The Bank Lending Channel and Corporate Innovation

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Preliminary Draft: Please do not cite or circulate without the author's permission.

April 6, 2014

Abstract

The purpose of the paper is to examine the impact of credit supply frictions on corporate innovation. In order to document the causal relationship between bank credit supply and corporate innovation, I exploit the cross-sectional dispersion in lender health induced by the collapse of Lehman Brothers as a source of exogenous variation in the availability of bank credit to borrowers. I find that there is a causal effect of disruptions in the bank credit market on both innovation output measured by the number of patents issued by a firm and the innovation impact captured by the number of non-self citations. In particular, firms that were maintaining a relationship with financial institutions that the liquidity shock induced a significantly less contraction in lending activity, increased innovative output by 7.2% followed by a 9.1% increase in non-self citations, as compared to firms that faced a higher credit supply decline. My evidence indicates that relationship lending fosters corporate innovation and that bank financing is material for the investment in the innovative process, thus leading to technological progress.

JEL-Classification: G21, G28, G34, O16, O31

Keywords: 2007-2009 Financial Crisis, Bank Lending Channel, Credit Supply, Relationship Lending, Innovation, Innovative Efficiency, Lehman Brothers' Collapse, Loan Syndication

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1 Introduction

Innovation is considered to be a driving force of firm growth allowing a means of differentiation from competition and of establishing a dominant role in an industry. As innovative activity is facilitated by the well-functioning of financial systems, the purpose of the paper is to investigate the potential link between frictions in credit supply and corporate innovation. Indeed, the causal effect of credit supply shocks on firms' innovative activity has escaped research attention, and the paper intends to complement the literature motivated by the recent financial crisis and provide empirical evidence in this direction. The focus on corporate innovation is reinforced by the fact that innovation is an important driver of economic growth (Solow (1957)) and a source of competitive advantage for firms (Porter (1992)) implying that maintaining the innovative activity of firms has been potentially part of the reasoning behind the policymakers' stance towards government support in the recent financial crisis. Besides, while extant literature has investigated the connection between corporate innovation and venture capital or private equity funding (e.g. Kortum and Lerner (2000); Lerner et al. (2011)), the impact of bank financing on fostering innovation remains a matter of debate due to theoretically ambiguous predictions as well as endogeneity concerns.

On the one hand, there is the notion that the use of bank credit is considered inappropriate to finance innovative activity either due to the uncertain nature of the outcome of the innovation process that discourages relationship-based lenders from providing funds or because of the lack of knowledge to evaluate the prospects of investment in an innovative technology (Scherer (1984); Atanassov et al. (2007)). On the other hand, in the presence of costs in public markets related to disclosure of sensitive information or higher expected returns due to information asymmetry issues, relationship lending provides a better alternative to finance innovative activity by easing information frictions and ensuring efficient effort through monitoring. Therefore, by exploring and delving deeper into the relationship between corporate innovation and bank credit supply is important so as to identify the optimal financing source to support technological progress. However, corporate innovation is likely endogenous with firm and market characteristics, including the level of bank credit supply and the firm choice between relationship-based financing and arm's length financing. In other words, firms have heterogeneous access to different funding sources implying that frictions in the supply of bank credit may be irrelevant for both the decision of the firm to innovate and the level of innovation conditional on engaging in innovative activity. Besides, even in the presence of a positive correlation between the level of bank financing and corporate innovation, we are unable to distinguish whether the increase in innovative output by acquiring additional bank credit is due to the actual use of the additional bank credit to finance the innovation process or due to relaxing financial constraints leading to diverting internal funds to the investment in innovative technology. Thus, a correlation between credit

supply changes and innovation contributes only a little in predicting the existence of a causal effect of bank credit supply on innovation.

