missing bias in R&D expenditures is lower than that in patents, then R&D expenditures should have greater explanatory power in these tests.

institution/universities, and companies for the sample period of 1999–2012. We focus on the patent applications of companies, which comprise 5,268,091 patentees. Our analysis relies on the registered names on the original patent applications to better capture the entities that performed the innovation activities.⁴ We merge the patent data with all publicly-listed firms in the Compustat Global database for 32 countries (39,801 unique firms). Our matching algorithm consists of two main steps. First, we standardize patent assignee names and firm names, focusing on unifying suffixes and dampening the non-informative parts of firm names. Second, we apply multiple fuzzy string matching techniques to identify the firm, if any, to which each patent belongs.

To facilitate country comparisons, we focus on countries with at least 100 publicly-listed firms (excluding Hungary, Iceland, and Ireland). However, including or excluding these countries leads to similar inferences in our analysis. Thus, our primary sample contains 29 countries over the sample period of 1999–2012. The countries in our sample are: Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Greece, Hong Kong, India, Israel, Italy, Japan, Korea, Malaysia, the Netherlands, New Zealand, Norway, Singapore, South Africa, Spain, Sweden, Switzerland, Taiwan, the UK, and the US. There are 30 patent offices in the sample because the EPO is a separate entity from each European country's patent office; European firms sometimes patent in their home patent office and other times with the EPO. Our baseline sample includes 333,920 firm-year observations and 37,272 unique firms, of which 5,374 are cross-listed firms. All accounting variables are from Compustat and are defined in Panel A of Table 1.

3. Univariate Analysis

3.1 Descriptive Statistics

Panel B in Table 1 reports the basic descriptive statistics of our sample firms. Only 35% of the observations in our sample report any information on R&D. Of those reporting R&D expenditures (118,264), 93% report positive R&D with an average R&D expenditure of 8% of their total assets. The 75th percentile of R&D expenditures captures firms where R&D equates to

⁴ We do not use patent ownership to identify the entities because patent ownership can be obtained without the owners performing any of the underlying innovation activities, such as via merger and acquisitions, acquisition of patent portfolios from other firms, etc.

roughly 6% of total assets. In addition, the sample firms invested an average of 6% of total assets in capital expenditure. Firms have an average of 9 patent applications, 4 patents granted, and 23 citations over the sample period. On average, firms are profitable with an average ROA (return on assets) of 1% (median of 5%) and are highly levered with a median leverage of 52%. In our analysis, we focus on patent applications but find similar results using patents granted.

3.2 Cross-Country Missing R&D Expenses and Patents

In this section, we examine the firms' R&D reporting characteristics across the 29 countries in our sample. Table 2 provides information on reporting and patent applications at the firm-year level for each country. Overall, we find that more than 60% of firms do not report R&D. There is a large variation in cross-country R&D reporting behavior, with over 83% of Australian firms and only around 25% of Taiwanese firms not reporting R&D. Interestingly, only Canadian and US firms report zero R&D. Using firm-level observations, Figure 1 documents similarly broad cross-country variations in missing R&D.

Table 2, Column (4), reports the number of observations with "Missing R&D." "Missing R&D" is defined as firms that do not report R&D but have patenting activity. A large number of firms in Germany, Korea, and the US do not report R&D but have patenting activity. Italy and Austria seem to suffer more severely from the missing R&D problem, while China and South Africa have very few firms with missing R&D. Figure 2 presents the proportion of missing R&D firms to (1) positive R&D firms and (2) positive R&D firms with patents across the 29 countries in our sample. We can clearly observe that both metrics vary significantly across countries. Missing R&D observations (non-reporting but positive patents) as a percentage of positive R&D observations range from near 0% in Hong Kong to 88% and 86% in Brazil and Italy, respectively. This variation is also observed among the traditionally research-intensive countries: Germany (39%), Japan (3%), and the US (13%). On average, missing R&D observations represent 25% of positive R&D observations in a country. Missing R&D observations relative to patent-positive R&D firms, arguably the correct comparison group, exhibit substantial cross-country variation and an average of 39%.

Turning to missing patents, in Table 2 Column (5), we classify an observation as "Missing Patent" when the firm files for patents with non-USPTO patent offices but not with

USPTO in that year.⁵ This is equivalent to the number of observations where patent activity actually exists but is considered not counted as such in cross-country studies that rely solely on the USPTO database. As a consequence, these cases are likely to be discarded. In particular, relying on the USPTO database to identify corporate innovation activity in a cross-country study results in discarding 11,094 firm-year observations with positive patent activity. As studies that strictly focus on positive R&D and patents would only contain 33,454 firm-year observations in our sample, this is a substantive deletion issue. Turning these numbers into percentages indicates that these erroneous deletions represent between 6% and 58% of observations depending on the specific country of interest. For instance, 39% of French and 29% of Japanese firms are erroneously classified as non-patenting firms when relying strictly on USPTO data. Similarly broad cross-country variations in missing patents are observed using firm-level observations (see Figure 1).

Figure 3 reports the proportion of Missing Patent firms (i.e. firms in a country that never file for a USPTO patent but file for non-USPTO patents) relative to both firms that report positive R&D and file for patents and firms that only report positive R&D. There is substantial variation in the proportion of firms that do not patent in the US. China and Brazil exhibit the highest ratio (above 200%) of non-USPTO filers to positive R&D and patenting firms. More than double the firms in most countries do not file for USPTO patents as a proportion of positive R&D and patenting firms.

In Table 2, Columns (6-9), we report the proportion of observations in each quadrant in Chart 1 to total observations in a country. Note that firms in Q1-Q3 provide observable displays of innovation activity either *via* reported R&D and/or patent applications. Using only reported R&D to capture innovative firms net between 53% (Brazil) and 99% (Hong Kong and Malaysia) of the firms with observable innovation, with a country-average of 83%. In contrast, relying strictly on patent data to capture innovative firms only nets between 1% (Hong Kong and Malaysia) and 62% (Italy) of the firms with observable innovation (country-average of 36%). In addition to demonstrating substantive cross-country variation in missing innovation data, this evidence suggests that missing patents are likely to be more problematic than missing R&D to the econometrician studying corporate innovation.

⁵ US firms are classified as Missing Patents if they file for patents with a foreign patent office but not with the USPTO in that particular year.

Our evidence thus far points to firms exercising discretion in deciding whether to report R&D expenditure in their financial statements as well as whether to patent their innovations. More importantly, these decisions and the levels of innovation vary significantly between countries. We observe similar patterns using firm-level data instead of firm-year data, and most importantly, there are no obvious patterns between the metrics. One potential implication is that different processes drive the R&D disclosure decision and the choice to patent corporate innovations.

3.3 Patenting with Domestic and Foreign Offices

Figure 4 depicts the total number of patent applications submitted by firms in the 29 countries of our sample. Firms from four countries—the US, Japan, Germany, and Korea—dominate in terms of patent applications filed around the world. Each of these countries submitted more than 150,000 applications during the sample period. This is followed by a cluster of two countries, France and Taiwan, with between 125,000 and 150,000 patent applications each. Given this background, we turn our attention to examining the cross-country differences in firms choosing to file patents domestically or with foreign patent offices.

Table 3 reports the country level patent applications in USPTO and non-USPTO patent offices. Columns (1) and (2) show the country-level number of patent applications filed in USPTO and non-USPTO patent offices. Column (3) reports the ratio of non-USPTO to USPTO patent filings. One obvious pattern that emerges is that the USPTO dominates patent applications, with 37% of all applications being filed in the US. Unsurprisingly, a large proportion of the USPTO filings (53%) come from US firms, which mainly file patents domestically. For example, for every one patent filed at a foreign office, 1.24 patents were filed domestically by US firms. Singapore is the only other country that files more USPTO than non-USPTO patents.

Among the top patent application countries (from Figure 4), Korean and Taiwanese firms file significantly more patents in non-USPTO offices than with USPTO offices. Specifically, among Korean firms, for every one patent filed with the USPTO, an average of 8 patents are filed with non-USPTO offices. Examining the other countries more broadly, we observe significant variation in the proportion of USPTO to non-USPTO patent office filings from 1.2 in Israel to 13 in Spain. Columns (4) and (5) show the average number of patent applications and

the number granted per firm per country. The average number of yearly patent applications per firm also varies substantially between countries. Germany has the highest number of applications at 33.71, while Hong Kong has the lowest at 0.01. Interestingly, other research-intensive countries such as Japan and the US only ranked fifth and seventh respectively based on yearly patent applications per firm.

In general, we observe significant cross-country variation in firm's choice to patent with the USPTO or non-USPTO offices. Given the scarcity of foreign company patents in the USPTO filings and the great variation between countries, relying on patents filed with the USPTO to examine innovation around the world appears potentially problematic. In a later section, we explicitly examine the potential consequences of relying solely on the USPTO patent data.

3.4 Cross-Country Variation in Missing R&D and Patents: White Noise or Systematic Variation?

In this section, we investigate whether our observed variation represents random noise or is systematically related to country-level institutional factors. Note that these tests do not seek to establish causality, but rather to emphasize association and rule out random noise as an explanation for the observed cross-country variation. Moreover, our choice of independent variables is somewhat ad-hoc, focusing on predictability rather than developing a determinants model.

The country-level institutional factors we examine include economic openness, manufacturing intensity, government subsidies, labor regulations, intellectual property rights, university ties, skilled labor, honesty, regulatory efficacy, and commonwealth countries. The data was obtained from the World Competitiveness Yearbook compiled by IMD (the International Institute for Management Development). Table A1 in the appendix provides the definitions for all these variables. Some survey-based variables are not available for all the countries in the sample.

In Table 4, we report the multivariate correlation between these country-level factors and the ratio of (1) missing R&D firms to positive R&D firms per year (Columns 1 and 2) and (2) missing patent firms to positive R&D firms per year (Columns 3 and 4). To provide a cleaner test setting, we exclude cross-listed firms from our main analysis given that cross-listed firms are

likely to be subjected to institutional factors from multiple countries.⁶ We find that the ratio of missing R&D to positive R&D firms is significantly related to most of the examined institutional factors, except for economic openness, intellectual property rights, and regulatory efficacy (Columns 1 and 2). Decisions not to disclose R&D expenditures (i.e. missing R&D) are positively associated with the level of intensity in various manufacturing industries, government subsidies, having a more skilled labor force, and being a less corrupt country (p -values < 0.00). In contrast, firms are more likely to report their R&D expenditure when labor regulations are conducive to business activities, when there are more ties between universities and firms to facilitate knowledge transfer, or in commonwealth countries (p -values < 0.00). Interestingly, institutional factors that have been generally perceived as desirable, such as having a skilled labor force and less corruption, are associated with firms choosing to hide their R&D expenditure information. Overall, our evidence thus far suggests that cross-country decisions not to disclose information pertaining to R&D expenditures are systematically associated with many institutional factors and are unlikely to be *missing completely at random*.

