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# Does Financial Innovation Lead to Technological Innovation? Evidence from Foreign Exchange Derivatives

By *Lora Dimitrova and Sapnoti K. Eswar*

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**WP Nº 25-010**

2nd Quarter 2025

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**Does Financial Innovation Lead to Technological Innovation?**
**Evidence from Foreign Exchange Derivatives***

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## Abstract

We investigate whether financial innovation, specifically the use of foreign exchange (FX) derivative products, spurs firms' technological innovation, measured with patent-based metrics. Using a quasi-exogenous shock that reduces the cost of using FX derivatives and varying FX equity exposure of firms, we find that increased utilization of FX derivatives results in higher patent production. The primary mechanism driving this relationship is the reduction in financial constraints and enhanced risk management. The effect is especially pronounced for firms facing difficulties in raising equity capital. Our results indicate that the use of FX derivatives boosts innovative output by improving firms' ability to raise equity capital, thereby increasing R&D investment, rather than by increasing risk-taking.

**Keywords:** Innovation, Exchange rate exposure, Currency derivatives, Risk management.

**JEL Classification Numbers:** G31, G32, O31.

Please visit link to Internet Appendix

*We thank Shashwat Alok, Jan Bena, Alex Borisov, Mike Eriksen, Michael Ferguson, Lei Gao, Dirk Jenter, Uday Rajan, Adriano Rampini, Farzad Saidi, Grzegorz Trojanowski and seminar participants at the 2023 Annual Workshop on Applied Economics, 2017 Summer Research Conference at ISB, 2017 International Risk Management Conference, 2017 European Financial Management Association, 2017 Securities Markets, Trends, Risks and Policies Conference at Bocconi University, 2017 Finance Forum, 2016 WFA-CFAR Conference at Olin Business School, 2016 European Summer Symposium in Financial Markets, SWUFE Research Workshop, and FMV Cluster Meeting for helpful comments and suggestions. We would also like to gratefully acknowledge the funding from Third Century Funding at the University of Cincinnati, The Lindner Research Excellence Committee, Public Policy Cluster at the University of Exeter and the Deloitte Institute of Innovation and Entrepreneurship at the London Business School. All errors are our own.

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Innovation is one of the most vital engines of economic growth, shaping the trajectory of industries and economies alike (Bloom and Van Reenen, 2002; Kogan et al., 2017). Over the past several decades, both financial and technological innovations have been pivotal in driving this growth. The significant expansion of the financial sector, in particular, has often been catalyzed by financial innovations born from technological advancements (Goldstein et al., 2019; Silber, 1983; Tufano, 2003). Conversely, financial innovations increase the efficiency of financial intermediation which in turn facilitates capital accumulation and investment in innovative projects.

This paper investigates the co-evolution of financial and technological innovation from a historical standpoint, focusing on the increased use of derivative contracts following a quasi-exogenous event in the derivatives markets in 1987 and its subsequent effect on technological innovation. Derivative contracts stand out as one of the most consequential financial innovations of recent decades. For example, the market for Foreign Exchange (FX) derivatives has exploded from $3 billion in 1983 to an astounding $118 trillion today. However, despite their widespread adoption, the critical question remains: have these financial innovations truly spurred economic growth?

Financial instruments like derivatives are designed to improve risk-sharing and better meet users' demands (Allen and Gale, 1994). We hypothesize that the enhanced market completeness following the standardization of financial derivatives, particularly through the International Swaps and Derivatives Association (ISDA) Master Agreement, would benefit firms by reducing cash flow volatility and fostering stability, which is essential for stimulating innovation (Brown et al., 2009). However, the flip side of this hypothesis is the potential for derivatives to encourage more speculative behavior, leading to increased risk-taking (Chernenko and Faulkender, 2011; Gennaioli et al., 2012; Simsek, 2013), which could hinder long-term economic growth.

Using a hand collected panel dataset of 1,432 U.S. non-financial firms, we explore whether the use of FX derivatives influences the quantity and quality of firms' technological innovations, measured by patent counts and cite-weighted patents, respectively. We focus on the period surrounding the introduction of the ISDA Master Agreement, a landmark event that standardized derivative contracts and significantly lowered transaction costs.[1,2] While many innovations have shaped financial markets, the establishment of the ISDA Master Agreement is arguably one of the most pivotal, impacting the vast over-the-counter (OTC) market and setting the standard for future derivatives contracts.[3]

Determining whether financial innovation drives technological innovation is challenging due to endogeneity–firms independently decide both to use financial derivatives and how much to invest in patent production. To address potential selection bias, we utilize two complementary identification strategies: a difference-in-differences (DID) approach and an instrumental variables (IV) method. The DID approach compares firms before and after the ISDA Master Agreement's introduction, distinguishing between those with higher and lower ex-ante currency hedging demand. Meanwhile, the IV method leverages both the ISDA Master Agreement and firms' ex-ante currency hedging demand to account for the non-randomness of FX derivatives usage.[4] We estimate ex-ante currency hedging demand by evaluating a firm's equity return exposure to foreign currency fluctuations prior to 1987, which serves as a proxy for hedging demand and likely correlates with subsequent currency derivatives use, independent of post-1987 innovation opportunities (Chernenko and Faulkender, 2011).

[1]Because of ISDA's Master agreement, the market for OTC derivatives has grown dramatically since the first "cross currency swap" was arranged in 1981 between IBM and the World Bank. Reports from the Bank for International Settlements show that the notional value of OTC derivatives contracts outstanding at the end of 2018 was $544 trillion, which was eight times greater than global output and 6.5 times larger than outstanding debt securities.

[2]See Flanagan (2001) for details related to agreements for OTC derivatives and the costs of drafting such agreements.

[3]"ISDA played a major role in the development and maturation of the OTC derivatives markets and continues to make important contributions through coordinating efforts to mitigate the legal risks, counter-party credit risks, and operational risks that use of these instruments entails." Alan Greenspan, Chairman (1987-2006), Federal Reserve.

[4]A shock-based IVs rely on a plausibly exogenous shock that divides the sample into treatment and control groups, providing a more robust foundation compared to non-shock IV designs (Atanasov and Black, 2017).

Our findings, which are robust across various specifications and controls, reveal that firms more likely to use FX derivatives also tend to be more innovative, both in terms of the quantity and quality of their technological outputs. One concern with our DID approach is that omitted (or unobservable) firm characteristics can be correlated with ex-ante hedging demand and innovation outcomes. For instance, the positive correlation between firm size and derivatives use is well-documented (Rampini et al., 2014), as is the tendency for larger firms to achieve greater patenting success (Acs and Audretsch, 1987; Amore et al., 2013). Additionally, prior research highlights the impact of access to banks on innovation (Amore et al., 2013; Cornaggia et al., 2015). In that case, such characteristics can be driving our result. We implement a propensity score matching approach to address this concern. Firms are matched based on several characteristics, including sales, leverage, profitability, tangibility, age, and industry characteristics. Using nearest-neighbor matching methods, we pair each firm with high ex-ante currency hedging demand (treated firm) with a firm that has low ex-ante currency hedging demand (control firm). We then re-estimate our DID specifications using this matched sample and find statistically similar results. Thus, our main findings remain robust even after accounting for differences in firm and industry characteristics.

In our analysis, treated firms are characterized by importer-type cash flows, while control firms exhibit exporter-type cash flows or have marginal exposure to foreign exchange. One consideration is that our specification might be capturing differences between importing and non-importing firms. Exporters often experience productivity gains through interactions with international partners and consumers (Salomon and Shaver, 2005), leading to increased patenting activity in their domestic markets. If exporting firms in our sample experience heightened learning and productivity, this could dilute our findings, as these exporters are included in the control group. We believe our results represent a lower bound on the true effect of financial innovation on technological innovation.

Our DID approach relies on the assumption of exogeneity regarding the shock, specifically the implementation of the ISDA Master Agreement. If market participants had anticipated this shock, they may have adjusted their risk management or innovation strategies, thereby violating the exogeneity assumption. To address this, we conduct two analyses: first, we examine the timing of events leading to the release of the ISDA Master Agreement, and second, we empirically test for innovation trends around 1987. The timing of these events suggests that most market participants were likely unaware of the forthcoming ISDA Master Agreement (Flanagan, 2001). Further, focusing on the period around 1987, when the ISDA Master Agreement was introduced, we find no significant pre-trends in innovation. This lack of pre-trend is reassuring, indicating that firms in our sample were not altering their innovation outcomes prior to the agreement. We do observe a notable impact starting in the third year after 1987. This delay aligns with the typical 2-3 year lag between investment and innovation (Hall et al., 2001).

We also test alternative specifications, including different FX indices for measuring exposure and log and inverse hyperbolic sine transformations of the dependent variable. Additionally, we analyze sub-samples of firms with varying numbers of patents and data from 1977 to 1997, applying different clustering methods and incorporating firm and state-level controls to account for economic changes influencing innovation.

Finally, we delve into the mechanisms through which financial innovation drives technological innovation, with a particular emphasis on risk management. Our findings reveal that the impact of derivatives usage is more pronounced among firms that were financially constrained prior to the shock, especially those facing significant equity constraints. These constraints often arise from informational asymmetries, while debt constraints typically result from covenant violations (Hoberg and Maksimovic, 2015). Firms with equity financing constraints are more susceptible to "equity rationing" and may underinvest in R&D during periods of negative cash flow (Krasker, 1986). Such constraints are frequently linked to growth opportunities. Consistent with this, we find that firms with high growth opportunities or significant information asymmetry exhibit a stronger relationship between derivatives use and innovation.

Additional analyses further support the risk management mechanism. We show that after adopting FX derivatives, firms are better able to alleviate financial constraints (Froot et al., 1993) and enhance their debt capacities (Smith and Stulz, 1985). This improved financial flexibility allows firms to increase their R&D investments, thereby driving greater innovation output.

While our findings support the hypothesis that FX derivatives foster innovation by easing financial constraints through risk management, they also suggest an alternative mechanism. Specifically, derivatives use may boost innovation by encouraging risk-taking in the innovation process, rather than simply increasing R&D investment. To explore this, we conducted several tests. Despite the potential for derivatives to facilitate riskier experimentation, we observed no significant shift from low-risk, incremental innovations to high-risk, radical innovations after adoption. This challenges the risk-taking hypothesis, suggesting that firms are more likely to enhance investments in low-risk areas, resulting in more incremental rather than exploratory innovations.

This paper makes two contributions. First, by focusing on another aspect of growth, innovation, the paper adds to the literature on the real effects of hedging and derivatives use. A significant body of empirical literature studies how firms use derivatives.[5] A number of papers provide evidence that firms, using derivatives to hedge specific exposures, benefit by reducing future constraints on profitable investment opportunities.[6] However, there is limited research on the role that financial derivatives play in the patent production process. Our results suggest that firms use financial derivatives to minimize

[5]Examples include broad cross-sectional analyses (Allayannis and Ofek, 2001; Bartram et al., 2011; Bretscher et al., 2018; Geczy et al., 1997; Graham and Smith, 1999; Mian, 1996), as well as specific industries such as gold mining (Tufano, 1996) and the oil and gas industry (Doshi et al., 2017; Jin and Jorion, 2006).

[6]Perez-Gonzales and Yun (2013) document that energy utilities are able to use weather derivatives to reduce distortions in future investments. Campello et al. (2011) find that hedgers pay lower interest rate spreads and are less likely to face restrictions on capital expenditures. Hottenrott and Peters (2012) document that when financial constraints are reduced, firms invest more in R&D.

cash flow volatility, allowing them to invest more in innovative projects. These findings enhance our understanding of the relationship between financial innovation and economic growth.

Second, this paper contributes to the literature on finance and innovation, which examines how various market characteristics–such as banking deregulation, bankruptcy laws, labor laws, competition, credit markets, banking relationships, and liquid options markets–affect innovation.[7] We extend this literature by providing evidence that financial innovation, specifically through the use of financial derivatives, can enhance firms' real innovation.

## 1. Over-the-Counter Financial Derivatives

Derivatives markets exist because of high trading (or other related) costs or trading restrictions in the market for the underlying asset. In contrast to exchange-traded contracts, which are standardized contracts executed over an exchange such as the Chicago Mercantile Exchange, OTC derivative contracts are privately negotiated contracts between two parties. The main advantage of OTC contracts is the flexibility in designing the contract, the main disadvantages are (1) both the buyer and the seller must spend time and effort in identifying each other, and (2) counterparty credit risk. In order to deal with these disadvantages, derivatives trades from the late 1800s to the early 1980s were mostly carried out on organized exchanges. The growth of the OTC derivatives market began in the 1980s with the formation of the International Swaps and Derivatives Association (originally the International Swaps Dealers Association).

The 1987 ISDA Master Agreement changed the ease of entering into and executing OTC transactions, which brought about a surge in the market for OTC derivatives. By

[7] Bloom et al. (2016), Cornaggia et al. (2015), Amore et al. (2013), Acharya and Subramanian (2009), Berkowitz and White (2004), Acharya et al. (2013), Saint-Paul (2002), Samaniego (2006), Aghion et al. (2005), and Blanco and Wehrheim (2017).

June 2000 early reports by the Bank for International Settlements show that the notional amount of OTC contracts outstanding reached $94.04 trillion, which represented close to 87% of the gross notional amount of all derivatives contracts. The top panel of Figure 1 shows the volume of OTC FX derivatives and interest rate derivatives outstanding in each year.