In order to alleviate the endogeneity problem and identify the causal relationship between access to bank credit and corporate innovation, I focus on the syndicated loan market and exploit the cross-sectional dispersion in lender health induced by the collapse of Lehman Brothers as a source of exogenous variation in the availability of bank credit to borrowers. Specifically, I hypothesize that firms that maintained lending relationships with financial institutions that were highly exposed to the negative liquidity shocks during the crisis were forced to reduce innovative activity. Indeed, the government decision not to provide support and allow Lehman Brothers to go bankrupt was considered unexpected, thus providing a useful laboratory to identify the relationship between corporate innovation and relationship lending. The rationale is that the collapse of Lehman Brothers imposed a liquidity problem in the financial institutions with which Lehman had a co-syndication relationship, as the exposed financial institutions were forced both to replace the role of Lehman in the syndicated loan and to be confronted with additional drawdowns in case of maintaining credit lines with the borrowers. Besides, as the impact was heteregeneous among lenders based on the exposure on the failing institution, the exogenous variation created is useful to examine the differential response of firms to the level and the quality of innovative activity. Therefore, the research design that I consider compares firms at the same point in time that have been subject to the same shock in an heteregeneous manner based on the level of exposure to the differentially liquidity-struck financial institutions. Firms that were dependent to less exposed financial institutions act as the control group in a continuous treatment difference-in-differences experimental design, thus separating the impact of bank credit supply contractions on corporate innovative policies.

The implicit assumption that allows me to identify a causal relation between changes in the supply of bank credit and corporate innovation depends on the extensively examined and well-established fact that the 2007-2009 financial crisis originated in the subprime mortgage market leading to a supply-side contraction in the lending activity that is unrelated to pre-crisis borrowers' characteristics. In other words, financial institutions decreased lending activity in the syndicated market for reasons that are independent of the quality of the pre-crisis loan portfolio, otherwise the ability to attribute any potential empirical impact on corporate innovation to a bank lending contraction channel would be shadowed by an alternative explanation pointing to the deterioration in firm performance as the factor affecting innovative activity. Moreover, in order to establish a causal interpretation of the effect of bank lending contraction on innovation, I rely on the assumption that the notion of relationship lending exists implying that bank-borrower relationships are sticky and play an important role in corporate policies. Therefore, firms that were dependent on finan-

cial institutions highly exposed to the collapse of Lehman Brothers due to co-syndication - thus induced to engage in a sharp decline in lending activity - were constrained in terms of acquiring additional bank financing by the lenders of the pre-crisis syndicate as switching between lenders is costly.

I find that there is a causal effect of disruptions in the bank credit market on both innovation output measured by the number of patents issued by a firm and the innovation impact captured by the number of non-self citations. In particular, firms that were maintaining a relationship with financial institutions that the liquidity shock induced a significantly less contraction in lending activity, increased innovative output by 7.2% followed by a 9.1% increase in non-self citations, as compared to firms that faced a higher credit supply decline. My evidence indicates that relationship lending fosters corporate innovation and that bank financing is material for the investment in the innovative process, thus leading to technological progress.

A challenge that I encounter is that unobservable firm characteristics drive both the the level of exposure and the firm response to the shock. There could be a case where borrowers of financial institutions that were more exposed to the collapse of Lehman Brothers share unobservable characteristics that influence both the demand for bank lending and corporate innovation. In order to overcome the aforementioned identification challenge, I address the concern using the following remedies. First, I control for a battery of observed borrower characteristics, including firm-level variables that may be correlated with both borrowing behavior and innovative activity, along with industry characteristics in the form of fixed effects. Most importantly, I follow Chodorow-Reich (2014) and employ a specification that relies on the Khwaja and Mian (2008) within-firm estimator, which uses borrower fixed effects to absorb variation in unobserved borrower characteristics. In case there is no change in the significance and magnitude of the estimated effect of lender heath in specifications that include or exclude the within-firm estimator directly demonstrates the internal validity of our identification strategy and mitigates the concern of unobserved characteristics correlated with lender health within the subsample of firms that obtain a new loan during the crisis. Third, I conduct placebo regressions corresponding both to the 2001 recession and to a period that there is no explicit expected relation between corporate innovations and conditions in the lending market as a means to validate the supply-side nature of the 2007-2009 crisis and justify the use of the cross-sectional dispersion in lender health induced by the collapse of Lehman Brothers as a source of exogenous variation. The results invalidate the soundness of the natural experiment design by providing support for the parallel trends assumption and indicate no false positives.

Moreover, I exploit cross-sectional variation in the innovative efficiency within the firms that were exposed to the supply-side credit shock in order to explain anecdotal evidence and validate existing empirical results (Almeida, Hsu and Li (2013)) that support the notion that financial constraints may induce taking

steps towards improving firm-level operational efficiency. Indeed, financially constrained firms may benefit innovation by leading to an increase in the level of innovative efficiency and alleviating agency problems of excess free cash flow that induce inefficient and unproductive R&D investment. My results support the above hypothesis.