Regarding patenting decisions, we find that the ratio of missing patents to positive R&D firms is significantly associated only with manufacturing intensity and commonwealth (Columns 3 and 4). Missing patents occur more often if there are more manufacturing-intensive industries and less often in firms located in commonwealth countries (p -values < 0.00). Once again, some institutional factors that are generally perceived as desirable are associated with missing patents.

We conduct a similar analysis of missing R&D and missing patents at the firm-year level. We estimate a probit model with year, industry, and country fixed effects. Panel B of Table 4 shows the effects of firm-specific fundamentals on the reporting of R&D and on patenting. Missing R&D and patents increase at the firm level with total assets and property, plant and equipment (PPE, p -values = 0.00 and 0.06 respectively), while they decrease with sales growth (p -values < 0.03). Missing patents also decrease with ROA (p -values < 0.00). Collectively, our evidence indicates a significant correlation between the missing patents and several institutional and firm-specific factors. Thus, the variation we observed in our earlier analysis appears to be inconsistent with R&D and patent activity *missing completely at random*.

⁶ Table A2 of the appendix presents the results of our additional analysis using samples that include cross-listed firms. Panel A reports the univariate correlation results, while Panel B reports on the multivariate correlation analysis. Both sets of results yield conclusions that are qualitatively similar to our main findings in Table 4. Furthermore, including a time trend variable in our multivariate correlation tests does not alter our conclusions.

4. Empirical Implications for Studies on Innovation

In the preceding sections, we have shown that decisions of whether to report R&D or to patent innovations are systematically associated with many institutional factors, suggesting that they are not *missing completely at random*. Against this backdrop, we evaluate the implications of these findings for the common treatments of innovation input (R&D expenditure) and output (patenting) measures in studies of innovation. Perhaps the most common treatment in economics for missing R&D data or unobservable patent data is to delete the missing or blank observations (listwise deletion). In Appendix 1, we analytically show that excluding firms without patents or R&D provides unbiased estimates if and only if the missing data represents white noise (iid, independent and identically distributed). However, our empirical evidence thus far is inconsistent with missing innovation representing white noise.

4.1 Approaches to Handling Missing Innovation Data

Missing data can be classified into three categories: *missing completely at random*, *missing at random*, or *missing not at random* (Rubin 1976, 1987). Common techniques for dealing with missing data include deletion, zero or mean substitution, regression substitution, and multiple imputation. Their appropriateness depends on the nature of the missing data problem. The mean substitution and single imputation approaches are common avenues for dealing with missing observations (e.g. the industry average plus the indicator variable or Heckman approach); however, these approaches have two key limitations. The first approach biases the missing variable toward the mean and distorts the variance covariance matrix, while the second approach depends on the quality of the instrument used by the econometrician. In addition, both approaches treat imputed values as though they were observed (i.e., estimated without uncertainty), which is not the case; imputations are only estimates. As a result, analyses of a single imputation can overstate confidence in the parameter estimates, meaning that the standard errors are biased downward.

Multiple imputation addresses this bias problem by introducing an additional form of error based on variation in the parameter estimates across the imputations. The advantages of multiple imputation are its generalizability and replicability—it explicitly models missingness and gives confidence intervals for estimates rather than trusting a single imputation. Of course,

all of these approaches rely on the model specified by the econometrician to predict the missing variables.

4.2. Comparison Analysis

To gauge the efficacy of different methods for handling missing innovation data, we describe the results of a simple simulation that compares five different approaches to handling the missing data problem, namely, multiple imputation, Heckman, mean substitution, deletion, and replacement with zero. Appendix 2 details the simulation process. Our basic analysis centers on estimating β_1 and β_2 in the regression:

$$E(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2.$$

We generate five variables (Y, X_1, X_2, X_3, X_4) and two instruments (X_5, X_6) drawn from a multivariate normal distribution with mean 0 and variance 1. We generate 5,000 data sets randomly with 2,000 observations each. We consider two data-generating processes with missing data, *missing at random*, MAR, and *missing not at random* MNAR, as well as the case with a complete data set (i.e. the benchmark for our evaluation). Intuitively, the first case corresponds to systematically missing data, while the second corresponds to data that is missing due to unobserved processes.

We evaluate the performance for various missing data strategies using the coefficient bias for β_1 and β_2 . Figure 5 presents the bias for coefficients β_1 and β_2 for all scenarios. As expected the coefficient estimates are heavily biased both under MAR and MNAR. This suggests that none of the techniques examined completely eliminates the bias associated with missing data. Multiple imputation provides regression estimates closest to the benchmark case, i.e. the true parameters, in both scenarios.⁷

⁷ The standard Heckman approach typically focuses on missing observations in a dependent variable rather than considering missing data in the independent variable, which is often the case in studies of innovation. In addition, Heckman models often center on problems with a single proxy for the variable of interest, while studies in innovation often incorporate two measures of innovation (R&D and patents), both with missing observations. At a minimum it can prove challenging to implement a Heckman model for two different proxies of innovation in the same analysis.

5. Empirical Analysis of Full Deletion Bias

Conceptually, it is straightforward to consider the effects of full deletion on innovation studies. We empirically evaluate the effects of deleting innovation input and output measures by comparing two approaches. The deletion of R&D expenditure arises by dropping observations without R&D expenditure. Implementing the deletion of patent data while still maintaining a viable counterfactual for empirical evaluation, requires the utilization of patents filed with various patent offices around the world. Specifically, given that the USPTO makes up 37% of total patent applications in our sample, we implement patent deletion by dropping observations without USPTO patent applications. This leaves us with a viable counterfactual of patent applications filed with the remaining 29 patent offices or 63% of the total number of patent applications.⁸ Thus, our “full deletion” group comprises only observations that have both positive R&D expenditure *and* USPTO patent information. Our counterfactual group is comprised of observations that have *either* reported positive R&D expenditure *or* patent applications with any of the 30 patent offices. We describe the latter group as having “partial deletion,” because we utilize all innovation input and output measures observable to researchers; however, other observations with unreported R&D and patenting are deleted.⁹

5.1 Illustration Using Country Innovation Capacity

Our first set of tests examines the effects of using the full deletion approach versus the partial deletion approach on a country’s innovation capacity. We measure the innovation capacity for each country as the ratio of firm-year observations where there is innovation to the total number of observations for a particular country. Under the full deletion approach, we only consider a firm-year to have engaged in innovation activity if it has both positive R&D expenditure and patent applications with the USPTO. In contrast, for partial deletion, a firm-year is considered to have engaged in innovation activity if it either reports positive R&D expenditure or files patents with any of the 30 patent offices. We then introduce a “discrepancy” measure, which is the difference in the country innovation capacity between the full and partial deletion

⁸ Note that this is equivalent to studies of international firms using only the USPTO to identify firms with patents.

⁹ By definition, the partial deletion approach includes missing R&D firms that have patent activity but no reported R&D expenditure and missing patents firms that have non-USPTO patent applications.

measures. We also rank the countries based on both measures of country innovation capacity and compute the difference in ranking between the two measures. Table 5 reports the findings.

Several key observations can be drawn from the results. First, and not surprisingly, the full deletion approach consistently underestimates the innovation capacity of all countries in our sample (Column 3). Second, we observe that the wedge between the two approaches varies significantly across countries, ranging from a high of 0.65 for Taiwan to a low of 0.07 for China. Third, the country ranking results suggest that full deletion does not alter country ranking uniformly across all countries. For example, countries such as Switzerland, Spain, and India are unaffected, while the country rankings for the US and Canada are severely overstated under the full deletion approach in comparison with the partial deletion approach—dropping from first place to eighth and from fifteenth place to twenty-third, respectively. The ranking for Taiwan, on the other hand, is severely understated under the full deletion approach (sixth) relative to the partial deletion approach (first).

Several implications follow. The above observations imply that the full deletion approach is likely to induce selection bias to the innovation measures (e.g. R&D efficiency) for both single-country and cross-country studies on innovation. For single-country studies, the bias is potentially higher for countries that have a high discrepancy measure, such as Taiwan and Japan, which are among the five most active innovative countries in terms of total patent applications. One stylized example of full deletion in single-country studies would be those studies that measure innovation by using patent data while excluding observations without R&D expenditure. Inappropriate inferences may be reached for cross-country studies, given that relative country rankings are altered by full deletion. For example, in unreported results, we also find that the discrepancy measure is systematically associated with several country-level institutional factors. Thus, innovation measurements based on full deletion may simply reflect the influence of these institutional factors rather than a country's genuine innovation achievement. Examples of stylized full deletion approaches in cross-country studies include: (1) measuring innovation using patent data from all patent offices around the world while excluding observations without R&D expenditure and (2) measuring innovation using patent data from a single patent office (e.g. the USPTO) while excluding observations without R&D expenditure.

5.2. Illustration Using Firm Growth

In the following set of tests, we compare different methods of dealing with missing data. Our empirical evaluation utilizes two methods: (1) a univariate comparison of the variables of interest under the full sample (i.e. no deletion based on either reported R&D or patent application), the partially deleted sample with positive R&D, or patent applications, and full deletion; and (2) regressions of sales growth on innovation under different approaches of dealing with missing data comprises full deletion, partial deletion, and multiple imputation (note that univariate tests do not rely on any imputation). The univariate analysis provides insights into whether deletions lead to different sample firm characteristics, thus addressing whether any bias is introduced by deleting the data, while the regressions allow us to examine any differential effects of innovation measures derived from different approaches to handling missing data.

Table 6 reports the univariate characteristics of the full and partial deletion subsets, and a univariate comparison of missing and non-missing R&D and patents. Panel A shows that deleting missing innovation data substantially reduces the number of observations and paints a very different picture in comparison to the full sample. The partial deletion sample has 122,546 observations; the total assets are larger than those in the full sample, while the rest of the variables are smaller (Column 4). The full deletion sample only consists of 26,273 observations. Total assets, Tobin's Q, and sales growth are larger than those in the full sample, while the rest of the variables are smaller (Column 5). It is worth pointing out that ROA decreases by 400% from the full sample to the full deletion sample. Comparing the full deletion sample to the partial deletion sample, we observe that the partial deletion sample is closer to the full sample by 8%–300% depending on the variable considered.

Panels B and C of Table 6 show the difference in characteristics between observations with and without R&D and patents. Missing R&D observations have lower Tobin's Q and sales growth, as well as higher total assets, PPE, ROA, patent applications, and patents granted than non-missing R&D observations. Notably, this evidence suggests that deleting missing R&D firms excludes firms that are genuinely and actively engaging in innovation activity. Missing patent observations have lower PPE, leverage, capital expenditure, and sales growth than non-missing patent observations. Total assets are higher for missing patent observations than for non-missing patent observations. Taken together, these results show that R&D and patenting are at least not *missing completely at random* and depend on observables.