INSERT Figure 1 ABOUT HERE

ISDA began as an informal swap documentation project undertaken by eleven financial institutions in 1984. An initial attempt to draft a standard agreement in the same year failed.[8] After the initial failure the group focused on developing standard definitions for terms commonly used in swap agreements. When the definitions were finalized the group of financial institutions created ISDA as an entity to release the definitions document and hold the copyright. The initial drafting of definitions was done by ISDA members based in New York who continued to publish new and updated definitions until early 1987.[9] In 1987 ISDA members based in London started working on a standard agreement. Most of the members in New York were not part of this exercise. In the spring of 1987 the Master Agreement was released. Given the recent failure to draft a common agreement and the unresolved disagreement across members in New York, the release of the Master Agreement came as a surprise to most members.

The ISDA Master Agreement set up the terms (representations and warranties, obligations, definitions, events of default, among others) that parties now include in any derivatives contract. In addition, the ISDA Master Agreement allowed for netting payments among all transactions made under the agreement between the parties (called

[8]See Flanagan (2001) for details on the issue related to the drafting failure. The author documents facts based on interviews with lawyers from Cravath, Swaine and Moore, who were and continue to be ISDA's primary United States counsel.

[9]In the early years of ISDA, membership in the organization was limited to swaps dealers only. The membership was expanded to include law firms, accounting firms, and end-users of derivatives only in later years.

"cross-transaction payment netting") thus reducing transaction costs by incorporating numerous swap payments into a single payment. Overall, the ISDA Master Agreement brought many benefits to parties using currency derivatives including a reduction in transaction costs, lower legal fees, less legal risk, and reduced default risk.[10]

The implementation of the ISDA Master Agreement represents a negative shock to the cost of using OTC FX derivatives[11], and, therefore, we expect firms with larger ex-ante exposure to foreign currency fluctuations to be more likely to use FX derivatives.

## 2. Data

This section, first, outlines the data sources used for the analysis. Next, it provides summary statistics from the data.

### *2.1. Construction of Variables*

Our data set is constructed from several data sources combining information on patent data, firms' use of financial derivatives and other firm characteristics. The patent data comes from Google patents database, which holds the entire history of patents awarded by the U.S. Patent and Trademark Office (USPTO) representing a total of 7.8 million patents. We start with the sample to firms in the Kogan et al. (2017) database, who match patents with firm identifiers.[12] We combine this dataset with firm financial information using the CRSP-Compustat Merged database on WRDS. We focus on granted patents applied for beginning in the year 1977, which results in observations 10 years

[10] "The transaction costs are reduced because the parties as a whole make fewer payments. The legal fees are lower because there is less drafting and consequently fewer reviews of contracts. The legal risk is less because the contract forms are carefully drafted and updated in response to litigation and regulatory developments. The default risk is reduced because of close-out netting." Flanagan S., 2001, Harvard Negotiation Law Review.

[11] The 1987 ISDA Master Agreement was applicable to FX and interest rate derivatives contracts. In this paper, we focus on FX derivatives. We conduct several robustness tests to account for the fact that interest rate derivatives were also included as a part of the same Master Agreement

[12] Kogan et al. (2017) have matched the patents in the Google patents database to U.S. firms in the CRSP database. We thank the authors for assembling the data and making it available to us.

before the ISDA Master Agreement was released. The sample ends in the year 2007. We exclude firms with negative or zero book values, financial firms (SIC codes between 6000 and 6799), and utility firms (SIC codes between 4900 and 4949). We arrive at a total of 31,546 firm-year observations.

We use patent count to proxy for a firm's innovative activity. Specifically, the measure of innovative output is a count of granted patents for each firm applied for in each year, *Pat*. However, patent counts cannot distinguish between breakthrough innovation and incremental discoveries (e.g., Griliches, 1990). To assess patent quality, we use citation-weighted patent counts, a well-regarded measure of the value of innovative output. Citation-weighted patents serve as an effective indicator of both innovation quality and economic significance (Hall et al., 2005).

To proxy for financial innovation adoption, we create an indicator variable that captures a firm's FX derivatives usage. We hand-collect data on FX derivatives usage for all U.S. firms in the database. We focus on FX derivatives, one of the categories of derivatives covered under the 1987 ISDA Master Agreement. Specifically, we use Securities and Exchange Commission (SEC) filings on EDGAR and LexisNexis Academic application, with a list of keywords to identify firms that relied on FX derivatives in the 1985-1997 period. We use a set of phrases to check for usage - "hedge", "exchange contract", "forward exchange contract", "forward exchange agreement", "foreign currency option", "foreign currency swap", and "notional". We manually review the relevant sections of each 10-K form to verify if the firm uses FX derivatives during the fiscal year. We then use an indicator variable that is set to one if the firm is classified as an FX derivatives user for that year, and zero otherwise.

To estimate the cross-sectional ex-ante demand for foreign currency hedging we use the pre-1987 exposure of firm equity returns to foreign currency fluctuations. That is, we capture the sensitivity of equity returns to changes in an index of foreign currencies by estimating a beta of the changes in the firm's equity returns to the changes in the average value of foreign currencies. More specifically, we follow Adler and Dumas (1984) and define the exposure of a firm's equity to FX fluctuations as the change in the market value of a firm from a unit change in the exchange rate (Allaayannis and Ofek, 2001; Bodnar and Gentry, 1993; Choi and Prasad, 1995; Jorion, 1990; 1991; Krapl, 2017; Williamson, 2001; and Wong, 2000). We estimate the following specification for each firm using monthly returns for the years before 1987.

$$\begin{aligned} R_{i,t} = \alpha_i + \beta_i^{OITP} \cdot R_t^{OITP} + \beta_{i,MCI} \cdot R_t^{MCI} + \beta_{i,M} \cdot R_t^M \\ + \delta_{1,i} \cdot R_t^{ST} + \delta_{2,i} \cdot R_t^{DS} + \epsilon_{i,t} \end{aligned} \tag{1}$$

where, $R_{i,t}$ is the monthly equity returns of a firm $i$ in month $t$, $R^{OITP}$ and $R^{MCI}$ are the inflation-adjusted monthly returns of the emerging and developed market currency indices respectively, $R^M$ is the value-weighted market portfolio, $R^{ST}$ and $R^{DS}$ are short-term interest rate and term spread variables.

Equation (1) uses two foreign-exchange indices and three control variables. A popular choice among studies is to include two foreign exchange indices, the Major Trading Partner Currency Index (MCI) and the Other Important Trading Partners Index (OITP) as reported by the Federal Reserve Board (Carrieri et al., 2006; Chaieb and Mazzotta, 2013).[13] The indices are expressed as a foreign currency weighted average value of the U.S. dollar and, therefore, by definition, an increase in the index corresponds to a real appreciation of the U.S. dollar. We include returns on the market portfolio as a control variable. This variable plays an important role in ensuring that the estimated expo-

[13]The Major Trading Partner Currency Index (MCI) includes sixteen widely traded currencies including all currencies of E.U. member countries (before 1999 and the euro after 1999), Japanese Yen, British pound, Swiss franc, Australian dollar, and the Swedish krona. The Other Important Trading Partners Currency Index (OITP) are mainly emerging market currencies. The other important trading partners include Mexico, China, Taiwan, Korea, Singapore, Hong Kong, Malaysia, Brazil, Thailand, Philippines, Indonesia, India, Israel, Saudi Arabia, Russia, Argentina, Venezuela, Chile and Colombia. We follow the convention used in the literature and express the returns as percentage changes in the value of the foreign currency baskets. Thus a positive (negative) coefficient indicates that equity returns increase (decrease) with the value of the U.S. dollar.

sures of equity returns to foreign exchange, are not unduly influenced by macro-economic events, especially over the short horizon of one month (Bodnar and Wong, 2003). We also include two interest-rate based macroeconomic control variables, $R^{ST}$ and $R^{DS}$, the short-term interest rate and long-term spread respectively (Adler and Dumas, 1984; Bartram, 2008). The short-term interest rate is defined as $R_t^{ST} = \frac{\Delta SR}{1+LR}$ and the long-term spread is defined as $R_t^{DS} = \frac{\Delta(LR-SR)}{1+LR}$, where $\Delta$ denotes a one-period change, $SR$ is the short rate (1-year U.S. Treasury Yield), and $LR$ is the long rate (10-year U.S. Treasury Yield).

The estimated coefficient, $\beta^{OITP}$ captures the sensitivity of equity returns to changes in the value of a basket of emerging market currencies. This is our measure for the exposure of a firm's equity to foreign exchange fluctuations or FX equity exposure. Existing studies document that FX equity exposure of U.S. firms is larger for emerging market currencies than developed market currencies (Koutmos and Martin, 2003; Krapl, 2017; Muller and Verschoor, 2006). A potential explanation is that U.S. firms can change their import/export activity more easily in developed countries than in emerging markets. This form of operational hedging can lead to a measurement error in FX equity exposures. To address this concern, we use FX equity exposures to emerging market currencies as our main measure of FX equity exposure where this form of operational hedging is less likely.[14] Although, using FX equity exposures to emerging market currencies does not eliminate the concern, we believe that using these exposures represents a more robust measure of FX exposure.

In the empirical specification, we follow Hall and Ziedonis (2001) among others and include firm's sales to control for firm size; profitability to control for the role of internal resources of financing; book leverage, and asset tangibility to control for existing dependence and access to bank credit. Following Aghion et al. (2005), we control for industry

[14] In robustness tests, we use FX equity exposures to developed market currencies as the measure for FX exposure and obtain qualitatively similar results.

concentration using the Herfindahl index (HI) constructed at the 4-digit SIC level. We include a variable that captures the number of years since the firm's IPO (as reported in CRSP) to control for a firm's age. In robustness checks, we also include the squared Herfindahl index to control for non-linear effects of industry concentration (Aghion et al., 2005; Hashmi, 2013; Igami and Uetake, 2019). All control variables are lagged by one-year to reduce simultaneity concerns. All continuous variables are winsorized at the 1st and the 99th percentiles to remove the influence of extreme outliers. Variable definitions are summarized in Table 1.

INSERT Table 1 ABOUT HERE

*2.2. Descriptive Statistics*

Table 2, Panel A reports the summary statistics of the variables used in the analysis.

INSERT Table 2 ABOUT HERE

The average (median) firm in the sample has total assets of $285 ($260) million, which translates to natural logarithm of assets of 5.654 (5.561). The average (median) revenue is $342 ($333) million, which translates into natural logarithm of sales of 5.836 (5.810). The mean (median) book leverage of firms in the sample is 0.248 (0.226). The mean (median) profitability of firms in the sample is 0.133 (0.139). Mean (median) tangibility ratio is 0.315 (0.283). The average (median) Herfindahl index is around 0.269 (0.222). The median firm in the sample has been in the CRSP-Compustat database for around 28 years, while 53.6% of observations in the sample are of years in which firms generated some revenue from exporting activities.

Table 2, Panel B reports innovation measures, and other variables. The average patent count for a firm in the sample is 15.08 patents. We also report the number of citation-weighted patents, using the number of citations a patent receives as weights and calculating the weighted average number of patents granted in the same year (Hall et al., 2005). The average number of citation-weighted patents in the sample is 15.42. The average R&D for a firm is $68.399 million. We use an indicator variable to classify firms as currency or FX derivatives users whenever the SEC filings describe such contracts. FX derivatives are used, on average, in 11.4% of firm-year observations. The derivatives usage statistics we document are in line with the literature.[15]

We calculate firm-level FX equity exposure, by regressing firm equity returns on the average trade-weighted emerging markets foreign currency index for the years before 1987. We use an indicator for firms which have significantly positive FX equity exposure, *High FX exposure*, to capture high exposure to foreign currency fluctuations. 30.6% of firm-year observations in our sample have a high FX exposure.

## 3. Identification Strategy and Results

A naïve regression to document the correlation between FX derivatives usage and innovation output can take the following form:

$$Y_{i,(t+1)} = \beta_1 \cdot FX\ Derivatives_{i,t} + \beta_X \cdot X_{i,t} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{2}$$

where, subscripts $i$, and $t$ denote firm and year respectively. The dependent variable, $Y_{i,(t+1)}$ is the measure of innovative activity for firm i, in year $t+1$ and *FX Derivatives* indicates whether the firm uses FX derivatives in the current year.

If FX Derivatives use was independent of other firm choices or characteristics, the OLS based measure of $\beta_1$ (Equation 2) would be an unbiased estimator of the effect of FX Derivatives use on innovation. However, the decision to use financial derivatives is not independent of other firm characteristics. While we can include a variety of independent control variables in a regression specification, the concern remains that unobserved firm

[15]Perez-Gonzalez and Yun (2013) find that 25 percent of their sample firms use weather derivatives. Chernenko and Faulkender (2011) find that 26.6 to 55.6 percent of firms use derivatives.

characteristics can be driving the result. As the decision to use derivatives is endogenous, the OLS based measure of the coefficient $\beta_1$ is likely to be biased. Therefore, to tease out the causal impact of FX derivatives usage on innovation we use a DID and IV identification strategies.

### *3.1. Methodology and Difference-in-Differences Results*

Our identification strategies use both time-series and cross-sectional variation in FX derivatives usage to overcome endogeneity concerns. In the time-series we use the introduction of the ISDA Master Agreement in 1987 as an exogenous shock to the market of financial innovation. The ISDA Master Agreement introduction arguably led to an exogenous change in the time-series variation in the costs of transferring currency risks. For the ISDA agreement time series instrument to be valid, it must affect derivatives usage. The bottom panel of Figure 1, shows the significant increase in OTC FX derivatives use after the shock, for the firms in the sample.