The results of the paper suggest that government policies that aim at bailing-out financial institutions and providing aggregate liquidity in the lending market may lead to positive spillovers in the economy by boosting innovative activity and, thereby, nurturing long-term economic growth. Bailing-out financial institutions in times of financial crises has been used extensively as an important policy tool to overcome credit supply disruptions and ameliorate tightening liquidity constraints. Indeed, in the burst of the 2007-2009 financial crisis, a material part of the policy response aimed at providing substantial government support to financial institutions so as to channel the flow of the credit provided to the real economy, while re-establishing systemic stability and guaranteeing the well-functioning of the financial system. The proponents of bailing-out strategies as a policy response to financial crises have provided economic stimulus arguments related to confronting potential unfavorable outcomes in the real economy (e.g. unemployment) that hinder economic growth and arise as a result of a sharp decline in bank lending. However, the benefits have been widely disputed. The magnitude of the bailouts expenses led to the policy receiving considerable attention by the public and being subject to criticism in terms of the inappropriateness in the use of government funding by the financial institutions and the inadequacy of the policymakers to control whether the government support is directed in an optimal manner minimizing potential social costs. Yet, Eurozone followed the U.S. paradigm in providing government funds to support failing institutions. Interestingly though, as Eurozone is still struggling to recover after the capital injection of $600 billion into the teetering European banks and the provision of $1.5 trillion guarantees, the member countries are moving towards a bail-in framework that is supposed to insulate taxpayers from immense rescue costs. Indeed, the criticism against bailout policies has been magnified by considering the long-term moral hazard concerns induced by the differential allocation of capital among financial institutions and the fiscal implications that triggered a tremendous hit on government deficits accelerating the European sovereign debt crisis. However, despite the central role of bailout mechanisms as a policy tool against financial crises, there is limited empirical evidence of potential spillovers in the real economy and the one that exists is focused either on the impact of credit availability on banks' financial claims (e.g. Veronesi and Zingales (2010); Bayazitova and Shivdasani (2012)) and the adjustment of the lending behavior of financial institutions (e.g. Peek and Rosengren (2005); Caballero, Hoshi, and Kashyap (2008)) or on corporate policies (e.g. Campello et al. (2010); Duchin et al. (2010); Giannetti and Simonov (2013)). Notable exceptions that explore non-financial outcomes are studies that examine the implications of the 2007-2009 financial crisis on

employment outcomes or growth (e.g. Feyrer and Sacerdote (2011); Oh and Reis (2012); Chodorow-Reich (2014)). Thus, my paper provides support for the existence of positive spillover of bailout mechanisms as bank credit contraction has a detrimental impact on corporate innovation.

Besides, the empirical findings reinforce the importance of bank credit for both the well-functioning and potential growth of firms. To the best of my knowledge, mine is the first study to: (i) examine directly the impact of the bank credit supply channel and the availability of bank financing in the innovative activity of firms through the contraction in bank lending during the 2007-2009 financial crisis as opposed to the existing literature that addresses the issue indirectly through the impact of banking deregulation and the easing of competition, (ii) add on the empirical results of the implications of the 2007-2009 financial crisis on non-financial outcomes, and (iii) demonstrate further the impact of financial constraints on innovative efficiency by addressing financial constraints induced by relationship lending.

The rest of the paper is organized as follows. In section 2, I briefly review related literature. Section 3 presents institutional details describing briefly the mechanisms of the syndicated loan market and the nature of the 2007-2009 financial crisis. In section 4, I explain the sources and construction of the data used in the empirical analysis, while in section 5 I discuss the methodological approach applied. The empirical results are presented in Section 6 and the robustness checks are employed in Section 7. Finally, I provide concluding thoughts in Section 8.