Next, we compare regression results for different approaches to missing data. Table 7 reports the regression results for innovation on future sales growth (three years ahead). We present the results for full and partial deletion, single imputation (with zero or the industry mean), Heckman and multiple imputation approaches. Full deletion (Column 1) includes only observations that have both R&D and USPTO patent applications, Partial deletion (Column 2) includes only observations that have either R&D or patent applications, Zero (Column 3) replaces non-reporting observations with zero, Mean (Column 4) replaces non-reporting observations with the industry mean, Heckman use lagged variables as instruments for non-reporting observations (Column 5), and Multiple Imputation (Column 6) imputes the non-reporting observations using multiple imputations where we create 100 imputed data sets using an imputation model that comprises ROA, total assets, PPE, and leverage. Panel A presents the results using only firm characteristics as control variables together with year, industry and country fixed effects, while Panel B additionally controls for country characteristics in the regression. We use three-year ahead sales growth to account for the varying time lag between R&D activities and future sales growth. Table A4 in Appendix 3 presents the results for two industries: Industrial and Commercial Machinery (SIC 35) and Chemical and Allied Products (SIC 28).¹⁰

Focusing on the results in Panel A, the estimated coefficients for R&D are positive and significant for all the approaches except for the multiple imputation approach in the three-year future sales growth regression (Columns 1 to 5; p -values < 0.01). On the other hand, patent applications have positively significant effects under the partial deletion, zero and mean replacement approaches in the three-year future sales growth regression (Columns 2 to 4; p -values < 0.01). Both R&D and patent applications have an insignificant effect on sales growth under the multiple imputation approach (Column 6). It is noteworthy that the estimated coefficients for R&D for the full deletion and Heckman samples are several times greater than those for the partial deletion, zero and mean replacement samples, suggesting that these two methods are likely to severely overestimate the economic effects of R&D on three-year ahead sales growth. We also observe that the coefficients of the other variables in the regression vary in

¹⁰ We estimate the same regressions with firm fixed effects and separately for the US and China and find qualitatively similar results. Neither of the tables provides evidence using inverse probability weighting, as the results do not converge in these specifications.

magnitude and sign depending on the sample used. For instance, the coefficient estimate of capital expenditure changes from negatively insignificant to positively significant across the specifications (Columns 1, 5 and 6 vs. Columns 2, 3, and 4). The coefficient of profitability in the full deletion sample is roughly 35% larger than that of the Heckman sample.¹¹ Panel B reports the results after controlling for country specific institutional characteristics. Controlling for these characteristics does not alter our findings on the effects of R&D and patent applications on 3-year ahead sales growth. In untabulated results we repeat the analysis using *R&D efficiency* measures with similar inferences.

Overall, the findings in this section demonstrate that different treatments of missing innovation data can lead to vastly different sample firm characteristics and varying regression results with potentially very large differences in the estimated economic effects of corporate innovation. This suggests that multiple approaches should be adopted to avoid potentially misleading inferences being made.

6. Summary and Strategies for Dealing with Missing Innovation Data

Overall, our analysis indicates significant cross-country bias in common measures of corporate innovation activity. Notably, we find that the proportion of missing R&D firms varies significantly between countries, and is more prevalent in countries with greater government subsidies, low corruption, and high human capital. In several countries, missing R&D firms average more patents than the positive R&D firms. Similarly, missing patents vary significantly across countries, suggesting that firms face different incentives to patent their intellectual property in different markets. This evidence implies that common input and output measures of innovation suffer a bias from missing data. We also document how relying on the USPTO data to capture innovation activity for either domestic or foreign firms introduces additional bias into patent-based measurements of innovation. Relying strictly on USPTO data creates a bias by

¹¹ In untabulated results, we repeat these tests using five-year sales growth, market-share and Tobin's Q as the dependent variables. On the five-year ahead sales growth, we find a positively significant R&D effects on future sales growth only among the full deletion, Heckman and multiple imputation samples (p -values < 0.05). In the market-share regressions, we observe the same effects; the full deletion sample leads to substantially higher coefficient estimates of R&D and patenting than in other specifications. In the Tobin's Q regressions, we find that the full deletion results are substantially lower than in the other estimates. Taken together, these empirical findings suggest that the direction of the bias depends on the nature of the investigation.

misclassifying firms that patent abroad but do not seek US patents. Thus, these results imply that R&D and patents are not *missing completely at random*.

One common approach for dealing with firms without any reported R&D or patents is to exclude or delete them from the study. Our analysis shows that this approach often magnifies the bias from missing observations rather than solving it. Moreover, our analysis speaks to the common approach of measuring innovation activity using *R&D efficiency* (patents/R&D). Predicated on our findings that innovation disclosure bias occurs across firms, time, and countries, using *R&D efficiency* heightens the disclosure bias.

Considering the extensive nature of missing patents and R&D, several practical issues arise. Naively deleting the missing observations leads to biased coefficients and standard errors. Simple replacement models (zero, industry average, etc.) allow full sample analysis but create difficulties in interpreting the standard errors. Arguably, replacing the data using multiple imputation with the *correct* model does not result in these problems. Alternatively, if innovation is the primary variable of interest, then identifying potential instruments could provide a robust approach for dealing with the missing innovation data problem. Given the difficulty in developing the appropriate instruments, future studies should consider applying multiple approaches to avoid arriving at potentially misleading conclusions. Moreover, as we find that inverse probability methods seldom converge using the real world innovation data, methods that rely on partial samples encounter severe challenges in adjusting for this selection bias. Consequently, approaches that incorporate more complete samples appear germane. At a minimum, simply excluding firms without reported R&D or patents intensifies the missing observation bias rather than solving the problem. The deletion cure is often worse than the disease.

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Table 1
Variable Definitions and Descriptive Statistics

This table shows the variable definitions and the descriptive statistics. Panel A shows the variable definitions. Panel B presents the sample characteristics. The sample period is 1999–2012.

Panel A. Variable Definitions

Variable Names	Variable Definitions	Code
R&D Expenditure	R&D expenditure divided by total assets	XRD/AT
Report R&D	Indicator variable: 1 if a firm reported zero or positive R&D expenditure; 0 otherwise	
PPE	Net property, plant, and equipment divided by total assets	PPENT/AT
Tobin's Q	Tobin's Q, measured as market value of equity divided by total assets	MKTVAL/AT
Leverage	Total liabilities divided by total assets	LT/AT
Log(Total Assets)	Log of total assets	Log(AT)
Capital Expenditure	Capital expenditure divided by total assets	CAPX/AT
ROA	EBIT divided by total assets	EBIT/AT
Sales Growth	Annual sales growth	$(\text{Sale}_t - \text{Sale}_{t-1}) / \text{Sale}_{t-1}$
HH Index	Herfindal industry concentration index	
No. of Patent Applications	Total number of patent applications	
No. of Patents Granted	Total number of patents granted	
Citations	Total number of citations per patent	

Panel B. Overall Sample

Variables	N	Mean	Median	Std. Dev.	25th	75th
	(1)	(2)	(3)	(4)	(5)	(6)
R&D Expenditure	118,264	0.08	0.02	0.60	0.00	0.06
Report R&D	333,920	0.35	0.00	0.48	0.00	1.00
Log(Total Assets)	330,790	6.74	6.64	2.96	4.75	8.61
PPE	328,021	0.28	0.23	0.23	0.01	0.43
Tobin's Q	225,349	1.67	0.64	19.97	0.31	1.30
Leverage	330,580	0.95	0.52	63.21	0.32	0.69
Capital Expenditure	311,017	0.06	0.03	0.78	0.01	0.07
ROA	328,801	0.01	0.05	0.22	0.01	0.10
Sales Growth	302,442	0.26	0.07	1.05	-0.04	0.25
No. of Patent Applications	333,920	9.36	0.00	140.78	0.00	0.00
No. of Patents Granted	333,920	4.50	0.00	69.54	0.00	0.00
Citations	333,920	23.43	0.00	442.67	0.00	0.00

Table 2
Country Characteristics

This table shows the country characteristics for firm innovation input and output variables in the sample. “Firm Years” represents the total number of observations per country in the sample, “Non-Reporting R&D” is the number of observations that fail to report R&D, “Zero R&D” is the number of observations that report zero R&D spending, “Missing R&D” is the number of observations without reported R&D and positive patent applications, and “Missing Patent” is the number of observations that file for a non-USPTO but no USPTO patent in the same year. Q1 is the proportion of observations that reports R&D and has positive patent activity in the PATSTAT database (in %), Q2 is the proportion of observations that reports R&D and has no patent activity (in %), Q3 is the proportion of observations that does not report R&D but has patenting activity (Missing R&D) (in %), and Q4 is the proportion of observations that does not report R&D and does not have patent activity (in %).

Country	Firm Years	Non-Reporting R&D	Zero R&D	Missing R&D	Missing Patent	Report R&D with Patents	Report R&D and no Patents	Non-report R&D with Patents	Non-report R&D and no Patents
	(1)	(2)	(3)	(4)	(5)	Q1 (6)	Q2 (7)	Q3 (8)	Q4 (9)
Australia	19,072	15,856	-	298	277	2.77	14.09	1.56	81.58
Austria	1,047	694	-	140	116	9.93	23.78	13.37	52.91
Belgium	1,455	965	-	86	89	14.30	19.38	5.91	60.41
Brazil	3,970	3,557	-	362	236	1.21	9.19	9.12	80.48
Canada	5,840	4,584	260	249	159	6.42	15.09	4.26	74.23
China	26,562	24,954	-	284	185	0.15	5.90	1.07	92.88
Denmark	1,746	1,191	-	137	89	14.09	17.70	7.85	60.37
Finland	1,677	687	-	131	275	26.89	32.14	7.81	33.15
France	8,850	6,636	-	1,041	731	9.57	15.45	11.76	63.22
Germany	9,338	6,273	-	1,185	964	13.93	18.89	12.69	54.49
Greece	2,450	1,792	-	32	25	0.90	25.96	1.31	71.84
Hong Kong	11,836	8,935	-	8	6	0.17	24.34	0.07	75.42
India	31,428	24,493	-	296	303	1.54	20.52	0.94	76.99
Israel	2,937	1,460	-	86	99	14.10	36.19	2.93	46.78
Italy	3,198	2,575	-	538	280	5.85	13.63	16.82	63.70
Japan	40,608	14,371	-	911	2,358	17.88	46.73	2.24	33.15
Korea	8,856	7,191	-	1,098	792	3.73	15.07	12.40	68.80
Malaysia	11,438	9,770	-	10	10	0.11	14.47	0.09	85.33
Netherlands	1,958	1,355	-	97	63	7.51	23.29	4.95	64.25
New Zealand	1,551	1,173	-	28	33	4.13	20.25	1.81	73.82
Norway	2,290	1,742	-	243	150	7.42	16.51	10.61	65.46
Singapore	7,668	6,636	-	129	70	0.95	12.51	1.68	84.86
South Africa	3,478	2,889	-	41	26	0.43	16.50	1.18	81.89
Spain	1,640	1,396	-	190	128	3.90	10.98	11.59	73.54
Sweden	5,204	3,537	-	399	336	10.55	21.48	7.67	60.30
Switzerland	2,803	1,613	-	148	155	15.38	27.08	5.28	52.27
Taiwan	15,800	3,966	-	301	1,363	19.42	55.47	1.91	23.20
UK	21,197	14,942	-	604	716	5.41	24.10	2.85	67.64
US	78,023	40,423	8,352	3,741	1,060	19.02	29.17	4.79	47.01
Total	333,920	215,656	8,612	12,813	11,094	10.02	25.40	3.84	60.75

Table 3
Differences in Patent Applications across Patent Offices

This table shows the total number of USPTO and non-USPTO patent applications across countries during the sample period. USPTO represents the number of patent applications with USPTO, non-USPTO represents the number of patent applications in any other patent office, Ratio is the ratio of non-USPTO to USPTO patents (3)=(2)/(1). Columns (4) and (5) show the average number of patent applications and patents granted per firm in each country.