In contrast, the market for exchange-traded derivatives, an alternative to OTC derivatives, has remained relatively small. Despite years of growth, the Bank for International Settlements reported that in 1998, exchange-traded FX derivatives constituted only 0.45% of the total notional amount of FX derivatives outstanding globally.

Although, the bottom panel of Figure 1 does not provide causal evidence of the effect of the introduction of the ISDA Master Agreement on FX derivatives usage, it provides anecdotal evidence in favour of our argument. In further sections, we use several econometric techniques to provide more robust evidence of the direct effect of the ISDA Master Agreement introduction on FX derivatives usage.

In the DID strategy, the first difference compares the years before and after 1987, while the second difference leverages cross-sectional variation in firms' exposure to currency fluctuations. We anticipate that latent demand for FX derivatives will vary across firms based on their exposure to FX fluctuations. Specifically, when the ISDA agreement reduces the costs of using FX derivatives, some firms will be more likely to adopt these contracts than others. We argue that the pre-1987 cross-sectional differences in latent demand for FX derivatives are exogenous to a firm's patent production after 1987.

Because all of the models will include firm fixed effects the assumption is even more narrowly defined. The assumption is that the pre-1987 cross-sectional heterogeneity in latent demand for FX derivatives is exogenous with respect to changes in a firm's post-1987 patent production, other than through FX derivatives usage.

Importantly, we evaluate each firm's FX exposure pre-1987, so that it cannot be affected by the ISDA agreement itself. Before performing the DID analysis we measure firms' exposure to foreign currencies. We regress firm equity returns on changes in the value of a foreign currency index for emerging market currencies using monthly returns for all months before 1987, as shown in Equation 1, to estimate the coefficient, $\beta^{OITP}$, which captures the sensitivity of equity returns to fluctuations of emerging market currencies. We argue that firms with positive and significant betas, $\beta^{OITP}$, are more likely to use derivatives after the 1987 shock. This choice is on account of two key factors influencing foreign exchange markets. The first reason is a key event of FX markets in 1985, The Plaza Accord, which led to a significant and sustained depreciation of the U.S. dollar (Frankel, 2015). The second related fact is the asymmetric behaviour of firms related to hedging activities, i.e., firms are more likely to time their hedges to offset losses and not hedge operational profits (Bodnar et al., 1998).

The Plaza Accord was the largest foreign currency intervention where U.S. officials and their counterparts among the Group of Five largest industrialized countries acted to bring down the value of the dollar (Frankel, 2015).[16] Figure 2 shows the value of two foreign exchange indexes, the Major Currency Index (MCI) and the Other Important Trading Partners Index (OITP) which measure the value of the dollar based on a trade-

[16]The Group of Five included France, West Germany, Japan, United Kingdom and the United States.

weighted basket of currencies. The figure shows the steady decline of the U.S. dollar beginning in 1985.

INSERT Figure 2 ABOUT HERE

The second reason is the asymmetric behavior of firms for hedging. Existing literature documents that firms are likely to be selective in their hedging practices. In a survey, Bodnar et al. (1998) find that 50% of firms alter the timing and size of their FX hedges to incorporate their market view. In the case of a U.S. importer, this firm will receive less cash flows as the dollar depreciates as prices are usually fixed in local (or international) currency which increases in value with dollar depreciation. Thus, a manager would hedge against expected dollar depreciation but is likely to leave the company exposed to expected increases in the value of the U.S. dollar. Although little is documented about the success of such selective hedging strategies, the presence of these strategies is key to our identification strategy (Krapl, 2017).

We argue that firms with positive and significant betas, $\beta^{OITP}$, are more likely to use derivatives soon after the 1987 shock. Firms with positive betas are more likely to experience negative equity returns as the U.S. dollar depreciates after the Plaza Accord. Firms with negative, significant betas are more likely to experience positive equity returns with U.S. dollar devaluation and not demand hedging products due to asymmetric hedging behaviour. In our specification, we indicate firms with high FX exposure as those which have positive and significant betas.

Next, we estimate the following DID equation.

$$Y_{i,(t+1)} = \beta_1 \cdot High\ FX\ Exposure_i \cdot Post_t + \beta_X \cdot X_{i,t} + \gamma_i + \theta_t + \epsilon_{i,t} \qquad (3)$$

where $High\ FX\ Exposure_i$ is an indicator variable which takes the value one if a firm has a positive and significant value for its FX equity exposure, or $\beta^{OITP}$ and $Post_t$ denotes the time series shock to currency hedging costs. Conceptually, firms with a high FX exposure represent the treatment group while firms with a low or insignificant FX exposures represent the control group. $Post_t$ takes the value one for all years after 1987 and zero otherwise. In a DID setup it is common to also include separately the individual variables that go into the interaction term. However, $High\ FX\ Exposure_i$ is time invariant and so on its own is soaked up by the firm fixed effect, and $Post_t$ is firm invariant and so is soaked up by the year fixed effect.

To estimate the model we use an OLS specification, where the dependent variable, $Y_{i,(t+1)}$ is the likelihood of FX derivatives usage, $FX\ Derivatives$. In further specifications, we use measures of innovative activity as dependent variables. The variable, $FX\ Derivatives_{i,t}$ is an indicator variable that takes the value one if firm $i$ reports using currency derivatives in year $t$ and zero otherwise; $X_{i,t}$ is the vector of firm characteristics which includes: Ln(Sales), Book Leverage, Profitability, Tangibility, the Herfindahl index, Herfindahl index squared, Ln(Age), and two indicator variables, one for inter-state and the second for intra-state banking deregulation; $\gamma_i$ and $\theta_t$ are firm and year fixed effects.[17] To avoid potential biases in the estimation of standard errors due to serial correlation we cluster standard errors at the 2-digit SIC industry level, which allows for an arbitrary covariance structure within an industry over time.[18]

The measure of innovative activity for firm $i$, in year $t+1$ is $LnPat_{i,(t+1)}$ or the natural logarithm of (1 + number of granted patents). More specifically, we are measuring the number of new patents applied for in year $t + 1$ and eventually granted. Note that while old patents have more time to accumulate citations than do newer patents, the specification's inclusion of year fixed effects soaks up the heterogeneity driven by patent age. To measure the quality of patents, we follow the literature and use $LnCwPat_{i,(t+1)}$,

[17] Changes in banking regulation: inter-state banking regulation (Black and Strahan, 2002), and intra-state banking regulation (Jayaratne and Strahan, 1992), have been found to have an effect on firm's quantity and quality of innovation.

[18] In robustness tests, we consider additional standard error clustering techniques to handle any latent autocorrelation.

which is the natural logarithm of (1 + citation-weighted patent counts) (Hall et al., 2005).

Table 3 shows the results of the DID specification.

INSERT Table 3 ABOUT HERE

The table reports two specifications for each dependent variable. Specifications in columns (1) and (2) use the indicator for FX derivatives use, *FX Derivatives*, as the dependent variable. The coefficient of the main variable of interest, *High FX Exposure* · *Post*, is positive and significant at the 1% level. This result implies that firms with high FX equity exposures pre-1987 are 3.2% more likely to use derivatives in the years after 1987. Given the average FX derivatives usage in our sample of 11.4%, this increase represents a sizeable increase of 28% in derivatives use for firms in the sample.

Columns (3) to (4) use patents as the dependent variable. The coefficient of the main variable of interest, *High FX Exposure* · *Post*, is positive and significant at the 5% level. This result implies that firms with high FX equity exposures have more patents a year after the year of derivatives use. In terms of economic magnitude, a year after the year of derivatives use, treated firms file for 8% higher number of patents.[19]

Consistent with the literature, we find that larger firms are more innovative (Mukherjee et al., 2017). We also find that more leveraged firms produce less innovation. Firm age is positively related to innovation which implies that older firms are more likely to innovate. Finally, we find that tangibility and the Herfindahl index have a statistically insignificant impact on innovation.

Columns (5) to (6) report that firms with higher FX equity exposures have more citation-weighted patents a year after the current year. The coefficient estimate of *High*

[19]The main paper reports on patents, but the main input to patent production is investment in R&D. For validity, we re-estimate the DID specification but replace the dependent variable with the natural logarithm of $(1 + R\&D)_{i,t}$ where, R&D represents the research and development expenses by firm $i$ in year $t$. The coefficient estimates for the first through fourth year are positive and statistically significant. These results suggest that firms invest more in innovative projects after derivatives use. Such increase in investment in R&D is consistent with firms using FX derivatives increasing their patent production.

*FX Exposure* · *Post* is significant at the 5% level. These results suggest that firms that are more likely to use derivatives, those that were more exposed to foreign currency changes pre-1987, produce more valuable innovation in the years after the introduction of the ISDA master agreement.

### *3.2. Dynamic Analysis of Regression Results*

One potential concern with our empirical strategy is that treated and control firms differ on observable dimensions. This difference may raise concerns of endogeneity in the empirical analysis given the possibility that these firms may also differ on unobservable dimensions in a way that violates the parallel trends assumption. These concerns are mitigated using two analyses. First, we provide a dynamic analysis of the regression coefficients to show that the treatment and control firms during the pre-treatment period seem to show parallel trends. Second, we provide a propensity score matching approach as a more formal test.

A standard method of checking for time series trends is to examine regression results that allow for a dynamic estimation of the variables of interest over time (Bertrand and Mullainathan, 2001; 2003). We want to verify that there is no common time trend in which the coefficients are drifting in one direction over the entire sample. In our setting we hope to observe the coefficients of interest being near zero before the ISDA Master Agreement year, 1987, and positive afterward. We re-estimate the DID specification (Equation 3) replacing the *Post* variable in the interaction term with separate indicator variables for each year. The dependent variable is $LnPat_{i,t+1}$, or the natural logarithm of (1 + number of patents in the year after the current year). Figure 3 reports the coefficient on each year's indicator variable interacted with the variable, *High FX Exposure* in addition to the 95% confidence interval of the coefficients when using patents as the dependent variable.

INSERT Figure 3 ABOUT HERE

Reassuringly, the figure indicates an absence of a trend before 1987, with nearly all coefficients lacking statistical significance. However, this changes post-1987. After 1987, firms with greater FX equity exposure are more likely to apply for and successfully obtain patents.

The relationship between FX derivatives use and patenting shows up in the third year after ISDA Master Agreement implementation. This is exactly what we would expect to find given the large time gap between investment and successful innovation. Innovation is generally thought to be a time-consuming project. When a firm hedges with derivatives, some of its existing projects generate more stable cash flows. This increased stability can lead the firm to shift internal funds to innovative projects.

In the bottom panel, we report dynamic effects of foreign exchange exposure on cite-weighted patents around the event year, 1987. We estimate the DID equation where the dependent variable is $LnCwPat_{i,(t+1)}$, or the natural logarithm of (1 + cite-weighted patents). The regression specification is the same as that in equation Equation 3 except that the variable, *High FX Exposure* is interacted with a series of year indicator variables instead of the variable *Post*.

This figure provides insights into differences in cite-weighted patents between the treatment and control groups around the event year. It suggests the absence of a trend before 1987. In particular, the level of cite-weighted patents granted to high FX equity exposure firms is no different than the level of cite-weighted patents granted to low FX equity exposure firms. The figure also suggests a short lag between the 1987 ISDA Master Agreement introduction and a statistically significant increase in patent quality by high exposure firms. The statistically significant increase in patent quality occurs three years after 1987. These figures provide support that the results are not driven by a general latent time trend.

### *3.3. Propensity Score Matching and Matched Sample Results*

A potential issue with the DID analysis could arise if the treated and control firms differ in their observable characteristics. If that is the case the regression-based analysis is likely to provide an inaccurate estimate of the effect of derivatives use on firms' innovative activity. To address the concern and provide greater balance between the treatment and the control groups, we undertake a propensity score matching approach. We implement a nearest-neighbor matching approach based on Rosenbaum and Rubin (1983) to ensure internal validity of the specification. The propensity scores are based on a probit regression at the firm level with the dependent variable, *High FX Exposure*, which takes the value of one if the firm has a positive and significant FX equity exposure measure, and zero otherwise. The probit model includes all control variables from the DID specification (Equation 3), measured in the year immediately preceding the year of release of the ISDA Master Agreement. We match on the following variables in the year 1986: Ln(Sales), Book Leverage, Profitability, Tangibility, Herfindahl, and Ln(Age). To address the varying propensities for innovation across industries, we match within industries by including 2-digit SIC industry fixed effects. We are particularly attentive to the issue of firm size due to the well-established evidence of a strong correlation between firm size and derivatives use. Matching firms based on size helps mitigate this concern.

INSERT Table 4 ABOUT HERE

The probit model estimates are provided in Table 4, Panel A, column (1), with robust standard errors adjusted for heteroskedasticity. We then use the predicted probabilities, or propensity scores, from column (1) to perform nearest neighbor propensity score matching. In particular, each firm with high FX exposure (treated firm) is matched to a firm with low or insignificant FX exposure (or control firm). We end up with 425 unique pairs of matched firms.

We conduct a number of tests to verify that the treated and control firms are similar on a set of observable characteristics. First, we re-run the probit test limited to the matched sample. The results are reported in Table 4, Panel A, column (2). None of the independent variables are statistically significant. A $\chi^2$ test of overall model fitness shows that we cannot reject the null hypothesis that all of the coefficients on the independent variables are zero (P-value of 0.999). In the second diagnostic test, reported in Panel B, we show the univariate statistics between the treated and control firms' pre-1987 characteristics and their corresponding t-statistics. The statistically insignificant differences in Ln(Sales), Book Leverage, Profitability, Tangibility, Herfindahl, Ln(Age), R&D/Assets, CAPX/Assets and Exporter suggest that treated and control firms in the matched sample are very similar.