2 Related Literature

My paper is related and contributes to two strands of literature. Following the 2007-2009 financial crisis, there has been generated an ample literature in an effort to explain the origins of the financial crisis and the impact on firm-level variables (Gorton and Metrick (2012) provide a comprehensive review). My paper is close to the category of empirical papers that study the effects of credit supply by exploiting potential constraints in credit availability induced by crises as a source of exogenous variation (Campello et al. (2010); Duchin et al. (2010); Lemmon and Roberts (2010); Lin and Paravisini (2011)). In particular, Khwaja and Mian (2008) exploit the 1998 unanticipated Pakistani nuclear tests that induced heterogeneous liquidity shocks to examine the impact of bank credit contraction on different firm types and Paravisini (2008) exploits a formula-based allocation of government capital to banks in Argentina to explore the potential impact on lending behavior and the aggregate credit supply. Slovin, Sushka, and Polonchek (1993) and Ongena, Smith, and Michalsen (2003) focus on the stock price reaction of the firms that are exposed to failing financial institutions. Besides, the Japanese banking crisis has been used to examine lending

contraction effects (Peek and Rosengren (1997); Peek and Rosengren (2000); Gan (2007a,2007b); Amiti and Weinstein (2011)) and the impact on corporate policies (Giannetti and Simonov (2013)), while Chava and Purnanandam (2011) and Schnabl (2012) use the 1998 Russian crisis as an exogenous shock to the U.S. banking system and as a liquidity shock transmission mechanism in an international setting respectively. Almeida et al. (2012) focus on firm heterogeneity in the maturity structure of debt to examine the impact of the recent financial crisis on corporate investment, while Ivashina and Scharfstein (2010) and Cornett et al. (2011) on lending by banks with exposure to Lehman Brothers' collapse through co-syndication.

Second, the paper contributes to the literature on the links between firm and market characteristics and innovative activity. The literature provides evidence on the relation between innovation and competition (Aghion et al. (2005)), capital development (Benfratello et al. (2008)), or exploits differences in the regulatory environment in terms of bankruptcy legislation (Acharya and Subramanian (2009)) or labor laws (Acharya et al. (2010)). Ownership structure and the decision to go public (Bernstein (2013); Ferreira et al. (2012)) have been used to explain the varying levels of innovation among firms. In particular, Aghion, Van Reenen, and Zingales (2012) focus on the role of institutional ownership as a monitoring mechanism to explain the positive relation between innovative activity and institutional ownership and Guadalupe, Kuzmina and Thomas (2012) point to the link between foreign ownership and corporate innovation. Seru (2011) takes advantage of conglomerate characteristics to examine the relation between firm boundaries and innovation, while Chemmanur and Tian (2013) focus on corporate governance effects. Finally, Tian and Wang (2011) look at the impact of investors attitudes towards failure on innovative activity, while Fang et al. (2011) and He and Tian (2012) explore the relation of innovation with stock market characteristics such as stock liquidity or analyst coverage respectively.

My paper is closer to the contemporaneous literature that focuses either on the impact of banking deregulation on innovative performance (Cornaggia, Tian and Wolfe (2013); Amore, Schneider, and Zaldokas (2013); Chava et al. (2013); and Hombert and Matray (2012)) or on the relation between financial constraints and innovative efficiency (Almeida, Hsu and Li (2013)). Indeed, these papers either take advantage of the passage of interstate and intrastate banking deregulation that has taken place in the U.S. banking industry during the 1980s and 1990s as a means to alleviate endogeneity concerns and identify the impact of banking development and competition on corporate innovation or examine the impact of financial constraints on innovative efficiency by exploiting the 1989 junk bond crisis and the mandatory contributions to defined benefit pension plans. Amore, Schneider, and Zaldokas (2013) provide evidence that interstate banking deregulation had a beneficial impact on innovation by public firms, whereas Cornaggia, Tian, and Wolfe (2012) find results in the opposite directions. Hombert and Matray (2012) find that intrastate

deregulation decreased innovative activity in all firms, while Chava et al. (2013) present contrasting effects between intrastate branching and interstate banking deregulation on innovation focusing primarily on young, private firms. Almeida, Hsu and Li (2013) document an increase in the innovative efficiency by financially constrained firms providing as an explanation the mitigation of agency problems of free cash flows. I differ from the aforementioned studies in four important ways. First, unlike the contemporaneous literature that focuses on banking development through the impact of banking deregulation on innovation, I document the explicit effect of the contraction in the bank lending channel that has been induced as a result of the 2007-2009 financial crisis. Therefore, I exploit existing borrower-lender relationships to uncover the potential impact of credit supply frictions on innovative activity. Second, I explore the heterogeneous outcomes in innovation based on the expected reliance on the bank credit channel according to various firm-level (size, age, private vs. public) and industry characteristics. Third, I demonstrate further the impact of financial constraints on innovative efficiency by addressing financial constraints induced by the availability of a bank credit channel contrary to financial constraints induced by access to public debt or precautionary savings policy and shed light on the different channels through which the effect in innovative efficiency takes place. Finally, I explore further the non-financial outcomes of the 2007-2009 financial crisis providing additional insight into the appropriateness of using government funds to support financial institutions.