Country	USPTO	Non-USPTO	Ratio	Average No. of Patent Applications	
	(1)	(2)	(3)	(4)	(5)
Australia	1,402	3,768	2.69	0.27	0.09
Austria	359	2,873	8.00	3.09	1.61
Belgium	1,982	9,573	4.83	7.94	4.34
Brazil	292	2,410	8.25	0.68	0.10
Canada	2,015	4,630	2.30	1.14	0.36
China	2,051	22,908	11.17	0.94	0.17
Denmark	4,634	19,890	4.29	14.05	6.08
Finland	11,940	42,446	3.55	32.43	12.76
France	19,870	107,173	5.39	14.36	8.01
Germany	47,266	267,491	5.66	33.71	14.13
Greece	23	80	3.48	0.04	0.02
Hong Kong	47	62	1.32	0.01	0.00
India	2,208	9,960	4.51	0.39	0.07
Israel	2,167	2,601	1.20	1.62	0.52
Italy	1,256	6,720	5.35	2.49	1.33
Japan	328,509	527,311	1.61	21.08	11.14
Korea	26,051	214,569	8.24	27.17	6.50
Malaysia	12	51	4.25	0.01	0.00
Netherlands	2,942	24,393	8.29	13.96	7.14
New Zealand	326	967	2.97	0.83	0.43
Norway	707	5,020	7.10	2.50	1.44
Singapore	1,794	1,590	0.89	0.44	0.19
South Africa	16	134	8.38	0.04	0.02
Spain	190	2,488	13.09	1.63	0.49
Sweden	4,328	18,142	4.19	4.32	2.85
Switzerland	6,406	62,237	9.72	24.49	10.49
Taiwan	55,424	92,401	1.67	9.36	5.48
UK	8,603	34,577	4.02	2.04	0.91
US	611,790	494,423	0.81	14.18	7.23
Total	1,144,610	1,980,888	1.73		

Table 4
Multivariate Correlations – Institutional Factors

This table shows the multivariate panel regressions of missingness at the country and firm level. Panel A shows the regression of the ratio of missing R&D firms to positive R&D firms and institutional factors as well as the ratio to positive R&D firms without patents and institutional factors. Standard errors are double clustered by year and country. Cross-listed firms are excluded from the sample. Panel B shows the coefficient, marginal effects, and p-value of the probit regression of missing R&D and missing patents on firm characteristics. Firms with positive patent activity that do not report R&D are classified as “Missing R&D”, firms with non-USPTO but no USPTO patents are classified as “Missing Patents”. The sample period is 1999–2012.

Panel A. Country Regressions

Dependent Variables:	Missing R&D / Positive R&D		Missing Patent / Positive R&D	
	Coeff. (1)	<i>p</i> -val. (2)	Coeff. (3)	<i>p</i> -val. (4)
Intercept	0.4823	0.01	1.8134	0.05
Economic openness	-0.0006	0.14	-0.0023	0.15
Manufacturing intensity	0.0125	0.00	0.0705	0.07
Government subsidies	0.0306	0.04	-0.3289	0.16
Labor regulations	-0.0518	0.00	-0.2403	0.14
Intellectual property rights	-0.0241	0.45	-0.5157	0.26
University ties	-0.1423	0.00	0.1059	0.69
Skilled labor	0.0596	0.00	0.0803	0.41
Honesty	0.0629	0.00	0.0991	0.35
Regulatory efficacy	-0.0128	0.55	0.1816	0.14
Commonwealth	-0.1916	0.00	-0.6668	0.00
Mean Dep. Var.	0.26		0.51	
R ²	0.37		0.06	
Obs. (Country-year)	334		360	

Panel B. Individual Firm Regressions

Dependent Variables:	Missing R&D			Missing Patents		
	Coeff. (1)	Marginal Effects (2)	<i>p</i> -val. (3)	Coeff. (4)	Marginal Effects (5)	<i>p</i> -val. (6)
Log(Total Assets)	0.098	0.0073	0.00	0.199	0.0036	0.00
PPE	0.112	0.0084	0.00	0.345	0.0097	0.06
Leverage	0.000	0.0000	0.75	0.000	-0.0009	0.21
Capital Expenditure	-0.010	-0.0008	0.80	-0.011	0.0025	0.68
ROA	-0.031	-0.0023	0.31	0.012	-0.0141	0.00
Sales Growth	-0.013	-0.0009	0.01	-0.027	-0.0016	0.03
Year/Industry/Country FE	YES			YES		
R ²	0.13			0.08		
Obs.	282,798			105,880		

Table 5
Country Innovation Capacity

This table shows country innovation capacity, which is defined as the number of firm-years that conduct innovation out the total number of firm-year observations for each country. “Full Deletion” includes only companies that have positive R&D and patent filings in the USPTO to be innovative. “Partial Deletion” includes companies that have positive R&D or patent applications in any patent office to be innovative. “Discrepancy” is the difference between innovation under partial deletion and full deletion. The table is arranged from the largest to the smallest discrepancy.

Country	Proportion			Ranking		
	Full Deletion (1)	Partial Deletion (2)	Discrepancy (3) = (2) - (1)	Full Deletion (4)	Partial Deletion (5)	Diff. in Ranking (6) = (4) - (5)
Taiwan	0.12	0.77	0.65	6	1	5
Japan	0.13	0.67	0.54	3	2	1
Finland	0.14	0.67	0.52	2	3	-1
Israel	0.12	0.53	0.42	7	4	3
Austria	0.06	0.47	0.41	12	6	6
Switzerland	0.12	0.48	0.36	5	5	0
Germany	0.10	0.46	0.36	9	7	2
Italy	0.03	0.36	0.33	16	13	3
Sweden	0.07	0.40	0.33	10	9	1
France	0.06	0.37	0.30	11	12	-1
Netherlands	0.06	0.36	0.30	13	14	-1
Korea	0.01	0.31	0.30	21	17	4
Norway	0.05	0.35	0.30	14	15	-1
UK	0.03	0.32	0.29	17	16	1
Belgium	0.11	0.40	0.29	8	11	-3
Greece	0.01	0.28	0.28	25	18	7
Denmark	0.12	0.40	0.27	4	10	-6
US	0.18	0.43	0.25	1	8	-7
Spain	0.02	0.26	0.25	19	19	0
Hong Kong	0.00	0.25	0.24	27	21	6
New Zealand	0.03	0.26	0.24	18	20	-2
India	0.01	0.23	0.22	22	22	0
Brazil	0.01	0.20	0.19	24	24	0
South Africa	0.00	0.18	0.18	26	26	0
Australia	0.02	0.18	0.17	20	25	-5
Canada	0.05	0.21	0.17	15	23	-8
Malaysia	0.00	0.15	0.15	29	28	1
Singapore	0.01	0.15	0.14	23	27	-4
China	0.00	0.07	0.07	28	29	-1

Table 6
Selection Bias

This table shows the selection bias across several variables. Panel A presents the sample characteristics for the full sample and the full and partial deletion sample. “Full Sample” uses all available observation without deletion based on either reported R&D or patent application information. “Partial Deletion” includes only observations that have positive R&D or patent applications in any patent office. “Full Deletion” includes only observations that have positive R&D and patent filings in the USPTO. Firm-years represent the maximum number of observations available for each subsample. Panels B and C show the comparison of the samples with missing and non-missing R&D (patent). Firms with positive patent activity that do not report R&D are classified as “Missing R&D”, firms with non-USPTO by no USPTO patents in a year are classified as “Missing Patent”. Variable definitions are presented in Table 1. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A. Univariate Comparison of Samples

	Full Sample (1)	Partial Deletio n (2)	Full Deletio n (3)	Differences		
				(4) =((1)- (2)) /(1)	(5) =((1)-(3)) /(1)	(6) =((3)- (2)) /(1)
Log(Total Assets)	6.74	7.34	7.40	-9%***	-10%***	1%***
PPE	0.28	0.24	0.20	14%***	29%***	-14%***
Tobin’s Q	1.67	1.56	1.86	7%***	-11%*	18%***
Leverage	0.95	0.56	0.48	41%***	49%***	-8%***
Capital Expenditure	0.06	0.05	0.05	17%***	17%***	0%***
ROA	0.01	0.00	-0.03	100%***	400%***	-300%***
Sales Growth	0.26	0.23	0.31	12%***	-19%***	31%***
N (Firm-years)	330,790	122,546	26,273			

Panel B. Univariate Comparison of Missing R&D

Variables	Missing R&D (N=12,813)		Non-Missing R&D (N=321,107)		Diff. (1)-(3)
	Mean (1)	SD (2)	Mean (3)	SD (4)	
Log(Total Assets)	7.48	3.39	6.71	2.94	0.77***
PPE	0.29	0.22	0.28	0.24	0.01***
Tobin’s Q	1.32	8.94	1.68	20.3	-0.36***
Leverage	0.82	15.32	0.96	64.39	-0.14
Capital Expenditure	0.06	0.06	0.06	0.79	0.00
ROA	0.03	0.2	0.01	0.22	0.02***
Sales Growth	0.22	0.93	0.26	1.06	-0.04***
No. of Patent Applications	23.69	318.18	8.79	128.70	14.90***
No. of Patents Granted	7.45	107.38	4.39	67.59	3.07***
Citations	27.05	297.17	23.28	447.5	3.77

Panel C. Univariate Comparison of Missing Patents

Variables	Missing Patents (N= 11,094)		Non-Missing Patents (N= 322,826)		Diff. (1)-(3)
	Mean (1)	SD (2)	Mean (3)	SD (4)	
R&D Expenditure	0.09	0.85	0.08	0.58	0.01
Log(Total Assets)	7.77	3.44	6.71	2.93	1.06***
PPE	0.27	0.19	0.28	0.24	-0.01***
Tobin’s Q	1.87	26.70	1.66	19.65	0.21
Leverage	0.56	2.61	0.97	64.29	-0.41***
Capital Expenditure	0.05	0.06	0.06	0.79	-0.01***
ROA	0.01	0.23	0.01	0.22	0.00
Sales Growth	0.20	0.93	0.26	1.06	-0.06***

Table 7
Alternative Treatments of Missing Innovation Measures

This table presents firm growth panel regressions for the period of 1999–2012. The dependent variable is three years' ahead sales growth. "Full Deletion" includes only observations where R&D is not missing and there are USPTO patents filed. "Partial Deletion" includes observations where either R&D is not missing or there are USPTO patents filed. "Zero" replaces all missing R&D and patents with zero. "Mean" replaces all missing R&D and patents with the country industry mean. "Heckman" uses a two-stage estimation procedure, where the lags of the other variables are used as instruments. "Multiple Imputation" is constructed by imputing all missing values using MCMC 100 times; using log(Total Assets), ROA, PPE, and leverage as conditioning variables; and then averaging across the 100 imputations (Schafer (1997)). Panel A presents the results with only firm characteristics as explanatory variables, Panel B presents the results with firm and country characteristics as explanatory variables. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The regressions include year, industry, and country fixed effects. Column 6 differs in observations from columns 3 and 4 due to the imputation 83 independent variable observations.