As a final test we re-estimate the DID regression from Equation 3, using only the firms included in the matched sample. The results are reported in Table 4, Panel C. Columns (1) and (2) show the effect of FX hedging on the number of patents, while columns (3) and (4) report its effect on the number of citation-weighted patents. Further, while in columns (1) and (3) we only control for firm and year fixed effects, in columns (2) and (4) we add all firm control variables that we have previously used. The coefficient estimate for *High FX Exposure* · *Post* is positive and statistically significant at the 5% level in all four specifications. These results confirm that firms that are more likely to use FX derivatives, produce more innovation, and higher quality innovation in the years after the introduction of the ISDA master agreement.

### *3.4. Instrumental Variables Results*

As an alternative identification approach we implement a two-stage least squares instrumental variables (2SLS-IV) identification strategy. The IV test adds to the insights provided by the DID approach as it requires the channel, in our case the exposure to currency rate fluctuations, to be explicitly tested in the first stage. The first-stage is given by:

$$FX\ Derivatives_{i,(t+1)} = \beta_1 \cdot High\ FX\ Exposure_i \cdot Post_t + \beta_X \cdot X_{i,t} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{4}$$

where *High FX Exposure* · *Post* is the instrumental variable, while *FX Derivatives* is the dependent variable. As *High FX Exposure* is time invariant, the stand-alone variable is contained in the firm fixed effect, and *Post* is firm invariant and so absorbs the year fixed effect. To estimate the model, we use an OLS specification where the dependent variable is an indicator variable. When the first stage is an indicator variable OLS is still appropriate as Angrist and Kreuger (2001) show that a logit model first stage can make the IV estimates inconsistent.

From Equation 4, we obtain an estimated value for *FX Derivatives*, or $FX\ \widehat{Derivatives}$. We use this estimated variable to test for the effect of FX derivatives usage on patent production in the second stage specification:

$$Y_{i,(t+1)} = \beta \cdot FX\ \widehat{Derivatives} + \beta_X \cdot X_{i,t} + \gamma_i + \theta_t + \eta_{i,t} \tag{5}$$

where, $Y_{i,(t+1)}$ is the measure of innovative activity for firm i, one year after the current year, t, and $FX\ \widehat{Derivatives}$ captures the predicted value from Equation 4. If the conditions for a valid instrumental variable are met, then $\beta$ (Equation 5) captures the causal effect of FX derivatives usage on innovation activity. Table 5 shows the results of the 2SLS-IV specification.

INSERT Table 5 ABOUT HERE

Column (1) reports the first stage of the 2SLS-IV specification. The dependent variable, *FX Derivatives*, is an indicator variable that takes the value one if the firm uses FX derivatives in the year and zero otherwise. The result, statistically significant at the 1%

level, suggests that firms with a high FX equity exposure pre-1987, are more likely to use derivatives after 1987.

Columns (2) to (3) report the second stage results of derivatives usage on innovation, measured by the number of patents, and citation-weighted patents. These columns present 2SLS-IV estimates of the effect of FX derivatives on firm innovation corresponding to the first-stage specification from column (1). The coefficient estimates for the two different measures of innovation are all statistically significant at the 5% level. We emphasize the direction and not the magnitude of the 2SLS-IV results as Jiang (2017) points out that magnitudes derived through this methodology tend to be inflated. The results support the hypothesis that the use of derivatives has a positive causal impact on the quantity and quality of innovation.

While we cannot test the exclusion restriction, we can test the validity assumption. To test whether we have an under-identified or weak instrument we calculate a number of statistics. The Sanderson-Windmeijer (2016) $\chi^2$ test is a test of under-identification and the Sanderson-Windmeijer F-statistic, a test of weak identification using standard errors clustered at the firm level. The first-stage F-statistic is the standard test of instrument relevance. In almost all of the specifications, the first stage F-statistic is identical to the Sanderson-Windmeijer $\chi^2$ statistic. The Angrist-Pischke (Sanderson-Windmeijer or SW) first-stage $\chi^2$ is a test of under-identification of the individual regressors. The SW first-stage F-statistic is the F form of the same test statistic, which tests whether an endogenous regressor is weakly identified. The first-stage test statistics reject the null hypotheses of a weak or under-identified model at the 5% level or higher. The first-stage output also includes the Anderson-Rubin (AR) test for weak-instrument robust inference for testing the significance of the endogenous regressors. Both the $\chi^2$ and the F-statistic of the Anderson-Rubin test are reported. All tests reject the null hypotheses of an under-identified or weak instrument at the 5% level or higher.

### *3.5. Robustness Tests*

The previous results show a positive causal relationship between FX derivatives usage and firm innovation. Here we conduct a series of robustness tests to check if the main result is valid in different specifications.

INSERT Table 6 ABOUT HERE

The first set of tests, reported in Table 6, show that our results are robust when we use the coefficient to an alternative foreign currency index, the Major Currency Trading Partners (MCI) index, as the basis for calculating high FX equity exposure of firms.

In the second row, we use the logarithm function in place of the functional form, $ln(1 + x)$ where $x$ is the number of patents or citation-weighted patents obtained by the firm in the given year. In the third row, we use the inverse hyperbolic sine function in place of the function form, $ln(1 + x)$. We address the concern that the main DID result may be driven by the right-skewed distribution of the patent variable. In the fourth row, we report results for treated and control firms which have at least one patent within the sample period. The DID estimators for patents and cite-weighted patents are positive and significant at the 5% level. In the fifth row, we report the results for treated and control firms which have at least five patents, which is the number of patents at the $75^{th}$ percentile within the sample. The DID estimator for patents is 0.087 and significant at the 1% level, and the DID estimator for cite-weighted patents is 0.081 and significant at the 1% level. The DID estimator in this sub-sample has a larger economic impact than the one obtained with the full sample (Table 3, columns (4) and (6)) because this sub-sample excludes firms which generate zero patents and is a more innovation-relevant sub-sample. In the sixth row, the threshold for the minimum level of patents is fifteen, based on the average number of patents in the full sample. The DID estimators continue to be positive and significant at the 5% level.

We limit our sample to ten years before after the year of the ISDA Master Agreement and find qualitatively similar results. This result is reported in the seventh row. In the eighth row, we include one additional control variable, an indicator variable for use of interest rate derivatives by the firm. We recognise that the ISDA Master Agreement applied to two types of derivatives, FX and interest rate derivatives and our specification may be subject to concerns of omitted variables. Although we cannot entirely rule out this concern, including this additional control helps address it. In the ninth row, we include additional state-level controls, indicator for changes in corporate income taxes and indicator for changes in takeover regulation in the regression specification (Atanassov and Liu, 2020; Atanassov, 2013). In the tenth row, we control for exporter firms. In the eleventh row, we cluster standard errors at the year level. In the twelfth row, we cluster standard errors at the firm-year level. In all alternative specifications, we find that our main results hold.

## 4. Potential Channels

The evidence presented so far demonstrates that firms with greater foreign exchange exposure, use FX derivatives more frequently. Greater FX derivatives usage leads to a larger number of patents, showing that financial innovation leads to higher technological innovation. In this section we explore the mechanisms through which financial innovation affects technological innovation.

Hedging can prevent firms from underinvestment in some states of the world when it may be costly or impossible to raise external finance (Froot et al., 1993; Geczy et al., 1997). High growth firms that desire external equity financing are some of the most constrained firms (Hoberg and Maksimovic, 2015). The use of derivatives might stop financially constrained firms from cutting back on R&D, capital expenditures, and equity issuance policies following negative cash flow shocks.

We offer evidence that firms that are more financially constrained ex-ante are likely to benefit more from the use of financial derivatives and innovate more ex-post. We provide supporting evidence that constraints in the equity market may be driven at least in part by informational asymmetries (Krasker, 1986). We also show that users of FX derivatives spur innovation by increasing firms' R&D investments and debt capacity, rather than by enhancing their risk-taking behavior.

### *4.1. Cross-sectional Heterogeneity*

We test whether firms with higher financial constraints benefit more from the use of derivatives compared to firms with lower financial constraints. Such a benefit would occur if firms, which may have been reducing investments due to financing constraints, are able to reduce these constraints by using FX derivatives. We begin by classifying firms into high and low financial constraints using three established approaches, the Kaplan-Zingales index, the Duchin et al. index, and the dividend payout ratio (Kaplan and Zingales, 1997; Duchin et al., 2010).

We divide the sample of matched firms into two subsamples based on their Kaplan-Zingales index score, the Duchin et al. index score, and the dividend payout ratio in 1986.[20] A firm is classified as *High Kaplan-Zingales Index* (*Low Kaplan-Zingales Index*) if the firm has above (below) the median Kaplan-Zingales index score. Second, we classify a firm as *High Duchin et al. Index* (*Low Duchin et al. Index*) if the firm has above (below) the median Duchin et al. index score. Third, a firm is classified as *High Dividend Payout Ratio* (*Low Dividend Payout Ratio*) if the firm has above (below) the median dividend payout ratio. If hedging reduces firms' external financial dependence, we expect firms with higher financial constraints (*High Kaplan-Zingales Index*, *High Duchin et al. Index*, *Low Dividend Payout Ratio*) to benefit more from the use of FX derivatives compared to firms with lower financial constraints (*Low Kaplan-Zingales Index*, *Low Duchin et al.*

[20]As a robustness test we use the average score over the years pre-1987 to re-classify the firms. Our unreported results show similar findings.

*Index*, *High Dividend Payout Ratio*). Table 7 reports the results.

INSERT Table 7 ABOUT HERE

Column (1) shows that for the subsample of firms with *High Kaplan-Zingales Index* the coefficient estimate of *High FX Exposure* · *Post* is positive and statistically significant. In column (2) for the subsample of firms with *Low Kaplan-Zingales Index*, the coefficient estimate is smaller in magnitude but also statistically significant, but the Z-test for the difference in coefficients in column (2) cannot reject the null hypothesis of their equality.

In columns (3) and (4) we report the results for the second measure of financial constraints, *Duchin et al. Index.* Column (3) shows that for the subsample of firms with high Duchin et al. index score the coefficient estimate of *High FX Exposure* · *Post* is statistically significant and larger compared to that of firms with low Duchin et al. index score, reported in column (4). The coefficients are in line with our expectation, statistically significant only for firms with high financial constraints. Moreover, the Z-test for the difference in coefficients in column (4) rejects the null hypothesis of equality of the coefficients.

Following prior literature, we use each firm's dividend payout ratio as our third proxy of financial constraints. The higher a firm's dividend payout ratio, the less likely is the firm to be financially constrained. Therefore, we expect that firms with less internal funds (*Low Dividend Payout Ratio*) are likely to benefit more from risk management.

The results are reported in columns (5) and (6) of Table 7. Column (5) shows that the coefficient estimate of *High FX Exposure* · *Post* for the subsample of firms with high dividend payout is positive but statistically insignificant. In column (6), for the subsample of low dividend payout firms, the coefficient estimate is statistically significant and larger in magnitude. Moreover, the Z-test rejects the null hypothesis of equality of the coefficients of the two subsamples. Overall, the results from this section suggest that based on the well-established proxies, firms that are likely to be more financially constrained and dependent on external financing, benefit more from FX derivatives use.

A limitation of the above measures of financial constraints is that they are unidimensional, even as theory recognizes that the binding constraints might separately relate to the ability to raise equity or to raise debt (Hoberg and Maksimovic, 2015). Financially constrained firms face different costs for internal vs. external funding and these differences may vary depending on whether the external funding is equity or debt. Hoberg and Maksimovic (2015) estimate firms' annual financial constraints by analyzing firms' 10-K filings and identifying firms reporting investment delays due to difficulties in raising capital. Their analysis reveals that firms with high debt-focused constraints often differ from those with high equity-focused constraints, though some firms may experience both types of constraints simultaneously. In addition, recent work by Farre-Mensa and Ljungqvist (2016) provides evidence suggesting that existing accounting-based measures do a poor job of capturing financial constraints.[21]

To address these concerns, we classify firms into high and low financial constraints using two alternative measures developed by Linn and Weagley (2023). The authors apply their methodology to extend the equity and debt-focused text-based constraint measures of Hoberg and Maksimovic (2015) to time periods pre-1997.[22] They construct two versions of the debt and equity constraint measures, one using many firm characteristics and the other using a small subset of these variables that are the most primitive to the firm and are less likely to be endogenously determined by firm managers. We split our sample of matched firms into two subsamples based on the firm's Linn-Weagley Debt index score, and the Linn-Weagley Equity index score in 1986, using the primitive model.[23] A firm

[21]The Kaplan-Zingales Index is a linear function of the accounting variables (firm cash flow, long-term debt, dividend-to-asset ratio and Tobin's Q) shown by Kaplan and Zingales (1997) to predict financial constraints.

[22]Linn and Weagley (2023) train a random forest on the textual analysis-based financial constraint measures of Hoberg and Maksimovic (2015). This allows them to expand coverage of equity and debt-focused constraint measures both in the cross section and time series.

[23]The results from the full model, which uses the union of accounting variables used in creating three leading constraint indices from the literature: those of Kaplan and Zingales (1997), Whited and Wu

is classified as *High Linn-Weagley Debt/Equity Index* (*Low Linn-Weagley Debt/Equity Index*) if the firm has above (below) the median Linn-Weagley Debt/Equity index score. The results are reported in Table 8.