3 Institutional Background

3.1 The Syndicated Loan Market

The syndicated loan market has rapidly expanded since its origination during the 1980s, turning into the dominant source of funding from financial institutions and institutional investors during the 2000s. The syndication process initiates with the lead arranger agreeing on the provision of funding in a preliminary basis with a borrowing firm, specifying the primary loan terms including the loan amount, the interest rate, potential existence of covenants, lending fees and the potential pledge of specific collateral requirements. Then, the lead arranger retains a large share of the loan and turns to potential participants willing to contribute to the financing deal. Whereas the lead arranger is responsible for the initial screening, monitoring and subsequently managing the lending contract, thus establishing a relationship with the borrower, the rest of the participants maintain an arm's length relationship with the borrower through the lead arranger. The financing provided through the syndicated loan market ranges from term loans for different purposes to revolving lines of credit.

The structure of the syndicated loans has been extensively examined in the literature as a means to identify the impact of asymmetric information among the participants in a syndicated loan due to the fact that the traditional informational asymmetry problem between the lender and the borrower is exacerbated by the existence of heterogeneous interests and delegation problems among syndicates. Dennis and Mullineaux (2000), Lee and Donald (2004), and Sufi (2007) provide empirical evidence consistent with the asymmetric information concerns documenting either an increase in the lead arranger's share in the case of opaque borrowers or the existence of small and concentrated syndicates in case of unavailability of information about the borrower. Besides, Gatev and Strachan (2009) examine the impact of liquidity risk management on syndicate structure, finding that commercial banks that are capable of absorbing liquidity risk, possess a higher stake of the syndicated market for lines of credit.

3.2 The 2007-2009 Financial Crisis and the Lehman Brothers' Collapse

The 2007-2009 financial crisis originated in the subprime mortgage market once the Federal Home Loan Mortgage Corporation (Freddie Mac) announced the termination of the purchase of risky subprime mortgages and mortgage-related securities, leading Bear Sterns to suspending redemptions of the High-Grade Structured Credit Strategies Enhanced Leverage Fund and subsequently liquidating two hedge funds that invested in mortgage-backed securities. BNP Paribas followed by halting redemptions on three investment funds inducing a sharp increase in the interest rate in the interbank market. Financial markets pressures intensified - as reflected in the decline in aggregate liquidity in interbank funding markets - and the need to engage in consolidation activity in the banking industry arises as a means to limit the adverse effects of the financial panic. Bank of America proceeded with the purchase of Countrywide Financial, while JPMorgan Chase agreed to engage in a financing arrangement with Bear Stearns. In an effort to prevent further contagion effects, the Federal Reserve Board announced that "the FED is monitoring market developments closely and will continue to provide liquidity as necessary to promote the orderly function of the financial system" and agreed to provide term financing to facilitate JPMorgan Chases acquisition of Bear Stearns.

Despite a temporary stabilization period induced by the continuous effort of the Federal Reserve Board to provide liquidity, Lehman Brothers filed for Chapter 11 bankruptcy protection on September 15, 2008 having recorded a $3.9 billion loss for the third quarter of 2008, while Bank of America announced its intent to purchase Merrill Lynch for $50 billion. The collapse of Lehman Brothers induced an immediate decline in the confidence among financial institutions leading to a sharp drying-out in the interbank market liquidity and exacerbating the need for government intervention as a source of liquidity in the financial markets. As a result, the Federal Reserve Board authorized the Federal Reserve Bank of New York to lend up to $85

billion to the American International Group (AIG), supported the forced sale of Wachovia and introduced the unpopular policy response to provide substantial government support for financial institutions through the TARP funds. The situation started to improve with the financial crisis to be considered to come to an end in the mid of 2009. Following the constraints in the provision of interbank liquidity and the timeline of the crash of financial markets, the quantity of credit supply by financial institutions in the syndicated loan market followed a similar pattern.