Panel A. Firm Characteristics

	DV = Sales Growth (t+3)					
	Full Deletion	Partial Deletion	Zero	Mean	Heckman	Multiple Imputatio n
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Firm controls:</i>						
Log(Total Assets)	-1.28***	-2.32***	-3.34***	-3.34***	-1.43***	-2.82***
ROA	-40.91***	-38.53***	-36.40***	-36.38***	-30.35***	-36.57***
Capital Expenditure	-0.60	3.66**	1.21*	1.21*	-0.57	-1.29
Leverage	-3.80***	-0.20	-0.01	-0.01	-5.17***	0.01
HH Index	-3.82	-1.16	0.73	0.72	-7.39**	0.78
R&D Dummy		0.18	1.14***	0.97***		0.43
Patent Dummy		-2.13***	-3.26***	-3.31***		-2.59***
R&D	13.39***	4.14***	3.68***	3.86***	18.44***	1.40
Patent App.	0.00	0.00***	0.00***	0.00***	0.00	0.00
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
R ²	0.08	0.05	0.05	0.05		0.07
Obs.	21,338	96,973	248,984	248,984	19,432	249,067

Table 7 (cont'd)

Panel B. Firm and Country Characteristics

	DV = Sales Growth (t+3)					
	Full Deletion (1)	Partial Deletion (2)	Zero (3)	Mean (4)	Heckman (5)	Multiple Imputation (6)
<i>Firm controls:</i>						
Log(Total Assets)	-1.26***	-2.29***	-3.23***	-3.22***	-1.36***	-2.29***
ROA	-43.30***	-40.22***	36.31***	-36.28***	-33.12***	-40.22***
Capital Expenditure	-0.84	2.09	0.86	0.86	-0.64	2.09
Leverage	-3.97***	-0.13	-0.01	-0.01	-5.37***	-0.13
HH Index	-3.63	-1.55	-0.10	-0.10	-6.47*	-1.55
<i>Country controls:</i>						
Economic openness	-0.21	0.03	0.09***	0.09***	-0.39	0.03
Manufacturing intensity	0.42	-0.16	-0.46***	-0.46***	0.84	-0.16
Government subsidies	-2.62	-0.22	-0.43	-0.44	-2.29	-0.22
Labor regulations	-2.44**	-2.21***	-2.29***	-2.29***	-2.50**	-2.21***
Intellectual property rights	5.25**	0.19	0.76	0.76	4.55*	0.19
University ties	-3.32	0.51	2.18***	2.18***	-2.84	0.51***
Skilled labor	-0.02	0.13	-2.09***	-2.08***	0.23	0.13***
Honesty	2.80**	3.50***	2.53***	2.53***	2.29*	3.50***
Regulatory efficacy	1.62	-1.17*	-0.50	-0.51	1.99	-1.17
R&D Dummy		-0.29	1.13***	0.97**		-0.29
Patent Dummy		-2.17***	-3.32***	-3.37***		-2.17***
R&D	13.92***	3.54***	3.32***	3.47***	18.97***	3.54
Patent App.	0.00	0.00**	0.00***	0.00***	0.00	0.00
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
R ²	0.08	0.06	0.05	0.05		0.10
Obs.	19,472	89,140	208,419	208,419	18,485	215,172

Figure 1: Firms by Country

This figure shows the number of firms in each country, the number of firms with non-reporting R&D, and the number of firms with missing patents. Unique Firms is the total number of firms per country in the sample, Non-Reporting R&D is the number of firms that have at least one missing R&D, Missing Patent (right axis) is the number of firms that never file for patents with USPTO.

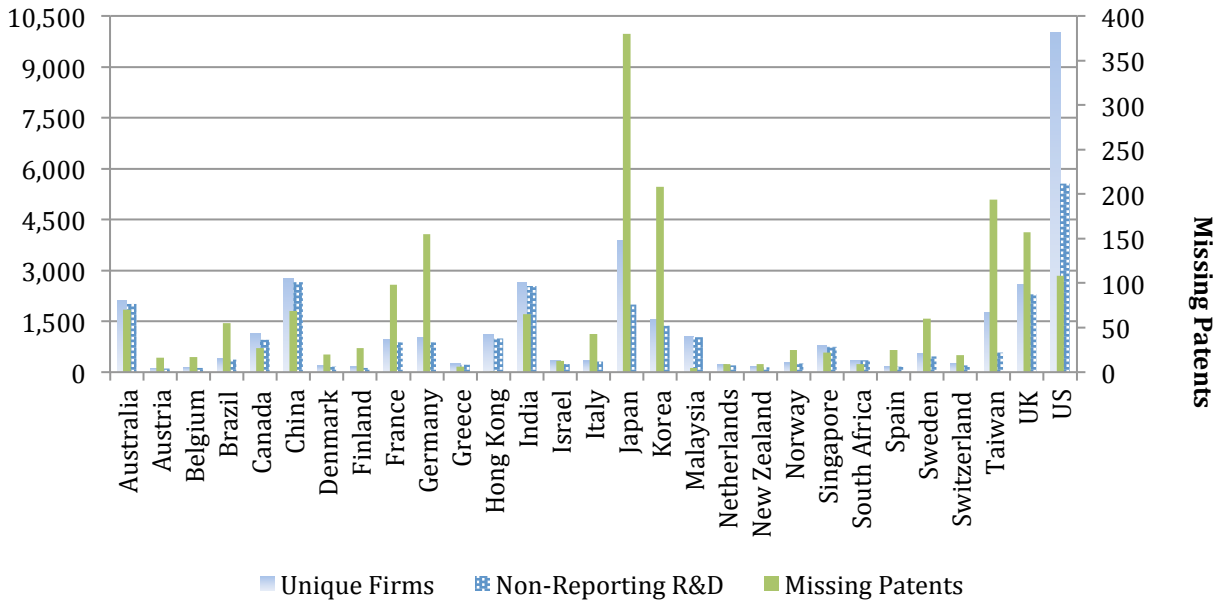


Figure 2: Missing R&D

This figure shows the proportion of (1) missing R&D to positive R&D with patent firms (left axis) and (2) missing to positive R&D firms (right axis) by country. Positive R&D with Patent is the number of firms that reports at least one positive R&D and has a patent application in that year. Firms with positive patent activity that do not report R&D are classified as “Missing R&D” firms.

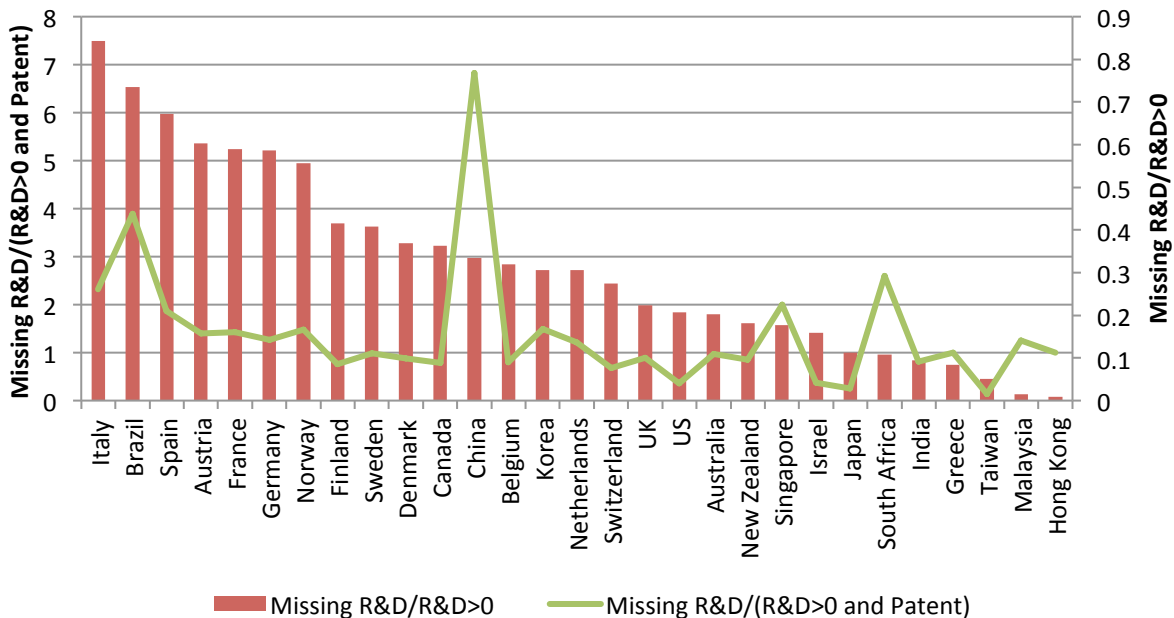


Figure 3: Missing Patents

This figure shows the proportion of (1) missing to positive R&D and patent firms (left axis) and (2) missing patent to positive R&D firms (right axis) by country. Positive R&D with Patent is the number of firms that reports at least one positive R&D and has a patent application in that year. Firms with positive non-USPTO and no USPTO patent activity are classified as “Missing Patent” firms.

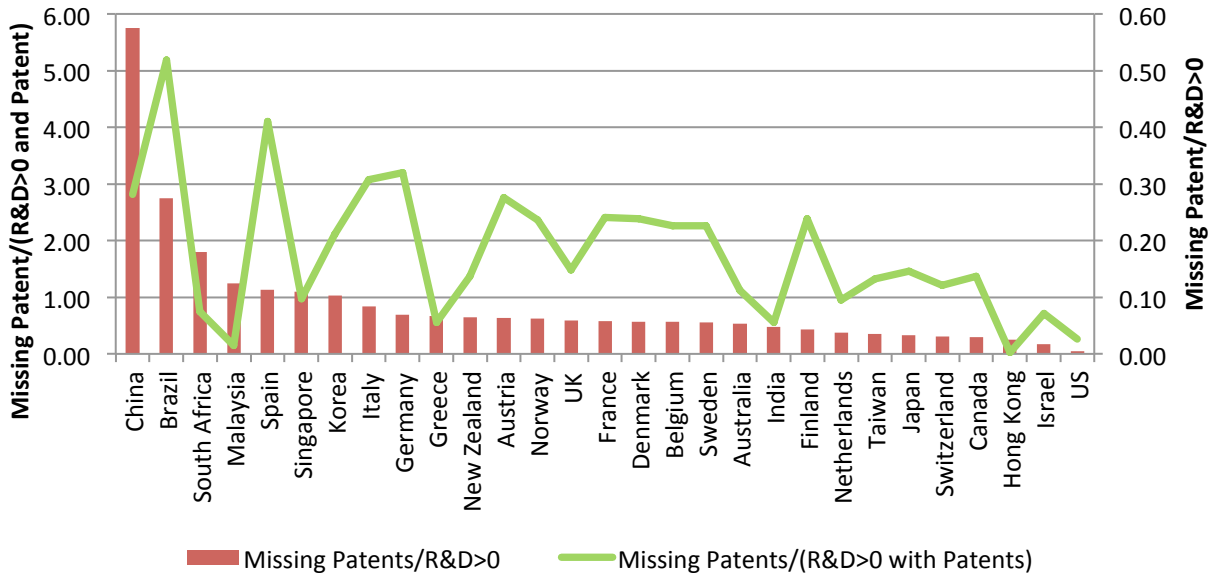


Figure 4: Total Patent Applications by Country

This figure shows the total patent applications by country across the 30 patent offices during the sample period of 1999–2012. The US, Japan, Germany, and Korea filed more than 150,000 patents and have been truncated at 150,000 to facilitate the reading of the number of applications in other countries.