INSERT Table 8 ABOUT HERE

In columns (1) and (2), the coefficient estimates of *High FX Exposure · Post* are positive for both subsamples, *High Linn-Weagley Debt Index* and *Low Linn-Weagley Debt Index* but the Z-test cannot reject the hypothesis of equality of the coefficients for debt constraint firms. In contrast, the results for equity constraint firms, reported in columns (3) and (4), illustrate that the coefficient estimate of *High FX Exposure · Post* is significantly larger and significant only for the subsample of *High Linn-Weagley Equity Index* firms. The significance of the Z-test also confirms that firms with high equity constraints are producing more patents after the use of FX derivatives. These findings are in line with the main results of Hoberg and Maksimovic (2015) who find that equity focused firms face more binding constraints than debt focused firms. The authors show that equity market constraints are typically associated with firms' funding growth opportunities, have more severe consequences for the firm following large unexpected negative shocks, and are likely driven by informational asymmetries. In contrast, firms' debt constraints are likely not driven by informational asymmetries but rather covenant violations, and differ substantially from equity market constraints.

We next test whether firms with more growth opportunities and higher informational asymmetries innovate more following the use of derivatives. If constrained firms are high growth firms that desire external equity financing, we would expect to find firms with higher growth opportunities ex-ante to benefit more from the use of FX derivatives (Hoberg and Maksimovic, 2015). Similarly, if asymmetric information can lead to "equity rationing", where firms with the best investment opportunities face a bounded issuance

(2006), and Hadlock and Pierce (2010) are reported in the Internet Appendix.

proceeds function (financial constraints), and are forced to underinvest, then firms with higher asymmetric information ex-ante are likely to experience a bigger ease in their financial constraints following the use of derivatives (Krasker, 1986).

In Table 8, columns (5) and (6) we split our firms into two subsamples based on the level of their growth opportunities in 1986, *High Tobin's Q* and *Low Tobin's Q*. In Table 9 we use three alternative proxies of information asymmetry: *Analyst Coverage*, *Intangible Assets* and *Forecast Dispersion*, and divide firms into subsamples of high and low information asymmetry in 1986.

INSERT Table 9 ABOUT HERE

The results from these additional tests confirm our hypothesis that firms with higher growth opportunities and higher information asymmetry benefit more from risk management. The coefficient estimates of *High FX Exposure · Post* are positive and statistically significant for the subsamples of firms with high growth opportunities and high information asymmetry. The coefficient estimates are smaller in magnitude and statistically insignificant for the subsamples of firms with low growth opportunities and low information asymmetry. Nevertheless, none of the Z-tests reject the hypothesis of equality of the coefficients.

### *4.2. Financial Constraints Channel – Supporting Evidence*

Our results suggest that firms that are more likely to benefit from risk management are firms that are financially constrained, have high growth opportunities but with high information asymmetry, they face higher "equity rationing" and potentially underinvest in R&D when hit by negative shocks to their cash flows. The use of FX derivatives can reduce these firms' cash flow variability (Geczy et al., 1997), increase their debt capacities (Smith and Stulz, 1985) and relax firms' financial constraints (Froot et al., 1993). Firms that use FX derivatives can possibly issue more debt and equity and use the proceeds to increase innovation input (i.e., R&D investments), giving rise to greater innovation output. In other words, firms' risk management can promote corporate innovation through a financing channel. Below we test this hypothesis and report the results in Table 10.

INSERT Table 10 ABOUT HERE

In column (1) we estimate the effect of foreign currency use on firms' future (one to three years post) R&D investments. We find a significant increase of R&D investments for users of derivatives in the post-1987 period. In the next two columns we test whether risk management increases firm's debt capacity. Specifically, the results in column (2) show that users of derivatives are likely to increase their net debt issues (debt issues minus debt reductions) in the next period, while the results in column (3) illustrate that these firms are also reducing their debt repayments in the future, in both columns the coefficient of interest, *High FX Exposure* · *Post*, is statistically significant. In column (4) we examine whether firms' hedging FX derivatives allows them to reduce their equity constraints and issue more equity in the future. The coefficient estimates of *High FX Exposure* · *Post* in column (4) are positive, statistically significant, and increasing in magnitude in year two and three. Overall, these results provide further support for the financing channel, illustrating that users of derivatives are able to increase their investments in R&D and increase their debt capacity in the future.

*4.3. Risk-taking Channel*

In this section we examine an alternative channel behind the risk management–innovation relationship. The increase in firm innovation that we find could be also explained by increased risk-taking behaviour by treated firms. Instead of putting more money into R&D, or relying more on external financing, the risk management policy of firms that use derivatives may allow them to tolerate more risky experimentation in their innovation. If that is the case we would expect firms that use derivatives to shift the trajectory of their innovation from low-risk and incremental innovations to high-risk and radical innovations after they start using derivatives. To test this hypothesis, we study whether the riskiness of firm's innovation changes following the use of FX derivatives.

INSERT Table 11 ABOUT HERE

In Table 11, column (1), we show the standard deviation of firms' citations. The coefficient estimate of *High FX Exposure* · *Post* is positive but statistically insignificant, suggesting that firms that use derivatives, on average, do not increase the riskiness of their innovation. In column (2) the dependant variable captures the number of patents that have received zero citations. We find that firms are likely to increase their zero-citations patents following the use of FX derivatives. In contrast to that, the results from columns (3) and (4), suggest that firms are not producing more highly cited patents, patents with citations in the $90^{th}$ percentile and higher or $95^{th}$ percentile and higher (in column (3) and (4), respectively). These results are contrary to the risk-taking hypothesis, as they illustrate that firms are less likely to increase the riskiness of their innovation, suggesting that they put more money instead into low-risk and incremental innovations.

As additional tests we examine whether firms that use FX derivatives change their innovation strategies ex-post. The results are reported in Table 12.

INSERT Table 12 ABOUT HERE

Column (1) shows that firms that have higher FX exposure, on average, produce more exploitative patents, while column (2) shows that they see a reduction in the number of more exploratory patents. A patent is categorized as exploitative if at least 60% of its citations are based on the firm's existing knowledge and as exploratory if at least 60% of its citations are based on new knowledge, i.e., patents not in the firm's existing knowledge (Balsmeier et al., 2017). As a second measure, we divide innovations into product and process patents. According to Chava et al. (2013), product innovations result in new products and are, thus, more radical and risky than process innovations.

We classify process patents as those which fall into the International Patent Classification (IPC) class B01 (Chava et al., 2013). We then define *Process* as the natural logarithm of (1 + the number of process patents) that each firm applies for in each year (Chang et al., 2019). Following Chen et al. (2016), we define *Depth* as the number of repeated citations divided by the total citations made by patents of a firm in each year. Repeated citations are citations that have been made by the firm in the past five years. Higher depth suggests that the firm's innovative activities are more concentrated in its existing knowledge. Overall, these findings further refute the risk-taking channel, demonstrating that the increase in firm innovation stems from more incremental, less exploratory, and less novel patents, which are typically associated with lower risk.

### *4.4. External Validity*

The results indicate that firms with greater exposure to foreign exchange fluctuations before the introduction of the ISDA Master Agreement are more likely to hedge with FX derivatives afterward. This hedging behavior correlates with increased production of more and highly cited patents, suggesting a positive impact of risk management policies on innovation. However, the generalizability of these findings to other firms in different time periods requires careful consideration.

#### *4.4.1. Specificity of Identification Strategy*

Our identification strategy focuses on measuring firms' exposure to foreign currencies using only positive exchange-rate exposures. This approach may be specific to the period studied. The 1985 Plaza Accord, an unprecedented foreign exchange intervention, led to a significant devaluation of the U.S. dollar. We hypothesize that firms with positive betas pre-1987 are more inclined to use FX derivatives in the post-1987 period, anticipating negative equity stock returns due to the dollar's devaluation. Conversely, firms with negative or statistically insignificant betas likely benefited from the intervention, experiencing positive stock returns and thus showing less demand for FX hedging products due to asymmetric hedging behavior. This strategy aligns with other studies from the period, that use positive and statistically significant betas to capture firms' FX exposure (Allayannis and Ofek, 2001; Allayannis et al., 2001; He and Ng, 1998). However, a potential critique is that our findings might not generalize to other periods, where firms might hedge symmetrically, making the absolute value of beta a more relevant predictor of derivatives use.

Although, we are unable to address this concern with empirical tests, we note that the external validity of our tests applies to the DID analysis and the first stage of the IV analysis. The second stage of the IV analysis is externally valid. This specification tests whether firms with greater derivatives usage produce more patents. Our IV specification results show that higher derivatives use leads to increased patenting, providing support for the external validity of our findings across different periods.

*4.4.2. Contextualizing the Study Period*

The period from 1985 to 1997, beginning with the Plaza Accord, was marked by significant economic cooperation aimed at devaluing the U.S. dollar. Before this, high real interest rates in the U.S. led to a 40% appreciation of the U.S. real effective exchange rate between 1980 and 1985. This appreciation harmed the price competitiveness of U.S. exporting and import-competing firms, contributing to trade and current account deficits and adversely affecting several sectors, including steel, textile, agriculture, automobile, and capital goods. In response, the U.S. Congress began considering passing protectionist laws in 1985, prompting the G5 nations to focus on reducing the dollar's value collaboratively (Destler, 1986).

We study this period because the introduction of the ISDA Agreement in 1987 represents a significant shock to the costs of using FX derivatives. While our findings may be specific to this period and partly driven by the increased competitiveness of U.S. manufacturers in export markets following the intervention, we have conducted robustness tests to strengthen our claim. These tests account for differences between exporting and non-exporting firms, further supporting the external validity of our results and underscoring the derivatives channel as a critical factor in firms' innovation.

## 5. Conclusion

We document the link between financial innovation such as FX derivatives and firms' technological innovation. One of the first few and widely used financial innovations, derivative contracts had come under harsh scrutiny during the Global Financial Crisis of 2007-09. Using a large sample of U.S. listed firms and a quasi-exogenous shock in derivatives markets, we document that firms with high FX exposure ex-ante are more likely to use FX derivatives ex-post. Firms with high FX exposure generate more successful patents after the shock. These results are robust to a host of model specifications and robustness tests.

We find that our results are more pronounced for firms which face equity financing constraints. The use of derivatives helps firms raise more equity capital and invest more in R&D, thus relaxing financial constraints. Additionally, we observe that the use of FX derivatives leads firms to focus more on low-risk, incremental innovations rather than novel, radical ones, implying that these firms do not enhance their risk-taking behavior.

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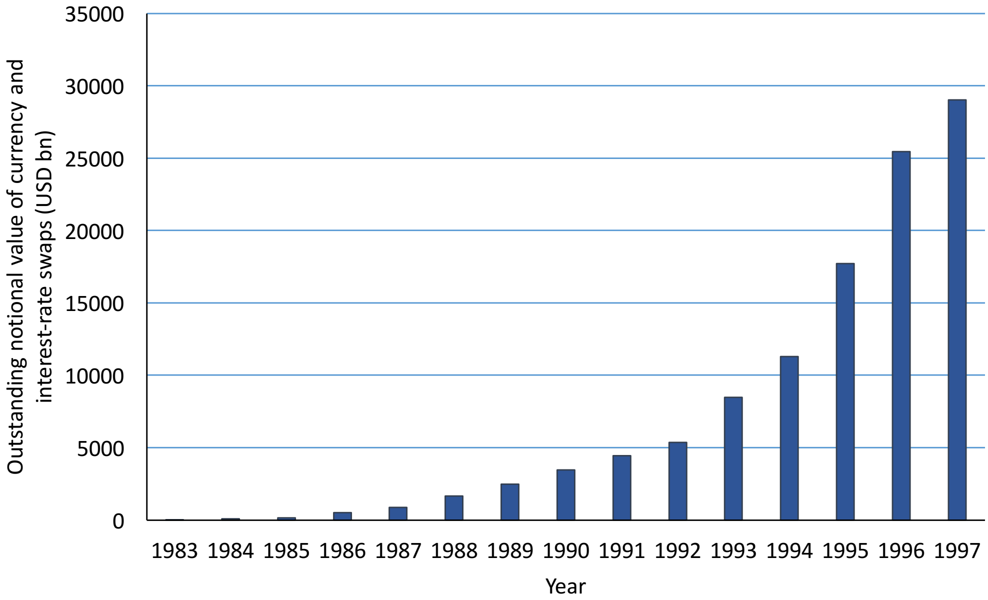
Figure 1: Foreign Exchange Derivatives Market

The top panel shows the global, notional value of outstanding foreign exchange and interest-rate swaps as reported by the International Swaps and Derivatives Association. The bottom panel shows the number of firms in our sample that use foreign exchange derivatives in each year.