4 Data

4.1 Sample Construction and Summary Statistics

Syndicated loan information comes from the Loan Pricing Corporation (LPC)'s Dealscan database. The data that are available comprise the identities of the borrowing entity and the lending institution that participated in the deal at origination, the terms of the loan, and the purpose of the loan. I focus on non-financial U.S. borrowers - by excluding borrowers performing in industries with SIC codes 6011-6799 - that have either obtained a syndicated loan between 2004 and August 2008 or obtained a loan prior to 2004 that matured after October 2007 with the purpose reported being either "working capital" or "corporate purposes". The selection of the previous sample is imposed by the requirement to capture and focus on borrowers that have an active relationship with a syndicate before or during the crisis so as to test the implications of the heterogeneous contraction in the credit supply for each borrower. In other words, the assumption is that in the presence of relationship lending, borrowers are going to extend or look for additional financing from the lenders that maintain an active relationship with. Besides, restricting the sample to facilities with the purpose either to be reported as "working capital" or "corporate purposes" is based on the fact that R&D is a crucial operation for the majority of corporations and, therefore R&D expenses are part of the working capital needs of a firm. Finally, I remove borrowers with missing information on industry, state, or public/private status leading to a sample of 5,069 unique borrowers and 12,938 loans. The crisis period is considered to be the the nine-month period from October 2008 to June 2009.

Information related to financial data of lenders is collected by hand-matching at the holding company level between the name, the geographic location and the operational period as reported in Dealscan and as presented in the Federal Reserve FR Y-9C Consolidated Financial Statements for Bank Holding Companies (for lenders where the highest level parent is either a domestic financial holding company or a domestic bank holding company), and in SNL Financial Institutions database (for foreign holding companies and

investment banks). In order to control for mergers prior to the burst of the crisis, the acquiring lenders inherit the target's syndicated lending relationships with both borrowers and other lenders, thus transferring the unexpired loans at the date of the merger to the acquirer's record. For mergers that take place following the collapse of Lehman Brothers, I maintain separate identifiers for the acquiring and the target firm, although in estimating lending supply changes I consider as borrowing from the target if a borrower of the target in the pre-crisis period obtains a crisis loan from the acquirer. Besides, I use the linking table between Dealscan and Compustat following the details provided in Chava and Roberts (2008) in order to match the borrowing firm to Compustat. In case of private firms, I hand-collect financial data from CapitalIQ using the name and geographic and industry identifiers of the borrowing entity.

Innovation data are extracted using existing patent databases that have gathered and compiled either innovation output data or both patent and citation data. As the patents file compiled by the National Bureau of Economic Research (NBER) provides patent coverage only between January 1976 and December 2006, I employ the Harvard Business School (HBS) patent database that provides coverage until 2010 and the KPSS patent database that has been introduced in Kogan et al. (2012). The HBS data contain all electronic records of the U.S. Patent and Trademark Office (USPTO) through 2010, however these records have been researched and consolidated, which is important since the names of assignees in the original USPTO database are riddled with misspellings and inconsistencies. The KPSS patent database includes the patents filed and eventually granted between 1926 and 2010 and contains the USPTO patent number which uniquely identifies the patents, along with CRSP unique identifier permno. It is necessary to mention that neither the HBS nor the KPSS patent database is likely to be affected by a survivorship bias issue. As long as a patent application is eventually granted, it is attributed to the applying firm at the time of application even if the firm later gets acquired or goes bankrupt. Moreover, since patent citations are attributed to a patent rather than the applying firm, the patent granted to a firm that later gets acquired or goes bankrupt can still keep receiving citations long after the firm disappears. Besides, both the HBS and the KPSS patent database do not share a common identifier with LPC Dealscan. As a result, I consider the following process to match the innovation and loan databases. First, I take advantage of the Compustat-CRSP linking table to associate patents from the KPSS database to public firms that appear in Compustat and, then use the Compustat identifier to get a link to my loan sample. Following the aforementioned procedure, I manage to link 877 borrowers. As regards the connection with the HBS database, I hand-match the databases based on information on the names of the borrowers and the assignees along with state and zip code identifiers leading to an additional match of 839 borrowers. Therefore, the final merged sample contains around 1,700 firms corresponding to about one third of the original Dealscan dataset. Next, using the USPTO patent number that exists and is unique in both the KPSS and HBS

patent database, I merge the patents with Harvard Patent Database, which provides detailed information about citations, patent classes and subclasses so as to gauge information on the impact of innovation.