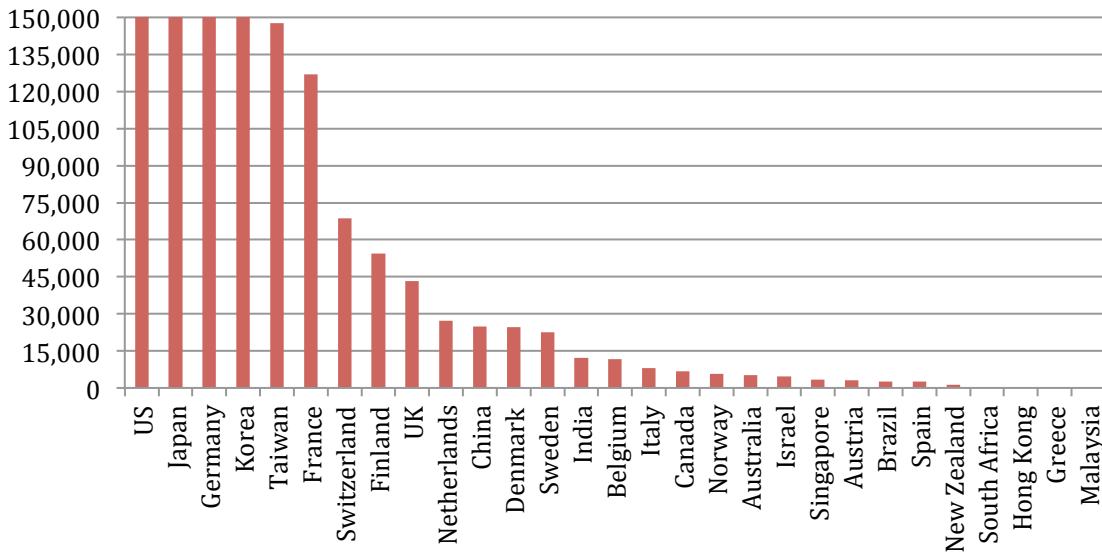
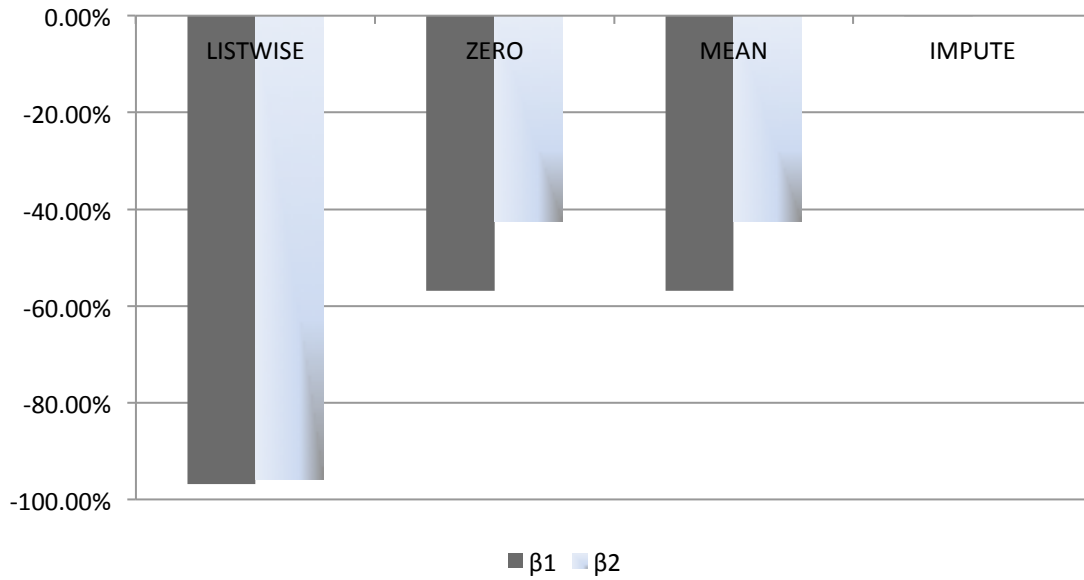


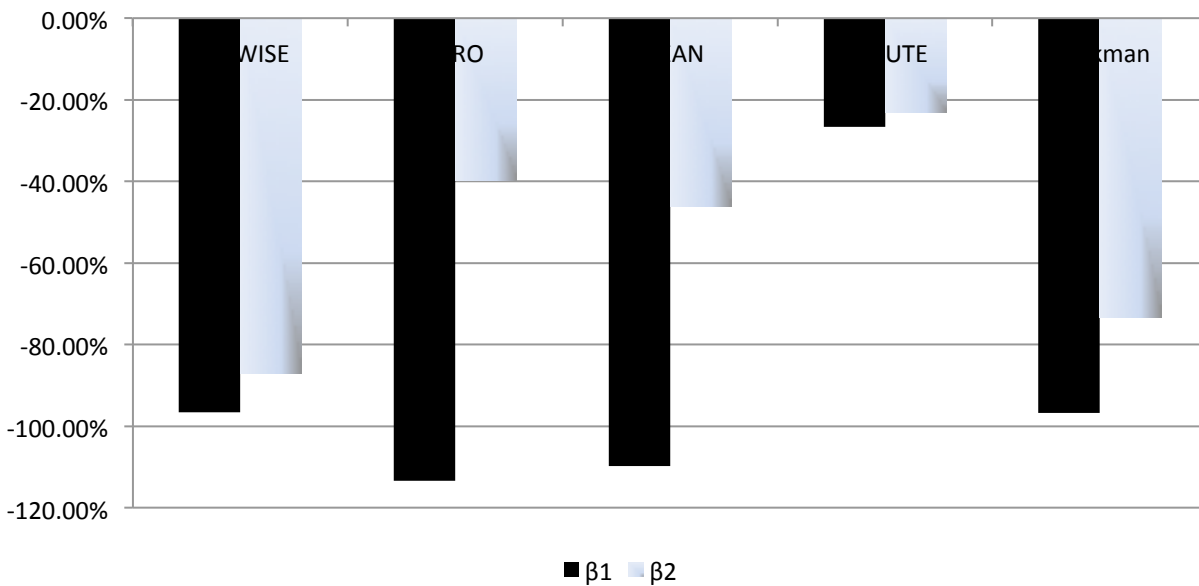
Figure 5
Monte Carlo Simulation Bias

This figure shows the bias of the coefficients for X_1 and X_2 under different approaches to dealing with missing data, as a percentage of the true sample parameters. LISTWISE deletes all rows with missing observations, ZERO replaces missing observations with zero, MEAN replaces missing observations with the sample mean, IMPUTE replaces missing observations with MCMC-imputed observations based on 100 imputations and Heckman estimates the coefficients using two instruments. Panel A presents the results for observations Missing at Random (MAR) and Panel B for observations Missing not at Random (MNAR). This simulation is described in Appendix 2.

Panel A. MAR



Panel B. MNAR



Appendix 1. *Missing Innovation and Deletion*

To evaluate the issue of data deletion with missing R&D or incomplete patent applications, we consider a simple linear regression model with one explanatory variable. Let the relation of the observed response y_i , for example firm value, of individual firm i , and the explanatory variable x_i , R&D expenditure or patent application, be described by:

$$y_i = \alpha + \beta x_i + \varepsilon_i. \quad (1)$$

However, instead of using all the available observations, N , in a sample, a researcher only uses a subsample of observations, deleting observations or firms without R&D expenditure data or patent applications.¹² Let s_i be a selection indicator where $s_i = 1$ when R&D (patenting) is not missing and firm i is included in the regression. If R&D (patenting) is missing, i.e., $s_i = 0$, then firm i is dropped from the data.

The simple deletion problem (listwise deletion) that we analyze captures missing inputs (R&D) or incomplete outputs (patents) of corporate innovation activity. A scholar studying innovation could perform a regression using the subsample of the data observations with reported R&D expenditures or patent application data ($s_i = 1$), which we represent as follows:

$$s_i y_i = \alpha s_i + \beta s_i x_i + s_i \varepsilon_i. \quad (2)$$

$s_i x_i$ is the explanatory variable and $u_i = s_i \varepsilon_i$ is now the error term. The OLS (ordinary least squares) estimator is unbiased if $E(s_i x_i \varepsilon_i | x_i, s_i) = E(s_i x_i \varepsilon_i | x_i, s_i) = 0$.

1 Effects of Single Dimension Deletion

1.1. Case 1: Sample selection is random

For the OLS estimator to be unbiased, where $E(u_i | x_i, s_i) = 0$, the sample selection has to be random. In other words, missing R&D or incomplete patents randomly occur across countries and firms. This is analogous to data *missing completely at random* where:

$$E(\varepsilon_i | x_i, s_i) = E(\varepsilon_i | x_i) = 0, \quad (3)$$

if the Gauss-Markov assumptions hold.

1.2. Case 2: Sample selection is correlated with u_i

Given that the reporting of R&D depends on the manager of firm i and not the econometrician, the sample selection indicator s_i will be correlated with u_i . For example, if firms choose to not provide information on R&D expenditures or seek patents for their innovations (i.e., maintain them as trade secrets), missing observations related to knowledge capital or s_i will be correlated with u_i . This is widely known as incidental deletion or sample selection bias. Our empirical results in Tables 1–6 suggest that the magnitude of this bias varies across countries and firms, and such variation is inconsistent with data *missing completely at random*. Therefore, studies that use either R&D expenditures or patent data and truncate them due to missing or incomplete data introduce selection bias into the analysis.

¹² We consider the univariate setup for simplicity. There might be other covariates of interest that drive the outcome variable, but including them in the regression does not change the problem of deletion.

1.3. Case 3: Sample selection is correlated with y-variable

If the manager's decision not to report R&D or file for patents is related to the current or future value of the firm, y_i , then the OLS estimate will still be biased because $s_i \varepsilon_i$ is correlated with the x -variable.