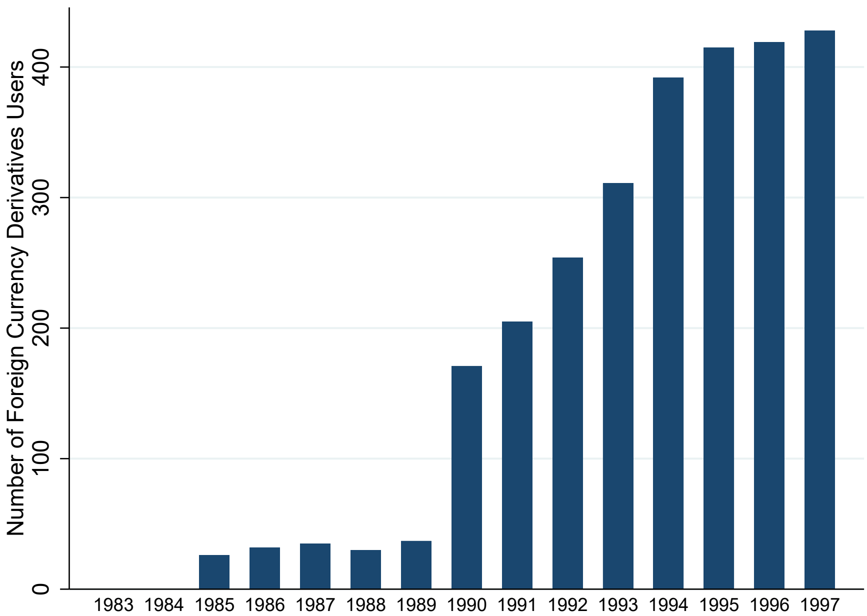



Figure 2: Foreign Exchange Indices

This figure shows the value of the foreign-exchange indices over time. The solid line shows the real (inflation-adjusted) value of the foreign exchange index (OITP) for all emerging market trading partner countries of the US, and the dashed, blue line shows the real value of the foreign exchange index (MCI) for all major trading partners of the US as reported by the Federal Reserve Board. MCI includes sixteen widely traded currencies including all currencies of EU member countries (before 1999 and the euro after 1999), Japanese Yen, British pound, Swiss franc, Australian dollar, and the Swedish krona. OITP includes emerging market currencies including currencies of Mexico, China, Taiwan, India, Korea, Singapore and others.

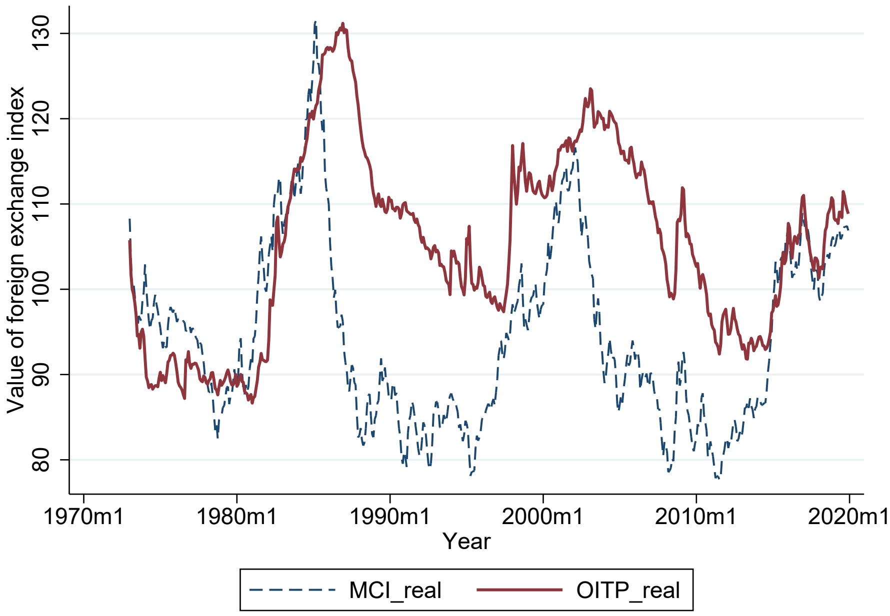
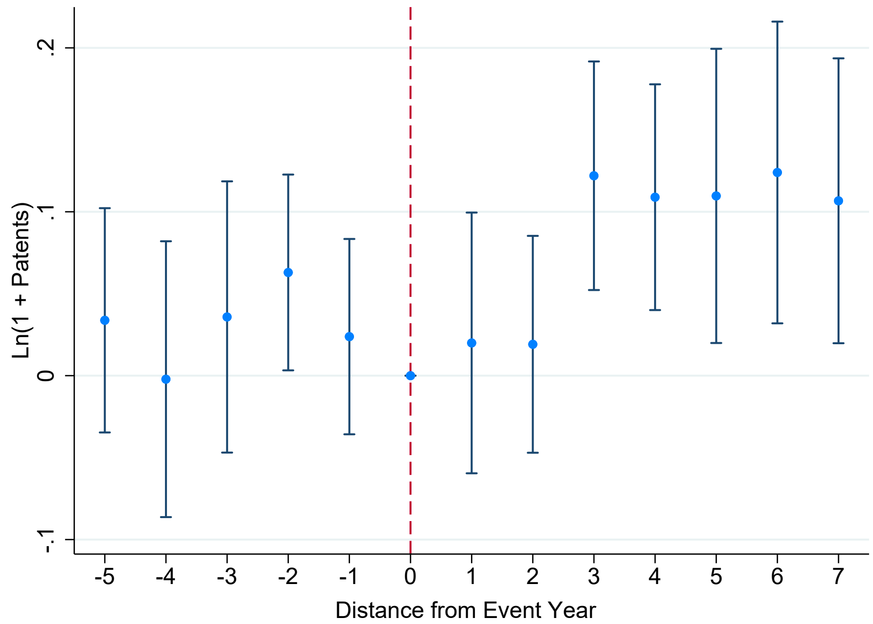


Figure 3: Dynamic Estimates of FX Equity Exposure

$$Y_{i,t+1} = \sum_t \beta_k \cdot High\ FX\ Exposure_i \cdot year_k + \beta_X \cdot X_{i,t} + \gamma_i + \theta_t + \epsilon_{i,t}$$

This figure shows the coefficient estimates from the regression equation above over the years to treatment or the year of introduction of the ISDA Master Agreement. The horizontal axis indicates event time. The negative numbers are pre-treatment years; zero is the year 1987 in which the ISDA Master Agreement was introduced; and positive numbers are post-treatment years. In the top panel, the dependent variable is $LnPat$ or the natural logarithm of (1 + number of granted patents) and in the bottom panel, the dependent variable is $LnCwPat$ or the natural lograithm of (1 + cite-weighted patents). The vertical axis shows the coefficient estimates, $\beta_k$'s from the specification. The solid dot plots the point estimates and the error bars plot the 95% confidence interval. Standard errors are clustered at the industry level.



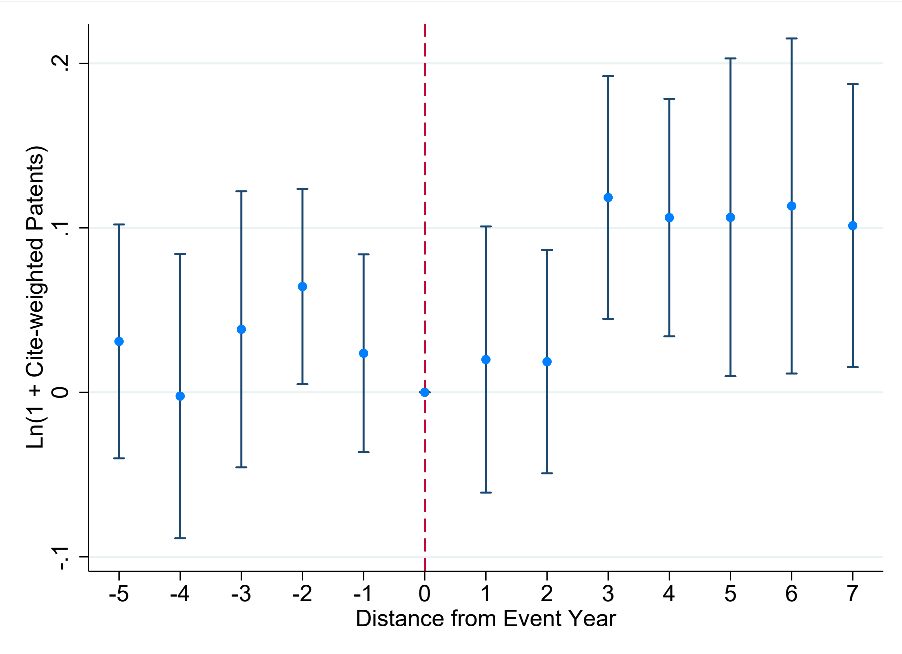



Table 1. Definitions of Variables

This table summarizes the variables used in the analyses.

| Variable name | Variable description |
|---|---|
| **Firm characteristics:** | |
| $\text{Assets}_{it}$ | Total assets of firm $i$ in year $t$ (in U.S. $ thousands). |
| $\text{Sales}_{it}$ | Sales by firm $i$ in year $t$ (in U.S. $ thousands). |
| $\text{Book leverage}_{it}$ | Total debt of firm $i$ in year $t$ divided by its Assets in year $t$. |
| $\text{Profitability}_{it}$ | Earnings before interest, tax, depreciation and amortization (EBITDA) of firm $i$ in year $t$ divided by its Assets in year $t$. |
| $\text{Tangibility}_{it}$ | Net property, plant and equipment of firm $i$ in year $t$ divided by its Assets in year $t$. |
| $\text{Herfindahl}_{it}$ ($\text{Herfindahl}^2_{it}$) | Sum of the squared share of firm $i$ in total industry sales at the 4 digit SIC industry code in year $t$. (Equal to $\text{Herfindahl}_{it}$ squared.) |
| $\text{Age}_{it}$ | Age of firm $i$ in year $t$ based on the years from firm $i$'s IPO (from CRSP). |
| $\text{R\&D}_{it}$ | Research and development expenses of firm $i$ in year $t$. |
| $\text{CAPX}_{it}$ | Capital expenditure of firm $i$ in year $t$. |
| $\text{Exporter}_{it}$ | An indicator variable that takes one a value of one if firm $i$ reports foreign sales in year $t$, and zero otherwise. |
| $\text{M/B}_{it}$ | The market-to-book ratio of firm $i$ in year $t$, calculated as market value of equity plus book value of assets minus book value of equity minus balance sheet deferred taxes divided by book value of assets. |
| $\text{ME}_{it}$ | The market capitalization of firm $i$ in year $t$, or the total market value of all shares outstanding. |
| **Firm innovation measures:** | |
| $\text{Pat}_{it}$ | Count of the number of granted patents to firm $i$ applied for in year $t$. |
| $\text{Cit}_{it}$ | Count of the number of citations to granted patents received by firm $i$ in year $t$. |
| $\text{CwPat}_{it}$ | Citation-weighted patents. For each patent we calculate the scaled citations or total number of citations received by the patent divided by the average number of citations received by all patents in the same year. We add this measure for all patents filed by firm $i$ in year $t$. |
| $\text{SD Cit}_{it}$ | The standard deviation of citations to patents of firm $i$ in year $t$. |
| $\text{Cit0}_{it}$ | Count of the number of zero-cited granted patents received by firm $i$ in year $t$. |
| $\text{Ci90t}_{it}$ ($\text{Cit95}_{it}$) | Count of the number of patents of firm $i$ which have citations which are in the 90th (95th) percentile or higher of citations for all patents in the same year $t$. |
| $\text{Exploitative}_{it}$ ($\text{Exploratory}_{it}$) | Fraction of total patents which are exploitative (exploratory) patents of firm $i$ in year $t$. A firm's existing knowledge comprises of its existing patents and the patents that its existing patents cite. A patent is categorized as exploitative if at least 60% of its citations are based on the firm's existing knowledge and as exploratory if at least 60% of its citations are based on new knowledge, i.e., patents not in the firm's existing knowledge. |
| $\text{Process}_{it}$ | Patents falling into the International Patent Classification (IPC) category B01 are defined as process patents, and all other patents are defined as product patents. *Process* is the natural logarithm of (1 + Process), where Process is the count of process patents of firm $i$ in year $t$. |
| $\text{Depth}_{it}$ | The ratio of the number of repeated citations made by the patents of firm $i$ in year $t$ to total number of citations made by all patents in the same year. Repeated citations are the citations that have been made by the firm in the past five years. |

*(Continued)*

Table 1 – Continued

| Variable name | Variable description |
|---|---|
| **Measures of currency hedging demand:** | |
| FX Derivatives$_{it}$ | An indicator variable that takes on a value of one if firm $i$ reports using currency derivatives in year $t$, and zero otherwise. |
| High FX Exposure$_i$ | An indicator variable which takes the value one if the value of the FX equity exposure for a firm is positive and significant, and zero otherwise. FX equity exposure for each firm is the beta to an inflation-adjusted index of emerging market currencies in a regression of the monthly equity returns of the firm on the inflation-adjusted index of emerging market currencies, and developed market currencies, the value-weighted market portfolio, and short-term interest rate, and term spread variables, estimated for all months before and excluding 1987. |
| Post$_t$ | An indicator variable that takes on a value of one for each year $t$ after 1987, and zero otherwise. |
| **Additional control variables:** | |
| Inter-state dereg$_{it}$ (Intra-state dereg$_{it}$) | An indicator variable that takes on a value of one if inter-state (intra-state) banking deregulation has been implemented before or in the year $t$ in the state in which firm $i$'s headquarters are located. |
| High Kaplan-Zingales Index$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on the Kaplan-Zingales Index in 1986 and zero otherwise. |
| High Duchin et al. Index$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on the Duchin et al. Index in 1986 and zero otherwise. |
| High Dividend Payout Ratio$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on the dividend payout ratio in 1986 and zero otherwise. |
| High Linn-Weagley Debt Index$_{it}$ (High Linn-Weagley Equity Index$_{it}$) | An indicator variable which takes the value one if firm $i$ is above the median of firms based on the Linn-Weagley Debt (Equity) Index in 1986 and zero otherwise. |
| High Tobin's Q$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on the Tobin's Q of firm $i$ in 1986. |
| Without Analyst Coverage$_{it}$ | An indicator variable which takes the value one if firm $i$ is not covered by analysts in 1986. |
| High Intangible Assets$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on tangible assets of firm $i$ in 1986. |
| High Forecast Dispersion$_{it}$ | An indicator variable which takes the value one if firm $i$ is above the median of firms based on standard deviation in one-year forward earnings of firm $i$ in 1986. |
| Debt Issue$_{it}$ | Net debt issuance (debt issuance - debt reductions + changes in net debt) of firm $i$ in year $t$ divided by its Assets in year $t-1$. |
| Debt Reduction$_{it}$ | Debt reductions minus changes in net debt of firm $i$ in year $t$ divided by its Assets in year $t-1$. |
| Equity Issue$_{it}$ | Net equity issuance (sale of equity - purchase of equity) of firm $i$ in year $t$ divided by its Assets in year $t-1$. |