Panel A of Table 1 concentrates on firm characteristics and provides a comparison between the full sample of borrowers with the subsample of borrowers after merging with USPTO data. Each borrower appears exactly once in the sample as I limit the sample to include only the last pre-crisis loan. It is apparent that the process of merging the Dealscan sample with data on innovation has no material effect, thus purging any sample selection issues. In fact, the full sample is quite similar to the merged one on the observable characteristics as firms match both on the size distribution and the risk characteristics.

4.2 Measures of Bank Health

The measure of loan supply that I consider is the one proposed in Chodorow-Reich (2014) and is defined based on the difference in the quantity of loans initiated by lender b to all borrowers other than firm i before and after the collapse of Lehman Brothers. The pre-crisis period that is considered is from October 2005 to June 2007, while the crisis period is from October 2008 to June 2009. The loan quantities have been weighted based on the participation rates of the lender in the syndicated loan. Hence, letting $L_{-i,b}$ equal 1 if bank b has a lending relationship with borrower j in period t and $a_{b,j,t}$ equal the participation rate of the syndicated loan, the change in the credit supply for a lender-borrower pair is constructed as follows:

$$\Delta L_{-i,b} = \frac{\sum_{j \neq i} a_{b,j,crisis} L_{b,j,crisis}}{0.5 \sum_{j \neq i} a_{b,j,pre-crisis} L_{b,j,pre-crisis}} \tag{1}$$

Then, the final measure of bank health corresponding to the last pre-crisis syndicated loan of each borrower is based on the participation rates of each lender of the last pre-crisis syndicated loan and the above measure of change in lending quantities before and after the Lehman collapse:

$$\Delta \tilde{L}_{i,s} = \sum_{b \in s} a_{b,i,last} \Delta L_{-i,b} \tag{2}$$

In case the actual share of each lender in a loan commitment is missing in Dealscan, the participation rate is calculated as the average share of lead lenders and participants in a facility involving the same structure.

Besides, I follow Ivashina and Scharfstein (2010) and estimate the exposure for each lender based on the fraction of outstanding loans co-syndicated with Lehman and in which Lehman is the lead arranger over

the total number of outstanding facilities at the time of the collapse as an additional measure to invalidate the causal relationship between credit supply frictions and corporate innovation. Then, for each borrower the level of exposure to the shock is given by:

$$LehmanExposure_{i,s} = \sum_{b \in s} a_{b,i,last} LehmanExposure_b \tag{3}$$

Finally, I augment the analysis by examining the relation with a battery of observable bank balance sheet and income statement measures in my empirical specification that were suggested in the existing literature. In particular, I consider the following observable bank characteristics:

- **Level of Core Deposits**: The level of deposits is constructed as the ratio of deposits to assets at the end of 2007 and is considered to capture the level of financial flexibility and liquidity of the funding base of the financial institutions.
- **Capital Ratio**: The capital ratio is measured as the ratio of equity capital to total assets at the end of 2007 and captures the ability of a financial institution to absorb losses in the loan portfolio and correspond to liquidity shocks in an efficient manner.
- **Trading Revenues**: The measure is constructed as the ratio of trading revenue to total assets over 2007-2008 and captures the variation in the bank losses in their trading accounts due to the subprime write-downs.
- **ROA**: The profitability measure is estimated as the ratio of total revenues to total assets over 2007-2008 and captures the performance of a financial institution.
- **Loan Losses**: The measure is the net loan charge-offs over 2007-2008 and captures the quality of the portfolio of a financial institution and the provisions that a financial institution considers based on the expectations of the loan portfolio behavior.
- **Net Real Estate Charge-offs**: As the crisis was triggered by the meltdown of the market for mortgage-backed securities, the banks exposure to the MBS market has been considered as an instrument for exposure to the crisis and variation in bank losses.