1.4 Case 4: Sample selection based on x-variable is correlated with ε_i

In this scenario, the managers' willingness to report R&D (thereby seeking patents) depends on their relative innovation activity in comparison to their industry peers (Koh et al., 2015). If other firms in the industry disclose their R&D expenditures or seek patents based on the activities of firm i , then the OLS estimator will be biased. For instance, consider the example of a manager's decision to disclose R&D expenditures of X if $X > v$. In this case, the selection is based on the x -variable and the random variable v . If v is independent from ε_i , then there is no bias, even if the selection is based on the x -variable. However, there is a bias if v is correlated with ε_i .

It seems reasonable that R&D expenditure is an endogenous variable and that firms consider the strategic effects of disclosing R&D, even though it is a mandatory or required disclosure for listed firms (e.g., Dye, 1986; Simon, 1989; Rogerson, 2008). For example, v might correspond to an industry average or a specific competitor's R&D expenditure. In this setting, the firm i manager's decision to report R&D is based on whether firm i 's expenditure is higher or lower than v . If disclosure choices are strategic (Admati and Pfleiderer, 2000; Lacko and Pappalardo, 2010), then truncating firms with either missing R&D or incomplete patent data creates a bias in the analysis. Our empirical results in Tables 1–6 suggest that the magnitude of this bias varies across countries and firms, and such variation is inconsistent with random noise.

1.5 Truncating either R&D or patenting

Truncating firms with missing R&D expenditures or incomplete patent data provides unbiased estimates only in Case 1. If missing R&D or incomplete patents represent white noise (iid, independent and identically distributed), then deletion is the appropriate solution, but there will be a loss in efficiency due to the lower number of observations. However, our evidence appears to be more consistent with Cases 2–4. Arguably, Case 2 suggests the use of a sample selection correction model (like Heckman) to incorporate the firms with missing innovation inputs or outputs when they are dependent variables. However, the Heckman procedure does not help in the case of explanatory variables. Thus, under Case 2, researchers using either R&D or patenting should not exclude firms with missing data. Unfortunately, solving Cases 3 and 4 proves more difficult. Truncating the missing variables creates a biased analysis. Instead, both of these cases require a suitable instrument. It also matters if innovation enters the analysis as a primary variable of interest, represents a control variable, or serves as the dependent variable in an analysis.

1.6 Effects of Full Deletion: The Case of R&D Efficiency

So far we have analyzed the problem when individually either R&D or patents are missing. However, in a more realistic scenario, any given firm faces a double-selection problem of whether to report R&D and file for a patent. Thus, we have the following generic representation of the double-selection problem:

$$\begin{aligned}
y_{1i}^* &= \beta_1' x_{1i} + \sigma_1 u_{1i} && \text{(first selection rule of whether to report R\&D),} \\
y_{2i}^* &= \beta_2' x_{2i} + \sigma_2 u_{2i} && \text{(second selection rule of whether to patent), and} \\
y_{3i} &= \beta_3' x_{3i} + \sigma_3 u_{3i} && \text{(true regression equation of interest).}
\end{aligned}$$

For $k = 1, 2, 3$ and individual firm i , X_{ki} are vectors of explanatory variables and β_k are the corresponding coefficients of interest. σ_k are the unknown scale parameters and u_{ki} represent white noise. Thus,

$$E(y_{3i} | x_{1i}, x_{2i}, x_{3i}, y_{1i}, y_{2i}) = \beta_3' x_{3i} + \sigma_3 E(u_{3i} | x_{1i}, x_{2i}, x_{3i}, y_{1i}, y_{2i}).$$

As before, selection bias exists if $E(u_{3i} | x_{1i}, x_{2i}, x_{3i}, y_{1i}, y_{2i}) \neq 0$. To be consistent with the earlier representation of the selection dummy, we can indicate the outcome of the selection as follows:

$$\begin{aligned}
s_1 &= \begin{cases} 1 & \text{if } y_1^* > 0; \\ 0 & \text{if } y_1^* \leq 0. \end{cases} \\
s_2 &= \begin{cases} 1 & \text{if } y_2^* > 0; \\ 0 & \text{if } y_2^* \leq 0. \end{cases}
\end{aligned}$$

Because of the selection problem, the selection dummies determine the subsample.¹³ Intuitively, selection bias should be smaller when our subsample is only based on s_1 or alternatively, on s_2 . In contrast, we exacerbate the bias by selecting our sample based on the availability of both R&D expenses and patent data. Thus, using the popular measure of R&D efficiency, typically defined as the ratio of a patent variable to R&D expenses, intensifies the bias.

Consider the following:

$$E(y_{3i} | x_{1i}, x_{2i}, x_{3i}, s_1 = 1, s_2 = 1) = \beta_3' x_{3i} + \sigma_3 E(u_{3i} | x_{1i}, x_{2i}, x_{3i}, s_1 = 1, s_2 = 1).$$

In order to correct for the selection bias, $\sigma_3 E(u_{3i} | x_{1i}, x_{2i}, x_{3i}, s_1 = 1, s_2 = 1)$, one has to estimate β_1 , β_2 , and the covariance matrix of the error terms in the spirit of a Heckman two-stage procedure when innovation is the dependent variable or carry out multiple imputation when innovation is the explanatory variable (Rubin, 1987).

¹³ The selection described here is based on the dependent variable y ; however, the same issues arise when selection is based on the independent variables x .

Appendix 2. Monte Carlo Simulation

In this appendix, we investigate the properties of OLS estimators for various approaches of handling missing data, namely, listwise deletion, mean substitution, zero substitution, Heckman and multiple imputation, and the case of having the true complete data set based on simulated data.

As noted earlier in the paper, we are interested in estimating β_1 and β_2 in the regression: $E(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2$. We follow and are consistent with studies in missing data statistics literature in our simulation. We randomly generate 5,000 data sets with 2,000 observations from each of the data-generating processes. We generate five variables (Y, X_1, X_2, X_3, X_4) drawn from a multivariate normal distribution with mean 0 and variance 1. We add two instruments (X_5, X_6) to this data that are correlated only with X_2 and X_4 . The correlation matrix for the simulated data is:

$$\begin{matrix} 1 & -0.12 & -0.1 & -0.5 & 0.1 & 0 & 0 \\ -0.12 & 1 & 0.1 & -0.6 & 0.1 & 0 & 0 \\ -0.1 & 0.1 & 1 & -0.5 & 0.1 & 0 & 1 \\ -0.5 & -0.6 & -0.5 & 1 & 0.1 & 0 & 0 \\ 0.1 & 0.1 & 0.1 & 0.1 & 1 & 0 & 0.4 \end{matrix}$$

We consider two data-generating processes with missing data and the case with a complete data set. Of the processes with missing data, there is one case of *missing at random*, MAR, and one of *missing not at random* MNAR.

MAR: Y is MCAR; X_1 and X_2 are MAR with missingness determined by X_3 , which is completely observed. If u_{Yij} (different uniform random number from above) is smaller than 0.1, then Y is missing for row i for data set j , where $i = 1, \dots, 2000$ and $j = 1, \dots, 5000$. X_1 is missing if $X_3 < 0$ and $u_{x_3ij} > 0.65$ and X_2 is missing if $X_3 < 0$ and $u_{2ij} > 0.45$ (with a separate value of u). 40% of the observations are missing.

MNAR: Y is MCAR; X_1 and X_2 are MNAR with missingness determined by X_3 and X_2 . If $Y < -0.95$ the it is missing for row i for data set j , where $i = 1, \dots, 4000$ and $j = 1, \dots, 5000$. X_1 is missing if $X_3 < -0.52$ and X_2 is missing if $X_2 > 0.48$. About 40% of the observations are missing.¹⁴

For each of the 5,000 data sets and two data-generating processes, we estimate the regression coefficients, β_1 and β_2 , with missing data methodologies based on listwise deletion (LISTWISE), substitution of missing variables with the mean of the variables and with missing observation dummies in the regression (MEAN), substitution with zero and missing observation dummies in the regression (ZERO), multiple imputation based on MCMC (IMPUTE), and Heckman procedure for the missing not at random case (Heckman). The instruments for the Heckman model are X_5 and X_6 .¹⁵

¹⁴ We have tried different parameters and have generated different densities reaching very similar conclusion. For brevity, we do not report these results. They are available upon request.

¹⁵ See Schafer (1997) for the MCMC multiple imputation procedure, which utilizes the data augmentation algorithm developed by Tanner & Wong (1987).

We evaluate the performance for various missing data strategies using the coefficient bias for β_1 and β_2 . Figure 5 shows the bias for the regression coefficients β_1 and β_2 for the MAR (Panel A) and MNAR (Panel B).

Appendix 3

Table A1
WDI (World Development Indicators) Variables

Variables on the institutional factors come from the World Competitiveness Yearbook (WCY) compiled by IMD Business School.

Index	Description	Start	End
Skilled labor	Brain drain (well-educated and skilled people) does not hinder competitiveness in your economy (IMD WCY executive survey based on an index from 0 to 10)	1995	2014
Honesty	Bribing and corruption do not exist (IMD WCY executive survey based on an index from 0 to 10)	1995	2014
Regulator efficacy	Bureaucracy does not hinder business activity	1995	2014
Government subsidies (%)	To private and public companies as a percentage of GDP	1995	2013
Intellectual property rights	Intellectual property rights are adequately enforced (IMD WCY executive survey based on an index from 0 to 10)	1995	2014
University ties	Knowledge transfer is highly developed between companies and universities (IMD WCY executive survey based on an index from 0 to 10)	1995	2014
Labor regulations	Labor regulations (hiring/firing practices, minimum wages, etc.) do not hinder business activities (IMD WCY executive survey based on an index from 0 to 10)	1995	2014
Manufacturing intensity	Breakdown as a percentage of GDP	1995	2013
Economic openness	$(\text{Exports} + \text{Imports}) / (2 * \text{GDP})$	1995	2013

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Table A2
Correlations – Institutional Factors

This table shows the correlations (univariate in Panel A and multivariate in Panel B) between the ratio of “Missing R&D” to positive R&D firms and institutional factors and “Missing Patent” to positive R&D firms and institutional factors. We show the results with and without cross-listed firms included in the sample. Firms with positive patent activity that do not report R&D are classified as “Missing R&D” firms, and firms with non-USPTO patent applications and no USPTO applications are classified as “Missing Patent” firms.