Table 2. Summary Statistics

This table presents summary statistics for the key variables used in the analyses. Panel A shows the firm financial characteristics, Panel B, the innovation and other relevant variables. See Table 1 for variable definitions.

| | N | Mean | St. Dev. | p25 | Median | p75 |
|---|---|---|---|---|---|---|
| Panel A: Firm Financial Characteristics | | | | | | |
| Ln(Assets) | 31,546 | 5.654 | 2.186 | 4.054 | 5.561 | 7.240 |
| Ln(Sales) | 31,546 | 5.836 | 2.142 | 4.348 | 5.810 | 7.375 |
| Book Leverage | 31,546 | 0.248 | 0.187 | 0.113 | 0.226 | 0.344 |
| Profitability | 31,546 | 0.133 | 0.112 | 0.087 | 0.139 | 0.191 |
| Tangibility | 31,546 | 0.315 | 0.179 | 0.184 | 0.283 | 0.411 |
| Herfindahl | 31,546 | 0.269 | 0.179 | 0.144 | 0.222 | 0.342 |
| Age | 31,546 | 27.664 | 17.015 | 15.000 | 24.000 | 35.000 |
| Exporter | 31,546 | 0.536 | 0.499 | 0.000 | 1.000 | 1.000 |
| Panel B: Innovation and Other Variables | | | | | | |
| Patents | 31,546 | 15.075 | 48.255 | 0.000 | 0.000 | 5.000 |
| CwPat | 31,546 | 15.421 | 49.232 | 0.000 | 0.000 | 5.041 |
| R&D | 31,546 | 68.399 | 401.967 | 0.000 | 0.712 | 11.350 |
| FX Derivatives | 31,546 | 0.114 | 0.318 | 0.000 | 0.000 | 1.000 |
| High FX Exposure | 31,546 | 0.306 | 0.461 | 0.000 | 0.000 | 1.000 |

Table 3. DID regression - Full sample

This table reports the effect of high FX exposure on patent production using a difference-in-differences approach. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. $LnCwPat_{t+1}$ is the natural logarithm of $(1 + \text{CwPat})_{t+1}$, where *CwPat* is the count of citation-weighted patents in year *t + 1*. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)*, *Herfindahl*, *Herfindahl*$^2$, *Inter-state dereg*, and *Intra-state dereg*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | FX Derivatives | | $\text{LnPat}_{t+1}$ | | $\text{LnCwPat}_{t+1}$ | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| High FX Exposure · Post | 0.031*** | 0.032*** | 0.106*** | 0.077** | 0.101** | 0.072** |
| | (0.011) | (0.010) | (0.037) | (0.030) | (0.038) | (0.031) |
| Ln(Sales) | | 0.051*** | | 0.209*** | | 0.211*** |
| | | (0.007) | | (0.032) | | (0.032) |
| Book Leverage | | 0.060** | | -0.226*** | | -0.231*** |
| | | (0.025) | | (0.051) | | (0.052) |
| Profitability | | -0.016 | | -0.209*** | | -0.217*** |
| | | (0.028) | | (0.040) | | (0.039) |
| Tangibility | | -0.127*** | | 0.023 | | 0.030 |
| | | (0.045) | | (0.112) | | (0.114) |
| Ln(Age) | | -0.248*** | | 0.298*** | | 0.298*** |
| | | (0.032) | | (0.099) | | (0.097) |
| Herfindahl | | -0.039 | | -0.145 | | -0.109 |
| | | (0.119) | | (0.386) | | (0.384) |
| Herfindahl$^2$ | | -0.009 | | 0.194 | | 0.161 |
| | | (0.116) | | (0.355) | | (0.354) |
| Inter-state dereg | | 0.003 | | 0.008 | | 0.011 |
| | | (0.012) | | (0.025) | | (0.025) |
| Intra-state dereg | | -0.014 | | -0.055* | | -0.053* |
| | | (0.012) | | (0.030) | | (0.030) |
| Firm F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 30,073 | 30,073 | 30,073 | 30,073 | 30,073 | 30,073 |
| R-squared | 0.424 | 0.439 | 0.845 | 0.853 | 0.844 | 0.852 |

Table 4. DID with Propensity Score Matching Approach on Derivatives Use and Innovation

This table reports the effect of FX derivatives on patent production using a DID approach and based on a matching using propensity score matching methods. The dependent variable in Panel A is an indicator variable equal to one if the firm has a positive and significant value of FX equity exposure before 1987 (treatment firm), and zero otherwise. The dependent variables in Panel C are $LnPat_{t+1}$, the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*, and $LnCwPat_{t+1}$ is the natural logarithm of $(1 + \text{CwPat})_{t+1}$, where *CwPat* is the count of citation-weighted patents in year *t+1*. In Panel C, control variables include *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)*, *Herfindahl*, *Herfindahl*$^2$, *Inter-state dereg*, and *Intra-state dereg*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

Panel A: Pre-match Propensity Score Regression and Post-match Diagnostic Regression

| | Pre-match | Post-match |
|---|---|---|
| | (1) | (2) |
| Ln(Sales) | 0.001 | -0.008 |
| | (0.023) | (0.028) |
| Book Leverage | 0.006 | 0.058 |
| | (0.193) | (0.237) |
| Profitability | -0.394 | 0.414 |
| | (0.327) | (0.444) |
| Tangibility | 0.252 | -0.238 |
| | (0.255) | (0.308) |
| Ln(Age) | -0.251** | 0.010 |
| | (0.098) | (0.126) |
| Herfindahl | 0.127 | -0.263 |
| | (0.222) | (0.266) |
| Industry FE | Yes | Yes |
| Observations | 1,381 | 851 |
| R-squared | 0.027 | 0.008 |
| P-value of $\chi^2$ | <0.001 | 0.999 |

Panel B: Differences in Pre-shock Characteristics

| | Treatment | Control | Difference | T-statistic |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Ln(Sales) | 5.332 | 5.361 | -0.029 | -0.21 |
| Book Leverage | 0.257 | 0.257 | 0 | -0.03 |
| Profitability | 0.116 | 0.11 | 0.006 | 0.78 |
| Tangibility | 0.334 | 0.339 | -0.005 | -0.38 |
| Ln(Age) | 3.034 | 3.045 | -0.011 | -0.25 |
| Herfindahl | 0.262 | 0.271 | -0.009 | -0.83 |
| RD/AT | 0.027 | 0.026 | 0.001 | 0.50 |
| CAPX/AT | 0.074 | 0.074 | 0 | 0.02 |
| Exporter | 0.462 | 0.518 | -0.056 | -1.61 |

*(Continued)*

Table 4 – Continued

Panel C: Difference-in-Differences Regression Specification

| | $LnPat_{t+1}$ | | $LnCwPat_{t+1}$ | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| High FX Exposure · Post | 0.170** | 0.144*** | 0.148** | 0.134** |
| | (0.066) | (0.052) | (0.057) | (0.051) |
| Controls | No | Yes | No | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 18,870 | 18,870 | 18,870 | 18,870 |
| R-squared | 0.759 | 0.771 | 0.849 | 0.858 |

Table 5. Instrumental Variable Approach on Derivatives Use and Innovation

This table reports the effect of FX derivatives on patent production using an instrumental variables approach. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. $LnCwPat_{t+1}$ is the natural logarithm of $(1 + \text{CwPat})_{t+1}$, where *CwPat* is the count of citation-weighted patents in year *t + 1*. *FX Derivatives* is an indicator variable taking the value of one if the firm uses FX derivatives (as per its SEC filings) in the year and zero otherwise. The instrumental variable is based on the beta of firm equity returns to fluctuations in a trade-based index of emerging market currencies. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise. The variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)*, *Herfindahl*, *Herfindahl*$^2$, *Inter-state dereg*, and *Intra-state dereg*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | FX derivatives | $\text{LnPat}_{t+1}$ | $\text{LnCwPat}_{t+1}$ |
|---|---|---|---|
| | (1) | (2) | (3) |
| High FX Exposure · Post | 0.029*** | | |
| | (0.009) | | |
| $\widehat{FX\ Derivatives}$ | | 2.634** | 2.466** |
| | | (1.050) | (1.047) |
| Ln(Sales) | 0.048*** | 0.083 | 0.093* |
| | (0.007) | (0.055) | (0.055) |
| Book Leverage | 0.058** | -0.380*** | -0.375*** |
| | (0.026) | (0.096) | (0.092) |
| Profitability | -0.016 | -0.166** | -0.177** |
| | (0.029) | (0.080) | (0.077) |
| Tangibility | -0.133*** | 0.375 | 0.359 |
| | (0.045) | (0.250) | (0.248) |
| Ln(Age) | -0.255*** | 0.970*** | 0.927*** |
| | (0.032) | (0.301) | (0.298) |
| Herfindahl | -0.039 | -0.042 | -0.012 |
| | (0.104) | (0.545) | (0.532) |
| Herfindahl$^2$ | -0.009 | 0.217 | 0.183 |
| | (0.101) | (0.500) | (0.487) |
| Inter-state dereg | 0.000 | 0.008 | 0.010 |
| | (0.012) | (0.033) | (0.032) |
| Intra-state dereg | -0.015 | -0.015 | -0.016 |
| | (0.012) | (0.039) | (0.038) |
| Firm F.E. | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes |
| Observations | 30,073 | 30,073 | 30,073 |
| SW $\chi^2$ | | 6.873 | 6.873 |
| P-value | | 0.009 | 0.021 |
| SW F-statistic | | 10.10 | 10.10 |
| AR $\chi^2$ | | 6.542 | 5.361 |
| P-value | | 0.011 | 0.009 |
| AR F-statistic | | 6.415 | 5.257 |
| P-value | | 0.014 | 0.026 |

Table 6. Robustness Tests for the DID Analysis

This table reports robustness test results for the difference-in-differences regression analysis. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. $LnCwPat_{t+1}$ is the natural logarithm of $(1 + \text{CwPat})_{t+1}$, where *CwPat* is the count of citation-weighted patents in year *t + 1*. The coefficient to *High FX Exposure* · *Post* is reported in columns (1) and (2). *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)*, *Herfindahl*, *Herfindahl*$^2$, *Inter-state dereg*, and *Intra-state dereg*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry, unless stated otherwise. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| Specification/Subsample | $\text{LnPat}_{t+1}$ | $\text{LnCwPat}_{t+1}$ | Observations |
|---|---|---|---|
| | (1) | (2) | (3) |
| Coefficient of MCI for High FX Exposure | 0.029** | 0.030** | 30,073 |
| | (0.011) | (0.011) | |
| Log transformation of independent variable | 0.111** | 0.098* | 14,849 |
| | (0.052) | (0.054) | |
| Inverse hyperbolic sine transformation | 0.103** | 0.098** | 30,073 |
| | (0.041) | (0.042) | |
| Firms with total patents > 1 | 0.077** | 0.073** | 29,609 |
| | (0.030) | (0.031) | |
| Firms with total patents > 5 | 0.087*** | 0.081** | 25,444 |
| | (0.032) | (0.033) | |
| Firms with total patents > 15 | 0.100*** | 0.093** | 20,265 |
| | (0.037) | (0.038) | |
| Years including and between 1977 and 1997 | 0.060* | 0.055** | 24,474 |
| | (0.032) | (0.022) | |
| Control for interest rate | 0.122*** | 0.071** | 30,068 |
| derivatives usage | (0.036) | (0.032) | |
| Additional firm and state-level controls | 0.076** | 0.071** | 30,073 |
| | (0.032) | (0.033) | |
| Control for exporter firms | 0.131*** | 0.073** | 29,294 |
| | (0.037) | (0.033) | |
| Cluster at year level | 0.077*** | 0.072*** | 30,073 |
| | (0.013) | (0.013) | |
| Cluster at firm-year level | 0.077*** | 0.072*** | 30,073 |
| | (0.016) | (0.016) | |

Table 7. Financial Constraints - I

This table reports results for the Financial Constraints Channel. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)* and *Herfindahl*. The Z-test for difference in coefficients is a t-test of whether the difference between the coefficients on *High FX Exposure · Post* in the two sub-groups is statistically significantly different from zero. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | $\text{LnPat}_{t+1}$ | | | | | |
|---|---|---|---|---|---|---|
| | Kaplan-Zingales Index | | Duchin et al. Index | | Dividend Payout Ratio | |
| | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| High FX Exposure · Post | 0.169** | 0.112** | 0.279*** | 0.027 | 0.128 | 0.559*** |
| | (0.074) | (0.057) | (0.085) | (0.065) | (0.079) | (0.164) |
| Ln(Sales) | 0.299*** | 0.220*** | 0.281*** | 0.217*** | 0.304*** | 0.163*** |
| | (0.061) | (0.064) | (0.048) | (0.056) | (0.088) | (0.064) |
| Book Leverage | -0.023 | -0.313*** | -0.238 | -0.025 | -0.091 | -0.181 |
| | (0.140) | (0.105) | (0.145) | (0.117) | (0.199) | (0.118) |
| Profitability | -0.225 | -0.349*** | -0.336 | -0.082 | -0.340 | -0.545 |
| | (0.197) | (0.125) | (0.210) | (0.128) | (0.260) | (0.352) |
| Tangibility | -0.029 | 0.043 | -0.247 | 0.306 | 0.315 | -0.682 |
| | (0.271) | (0.200) | (0.304) | (0.265) | (0.321) | (0.545) |
| Ln(Age) | -1.205*** | -0.464** | -0.981*** | -1.108*** | -1.057*** | -1.230*** |
| | (0.280) | (0.218) | (0.364) | (0.207) | (0.285) | (0.408) |
| Herfindahl | -0.044 | -0.115 | -0.069 | 0.308** | 0.018 | -0.713 |
| | (0.176) | (0.169) | (0.162) | (0.146) | (0.202) | (0.564) |
| Firm F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 9,993 | 8,760 | 7,795 | 10,975 | 11,637 | 1,983 |
| R-squared | 0.068 | 0.036 | 0.067 | 0.052 | 0.046 | 0.096 |
| Z-test for diff. | | 0.057 | | 0.252*** | | -0.431*** |
| in means | | (0.094) | | (0.107) | | (0.182) |