Panel A. Univariate Correlation

Variables	Without cross-listed		With cross-listed	
	Missing R&D / Positive R&D	Missing Patent / Positive R&D	Missing R&D / Positive R&D	Missing Patent / Positive R&D
	(1)	(2)	(3)	(4)
Economic openness	-0.05	-0.05	-0.05	-0.05
Manufacturing intensity	0.13	0.12	0.13	0.14
Government subsidies	-0.10	-0.09	-0.10	-0.10
Labor regulations	-0.12	-0.12	-0.15	-0.15
Intellectual property rights	-0.15	-0.14	-0.15	-0.15
University ties	-0.08	-0.07	-0.15	-0.15
Skilled labor	-0.01	-0.01	-0.08	-0.08
Honesty	-0.10	-0.10	-0.14	-0.13
Regulatory efficacy	-0.07	-0.07	-0.13	-0.13
Commonwealth	-0.08	-0.08	-0.08	-0.08

Panel B. Multivariate Correlations (including ADR firms)

Dependent Variables: Variables	Missing R&D / Positive R&D		Missing Patent / Positive R&D	
	Coeff. (1)	p-val. (2)	Coeff. (3)	p-val. (4)
Intercept	0.2752	0.06	2.0073	0.02
Economic openness	-0.0002	0.57	0.0030	0.51
Manufacturing intensity	0.0125	0.00	0.1374	0.08
Government subsidies	0.0368	0.02	-0.4322	0.07
Labor regulations	-0.0393	0.00	-0.1042	0.50
Intellectual property rights	0.0229	0.40	-0.1674	0.56
University ties	-0.1446	0.00	-0.2596	0.23
Skilled labor	0.0477	0.00	-0.1984	0.60
Honesty	0.0409	0.01	0.1007	0.48
Regulatory efficacy	-0.0186	0.32	-0.1505	0.69
Commonwealth	-0.1904	0.00	-1.5680	0.08
Mean Dep. Var.		0.24		0.78
R ²		0.39		0.08
Obs. (Country-year)		334		356

Table A3
Relaxing Firm Constraints

This table replicates the results of Table 6 Panel A on the difference between the univariate comparisons of the sample data with the full and partial deletion sample. Panel A only includes countries with more than 1,000 listed firms in the sample, Panel B only firms from Industrial and Commercial Machinery (SIC 35) and Chemical and Allied Products (SIC 28) industries, and Panel C excludes small firms, i.e. firms that have total assets smaller than the 10th percentile of the total assets in the country sample.

Panel A. Countries with more than 1,000 listed firms

	Full	Partial	Full	Differences		
	Sample	Deletion	Deletion	(4) =	(5) =	(6) =
	(1)	(2)	(3)	$((1)-(2))/(1)$	$((1)-(3))/(1)$	$((3)-(2))/(1)$
Log(Total Assets)	6.92	7.54	7.46	-9%***	-8%***	-1%***
PPE	0.29	0.25	0.20	14%***	31%***	-17%***
Tobin's Q	1.29	1.37	1.88	-6%***	-46%***	40%***
Leverage	0.80	0.56	0.48	30%***	40%***	-10%***
Capital		0.05	0.05			
Expenditure	0.06			17%***	17%***	0%
ROA	0.01	0.00	-0.03	100%***	400%***	-300%***
Sales Growth	0.26	0.23	0.30	12%***	-15%***	27%***

Panel B. SIC 25 and 38 Industries

	Full	Partial	Full	Differences		
	Sample	Deletion	Deletion	(4) =	(5) =	(6) =
	(1)	(2)	(3)	$((1)-(2))/(1)$	$((1)-(3))/(1)$	$((3)-(2))/(1)$
Log(Total Assets)	5.76	5.92	6.17	-3%***	-7%***	4%***
PPE	0.19	0.17	0.16	11%***	16%***	-5%***
Tobin's Q	1.69	1.76	2.01	-4%**	-19%***	15%***
Leverage	0.56	0.53	0.40	5%	29%***	-23%**
Capital		0.04	0.04			
Expenditure	0.05			20%***	20%	0%
ROA	-0.02	-0.03	-0.02	-50%***	0%	-50%**
Sales Growth	0.26	0.25	0.25	4%	4%	0%

Panel C. Excluding small firms

	Full	Partial	Full	Differences		
	Sample	Deletion	Deletion	(4) =	(5) =	(6) =
	(1)	(2)	(3)	$((1)-(2))/(1)$	$((1)-(3))/(1)$	$((3)-(2))/(1)$
Log(Total Assets)	7.08	7.71	7.75	-9%***	-9%***	1%**
PPE	0.29	0.25	0.21	14%***	28%***	-14%***
Tobin's Q	1.57	1.47	1.78	6%	-13%***	20%***
Leverage	0.53	0.50	0.45	6%***	15%***	-9%***
Capital		0.05	0.05			
Expenditure	0.06			17%***	17%***	0%
ROA	0.03	0.03	0.01	0%	67%***	-67%***
Sales Growth	0.26	0.23	0.30	12%***	-15%***	27%***

Table A4
Alternative Treatments of Missing Innovation Measures – Industries

This table presents firm growth panel regressions for the period of 1999–2012 for industries 28 and 35. The dependent variable is three years' ahead sales growth. "Full Deletion" includes only observations where R&D is not missing and there are USPTO patents filed. "Partial Deletion" includes observations where either R&D is not missing or there are USPTO patents filed. "Zero" replaces all missing R&D and patents with zero. "Mean" replaces all missing R&D and patents with the country industry mean. "Heckman" uses a two-stage estimation procedure, where the lags of the other variables are used as instruments. "Multiple Imputation" is constructed by imputing all missing values using MCMC 100 times; using log(Total Assets), ROA, PPE, and leverage as conditioning variables; and then averaging across the 100 imputations (Schafer (1997)). Panel A presents the results with only firm characteristics as explanatory variables, Panel B presents the results with firm and country characteristics as explanatory variables. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The regressions include year, industry, and country fixed effects.

Panel A. Firm Characteristics

	DV = Sales Growth (t+3)					
	Full Deletion (1)	Partial Deletion (2)	Zero (3)	Mean (4)	Heckman (5)	Multiple Imputation (6)
<i>Firm controls:</i>						
Log(Total Assets)	-1.59**	-2.60***	-3.12***	-3.11***	-1.43***	-2.98***
ROA	-	-	-	-	-	-
Capital Expenditure	45.38***	-45.17***	-44.39***	44.46***	-30.35***	-45.10***
Leverage	-34.52	-4.36	-0.40	-0.46	-0.57	1.91
HH Index	-7.52***	-0.12	-0.07	-0.07	-5.17***	2.16***
R&D Dummy	-	-5.84	-6.07*	-6.07*	-7.39**	-5.77
Patent Dummy	-	-1.32	0.87	0.57	-	0.65
R&D	-	-4.28***	-4.19***	-4.30***	-	-4.45***
Patent App.	21.91***	3.85***	3.65***	3.64***	18.44***	-6.12***
Year FE	0.00	0.00	0.00	0.00	0.00	0.00
Industry FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
R ²	0.07	0.06	0.05	0.05	-	0.09
Obs.	7,510	24,443	37,716	37,716	19,432	38,278

Table A4 (cont'd)

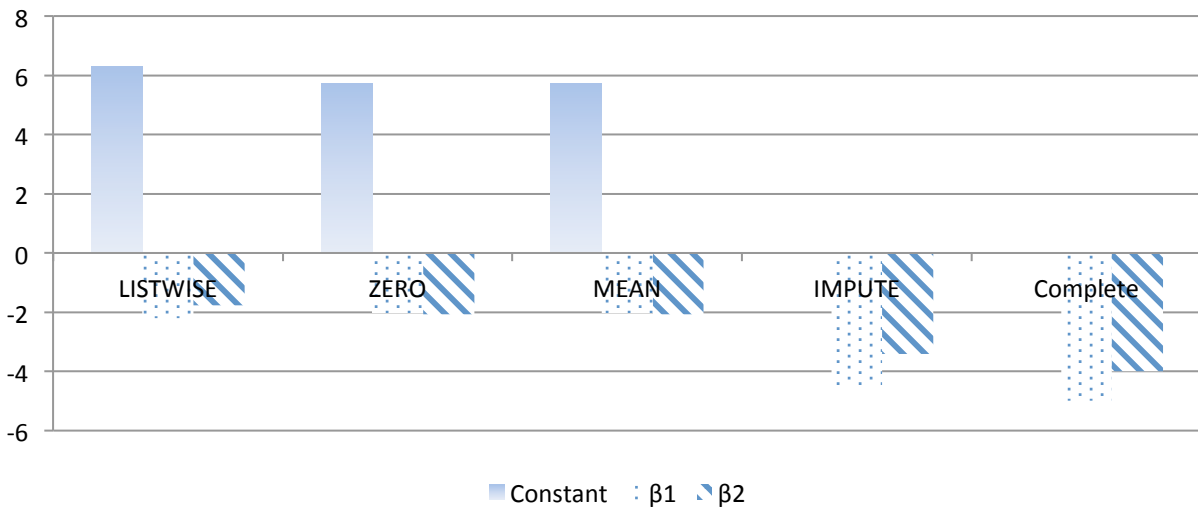
Panel B. Firm and Country Characteristics

	DV = Sales Growth (t+3)					
	Full Deletion (1)	Partial Deletion (2)	Zero (3)	Mean (4)	Heckman (5)	Multiple Imputation (6)
<i>Firm Controls:</i>						
Log(Total Assets)	-1.47*	-2.60***	-2.91***	-2.91***	-1.36***	-2.46***
ROA	-	-	-	-	-	-
Capital Expenditure	48.31***	-48.33***	46.40***	-46.49***	-33.12***	-41.47***
Leverage	-16.24	-5.35	-3.40	-3.48	-0.64	2.42
HH Index	-8.54***	-0.11	-0.14	-0.14	-5.37***	-1.25
	-6.79	-7.35	-9.26	-9.27**	-6.47*	-5.90
<i>Country Controls:</i>						
Economic openness	0.09	0.06	0.15	0.15	-2.29	0.13
Manufacturing intensity	0.21	0.34	-0.32	-0.33	-2.50*	0.08
Government subsidies	8.56	-1.25	-1.13	-1.13	4.55*	-1.01
Labor regulations	-3.25	-1.96	-1.61	-1.62	-2.84	-2.19*
Intellectual property rights	9.02	2.39	1.94	1.93	0.23	0.83
University ties	-4.03	-0.29	-0.77	-0.77	2.29*	-0.57
Skilled labor	-2.70	-3.78***	-2.66***	-2.64**	1.99	-1.68
Honesty	2.13	4.02***	3.59***	3.61***	8.26	2.83**
Regulatory efficacy	6.80	0.08	-0.11	-0.11		0.67
R&D Dummy		-2.12	0.76	0.41	-0.39	0.98
Patent Dummy		-4.28***	-4.00***	-4.09***	0.84	-3.74***
R&D	24.38***	3.79***	3.89***	3.87***	18.97***	6.21
Patent App.	0.00	0.00	0.00	0.00	0.00	0.00
Year FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
R ²	0.08	0.06	0.06	0.06	0.08	0.06
Obs.	6,873	22,411	29,736	29,736	18,485	30,437

Figure A1
Monte Carlo t-stat

This figure shows the t-statistics of the coefficients for the constant, X_1 , and X_2 under different approaches to dealing with missing data. LISTWISE deletes all rows with missing observations, ZERO replaces missing observations with zero, MEAN replaces missing observations with the sample mean, IMPUTE replaces missing observations with MCMC-imputed observations based on 100 imputations, and Heckman estimates the coefficients using two instruments. Complete comprises the simulated true non-missing observations, the benchmark case. Panel A presents the results for observations Missing at Random (MAR) and Panel B for observations Missing not at Random (MNAR). This simulation is described in Appendix 2.

Panel A. MAR



Panel B. MNAR