Table 8. Financial Constraints - II

This table reports results for the Financial Constraints Channel. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)* and *Herfindahl.* The Z-test for difference in coefficients is a t-test of whether the difference between the coefficients on *High FX Exposure · Post* in the two sub-groups is statistically significantly different from zero. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | $\text{LnPat}_{t+1}$ | | | | | |
|---|---|---|---|---|---|---|
| | Linn-Weagley Debt Index | | Linn-Weagley Equity Index | | Tobin's Q | |
| | High | Low | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| High FX Exposure · Post | 0.091 | 0.204*** | 0.274*** | 0.068 | 0.197** | 0.080 |
| | (0.064) | (0.069) | (0.094) | (0.072) | (0.096) | (0.076) |
| Ln(Sales) | 0.194*** | 0.330*** | 0.314*** | 0.230*** | 0.297*** | 0.219*** |
| | (0.053) | (0.050) | (0.065) | (0.060) | (0.062) | (0.044) |
| Book Leverage | -0.114 | -0.206 | -0.209 | -0.117 | -0.269 | -0.097 |
| | (0.102) | (0.156) | (0.136) | (0.116) | (0.160) | (0.130) |
| Profitability | -0.231* | -0.374*** | -0.332 | -0.228 | -0.116 | -0.408** |
| | (0.126) | (0.157) | (0.198) | (0.175) | (0.145) | (0.191) |
| Tangibility | 0.219 | -0.071 | 0.223 | -0.089 | 0.207 | -0.059 |
| | (0.242) | (0.249) | (0.229) | (0.230) | (0.219) | (0.271) |
| Ln(Age) | -0.496*** | -1.688*** | -1.159*** | -0.925*** | -1.201*** | -0.850*** |
| | (0.193) | (0.294) | (0.187) | (0.283) | (0.337) | (0.272) |
| Herfindahl | 0.060 | -0.100 | -0.279 | 0.189 | -0.169 | 0.118 |
| | (0.171) | (0.121) | (0.186) | (0.135) | (0.194) | (0.139) |
| Firm F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 11,631 | 7,239 | 7,529 | 11,341 | 8,745 | 10,095 |
| R-squared | 0.024 | 0.113 | 0.074 | 0.044 | 0.065 | 0.040 |
| Z-test for diff. | | -0.112 | | 0.206* | | 0.117 |
| in means | | (0.094) | | (0.118) | | (0.122) |

Table 9. Information Asymmetry

This table reports additional results related to information asymmetry. The dependent variables, $LnPat_{t+1}$ is the natural logarithm of $(1 + \text{Pat})_{t+1}$, where *Pat* is the patent count in year *t + 1*. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)* and *Herfindahl*. The Z-test for difference in coefficients is a t-test of whether the difference between the coefficients on *High FX Exposure · Post* in the two sub-groups is statistically significantly different from zero. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | $\text{LnPat}_{t+1}$ | | | | | |
|---|---|---|---|---|---|---|
| | Analyst Coverage | | Intangible Assets | | Forecast Dispersion | |
| | Without | With | High | Low | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| High FX Exposure · Post | 0.197*** | 0.071 | 0.134*** | 0.123 | 0.191*** | -0.015 |
| | (0.055) | (0.089) | (0.042) | (0.105) | (0.054) | (0.135) |
| Ln(Sales) | 0.228*** | 0.314*** | 0.248*** | 0.270*** | 0.236*** | 0.309*** |
| | (0.053) | (0.054) | (0.071) | (0.048) | (0.048) | (0.096) |
| Book Leverage | -0.073 | -0.336** | -0.364*** | 0.057 | -0.113 | -0.475** |
| | (0.106) | (0.162) | (0.096) | (0.170) | (0.094) | (0.240) |
| Profitability | -0.233 | -0.308 | -0.441** | -0.193 | -0.253* | -0.258 |
| | (0.144) | (0.217) | (0.191) | (0.146) | (0.132) | (0.404) |
| Tangibility | -0.152 | 0.488 | 0.286 | -0.158 | 0.003 | 0.218 |
| | (0.271) | (0.291) | (0.241) | (0.234) | (0.210) | (0.335) |
| Ln(Age) | -1.024*** | -1.040*** | -1.256*** | -0.683*** | -0.990*** | -1.295*** |
| | (0.293) | (0.301) | (0.223) | (0.235) | (0.238) | (0.380) |
| Herfindahl | 0.061 | -0.151 | -0.085 | 0.079 | 0.016 | -0.058 |
| | (0.124) | (0.305) | (0.180) | (0.141) | (0.103) | (0.258) |
| Firm F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 12,298 | 6,572 | 10,996 | 7,874 | 15,587 | 3,255 |
| R-squared | 0.054 | 0.059 | 0.057 | 0.053 | 0.052 | 0.059 |
| Z-test for diff. | | 0.126 | | 0.011 | | 0.206 |
| in means | | (0.105) | | (0.113) | | (0.145) |

Table 10. Financial Constraints Channel: Supporting Evidence

This table report additional results for the Financial Constraints Channel. The dependent variables, $LnR\&D_{t+s}$ is the natural logarithm of $(1 + \text{R\&D})_{t+s}$, where *R&D* is the research and development expenses of firm $i$ in year $t+s$. $Debt\ Issue_{t+s}$ is debt issuance minus debt reductions plus changes in net debt of firm $i$ in year $t+s$ divided by its Assets in year $t+s-1$. $Debt\ Reduction_{t+s}$ is debt reductions minus changes in net debt of firm $i$ in year $t+s$ divided by its Assets in year $t+s-1$. $Equity\ Issue_{t+s}$ is sale of equity minus purchase of equity of firm $i$ in year $t+s$ divided by its Assets in year $t+s-1$. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)* and *Herfindahl*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | $\text{LnR\&D}_{t+1}$ | $\text{Debt Issue}_{t+1}$ | $\text{Debt Reduction}_{t+1}$ | $\text{Equity Issue}_{t+1}$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| High FX Exposure · Post | 0.003*** | 0.012** | -0.034** | 0.004* |
| | (0.001) | (0.006) | (0.016) | (0.002) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 18,870 | 18,870 | 18,870 | 18,870 |
| R-squared | 0.017 | 0.032 | 0.060 | 0.016 |
| | $\text{LnR\&D}_{t+2}$ | $\text{Debt Issue}_{t+2}$ | $\text{Debt Reduction}_{t+2}$ | $\text{Equity Issue}_{t+2}$ |
| High FX Exposure · Post | 0.003*** | 0.013*** | -0.035* | 0.006*** |
| | (0.001) | (0.005) | (0.018) | (0.002) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 18,008 | 18,008 | 18,008 | 18,008 |
| R-squared | 0.009 | 0.027 | 0.035 | 0.016 |
| | $\text{LnR\&D}_{t+3}$ | $\text{Debt Issue}_{t+3}$ | $\text{Debt Reduction}_{t+3}$ | $\text{Equity Issue}_{t+3}$ |
| High FX Exposure · Post | 0.003*** | 0.016*** | -0.036* | 0.006*** |
| | (0.001) | (0.006) | (0.020) | (0.002) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 17,142 | 17,142 | 17,142 | 17,142 |
| R-squared | 0.009 | 0.021 | 0.020 | 0.016 |

Table 11. Risk-Taking Channel

This table report results for the Risk-Taking Channel. The dependent variables, $LnSDCit_{t+s}$ is the natural logarithm of (1 + SD Cit)$_{t+s}$, where *SD Cit* is the standard deviation of citations to patents in year $t+s$. $LnCit0_{t+s}$ is the natural logarithm of (1 + Cit0)$_{t+s}$, where *Cit0* is the count of zero-cited patents in year $t+s$. $LnCit90_{t+s}$ is the natural logarithm of (1 + Cit90)$_{t+s}$, where *Cit90* is the count of the patents which have citations which are in the 90th percentile or higher for all patents in year $t+s$. $LnCit95_{t+s}$ is the natural logarithm of (1 + Cit95)$_{t+s}$, where *Cit95* is the count of the patents which have citations which are in the 95th percentile or higher for all patents in year $t+s$. The coefficient to *High FX Exposure · Post* is reported. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)* and *Herfindahl*. The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | LnSD Cit$_{t+1}$ | LnCit0$_{t+1}$ | LnCit90$_{t+1}$ | LnCit95$_{t+1}$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| High FX Exposure · Post | 0.041 | 0.111*** | 0.023 | 0.001 |
| | (0.038) | (0.042) | (0.023) | (0.021) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 14,234 | 14,234 | 14,234 | 14,234 |
| R-squared | 0.023 | 0.034 | 0.028 | 0.018 |
| | LnSD Cit$_{t+2}$ | LnCit0$_{t+2}$ | LnCit90$_{t+2}$ | LnCit95$_{t+2}$ |
| High FX Exposure · Post | 0.063 | 0.117*** | 0.029 | 0.002 |
| | (0.040) | (0.048) | (0.024) | (0.022) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 14,224 | 14,224 | 14,224 | 14,224 |
| R-squared | 0.021 | 0.034 | 0.026 | 0.017 |
| | LnSD Cit$_{t+3}$ | LnCit0$_{t+3}$ | LnCit90$_{t+3}$ | LnCit95$_{t+3}$ |
| High FX Exposure · Post | 0.040 | 0.123** | 0.027 | 0.001 |
| | (0.040) | (0.055) | (0.024) | (0.023) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 14,206 | 14,206 | 14,206 | 14,206 |
| R-squared | 0.018 | 0.034 | 0.024 | 0.015 |

Table 12. Innovation Strategies

This table reports additional results related to innovation strategies. The dependent variables, *Exploitative (Exploratory)* is the fraction of total patents which are exploitative (exploratory) patents of firm $i$ in year $t + s$. A firm's existing knowledge comprises of its existing patents and the patents that its existing patents cite. A patent is categorized as exploitative if at least 60% of its citations are based on the firm's existing knowledge and as exploratory if at least 60% of its citations are based on new knowledge, i.e., patents not in the firm's existing knowledge. Patents falling into the International Patent Classification (IPC) category B01 are defined as process patents, and all other patents are defined as product patents. *Process* is the natural logarithm of (1 + Process)$_{t+s}$, where Process is the process patents count in year $t + s$. *Depth* is the ratio of the number of repeated citations made by patents of a firm in year in year $t + s$ divided by the total number of citations made by all patents applied for in the same year. Repeated citations are citations that have been made by the firm in the past five years. *High FX Exposure* is an indicator variable which takes the value one if the firm has a positive and significant value of FX equity exposure before 1987, and zero otherwise, and variable, *Post* takes the value one for years after 1987 and zero otherwise. All specifications include firm and year fixed effects, and controls for *Ln(Sales)*, *Book Leverage*, *Profitability*, *Tangibility*, *Ln(Age)*, and *Herfindahl.* The standard errors, reported in parentheses, are heteroskedasticity consistent and clustered by industry. ***, **, and * denote significance at the 1%, 5% and 10% levels respectively.

| | Exploitative$_{t+1}$ | Exploratory$_{t+1}$ | Process$_{t+1}$ | Depth$_{t+1}$ |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| High FX Exposure· Post | 0.028** | -0.029** | 0.108** | 0.061 |
| | (0.013) | (0.012) | (0.048) | (0.046) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 7,907 | 7,907 | 14,396 | 7,765 |
| R-squared | 0.532 | 0.416 | 0.837 | 0.204 |
| | Exploitative$_{t+2}$ | Exploratory$_{t+2}$ | Process$_{t+2}$ | Depth$_{t+2}$ |
| High FX Exposure · Post | 0.030** | -0.035*** | 0.119** | 0.073 |
| | (0.013) | (0.012) | (0.047) | (0.051) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 7,902 | 7,902 | 14,384 | 7,761 |
| R-squared | 0.533 | 0.416 | 0.836 | 0.206 |
| | Exploitative$_{t+3}$ | Exploratory$_{t+3}$ | Process$_{t+3}$ | Depth$_{t+3}$ |
| High FX Exposure · Post | 0.027** | -0.021* | 0.104** | 0.074 |
| | (0.013) | (0.010) | (0.047) | (0.053) |
| Controls | Yes | Yes | Yes | Yes |
| Firm F.E. | Yes | Yes | Yes | Yes |
| Year F.E. | Yes | Yes | Yes | Yes |
| Observations | 7,897 | 7,897 | 14,364 | 7,755 |
| R-squared | 0.534 | 0.415 | 0.835 | 0.206 |

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