Panel B of Table 1 provides summary statistics for the observable bank characteristics. The final sample includes 61 banks. Financial institutions respond to the liquidity shock with an extensive contraction in lending activity following the Lehman collapse. The average bank has $702 million in assets in the pre-Lehman period and negative profitability in 2008.

In order to evaluate the effectiveness of the measure of bank health to fulfill the role of capturing the relevant exposure to the liquidity shock and the relatedness to observable measures of bank health, I examine whether the change in the lending activity of the financial institutions - as captured by the change in the number of loans in the period before and after the Lehman collapse - is correlated with the Lehman exposure measure and the observable bank performance characteristics. Therefore, I report the correlation of the main lender health measure with bank characteristics based on the following specification:

$$\Delta L_b = \alpha + \beta H_b + u_b \tag{4}$$

ΔL_b is the change in the number of loans and H_b is either the alternative bank exposure measure ($LehmanExposure$) or a vector of bank variables that includes the above observable characteristics.

The results are presented in Table 2 demonstrating that there is a significant contraction in the bank lending channel following the Lehman collapse, the dispersion of which among financial institutions is sufficiently captured by the bank health measures proposed. In particular, the credit supply measure is negatively correlated with the exposure to the Lehman collapse, indicating that the contraction in bank credit is supply-driven. Besides, the results exhibit that financial institutions with a higher deposits over assets ratio involved in higher lending activity during the crisis implying that banks ex-ante healthier to absorb the liquidity shock had the propensity to lend more during the crisis. However, there are still concerns of a potential credit demand channel, as borrower characteristics are absent and, thus, bank-firm matchings may drive both the change in credit supply and the exposure level to the Lehman collapse. I discuss and exhibit tests that alleviate these concerns in Section 5.

4.3 Measures of Innovation and Innovative Efficiency

In order to proxy for the level of innovative output, I use the number of patents filed by firms with the United States Patent and Trademark Office (USPTO) and subsequently granted. However, the aforementioned measure is unable to capture the impact of a patent and to distinguish influential from incremental innovation. Therefore, I augment the innovation analysis with a measure of corporate innovation that depends on the the total number of non-self citations received by a patent in subsequent years (Griliches (1990) and Hall, Jaffe, and Trajtenberg (2001)).

Following the existing innovation literature, I adjust the innovation measures used to address the truncation problems associated with the innovation data. The first truncation problem is the result of the fact that patents appear in the database only after they are granted, leading to a mechanical gradual decrease in

the number of patent applications that are eventually granted as we approach the last years in the sample period. The aforementioned truncation occurs because the lag between a patent application year and the year that is granted is significant (about two years on average) and patent applications filed during the last years of the sample were under review and had not been granted by 2010. In order to overcome the problem, I supplement the patent data by manually collecting the patents granted since 2010 through the U.S. Patent and Trademark Office (USPTO) website for each firm in my sample. Therefore, as I gradually incorporate the patents filed until 2010 but granted since then and until the end of 2013 (3-year period) I overcome the truncation bias. However, the results are similar by following Hall, Jaffe, and Trajtenberg (2001) and correcting for the truncation bias in patent counts using the weight factors computed from the application-grant empirical distribution.

The second type of truncation problem considers the citation counts, as a patent is cited over a long period of time, but only citations up to 2010 are observed. Following Hall, Jaffe, and Trajtenberg (2001), I correct for the truncation in citation counts by estimating the shape of the citation-lag distribution.

Besides, following Seru (2011) I adjust citations in an attempt to control for the patenting and citing propensities associated with application year and technological class. In particular, I scale the number of citations received by each patent by the average number of citations received by patents applied in the same year and assigned to the same technological class.

Finally, as a measure of innovative efficiency I use patents or patent citations scaled by R&D investment (Lanjouw and Schankerman (2004); Hirshleifer et al. (2012); Acharya et al. (2012a and 2012b); Almeida et al. (2013)). Similarly, I follow Almeida et al. (2013) and adjust innovative input (the denominator of the IE measures) by scaling R&D by the corresponding industry average R&D expense in the same year based on Fama-French (1997) 48 industry classifications to remove the industrial component in R&D expenditures.

Panel C of Table 1 includes summary statistics corresponding to measures of innovation demonstrating the decline in the innovative output of firms. Specifically, in the subsample of firms that involve in innovative activity, the effect appears to be more pronounced.

5 Revisiting Assumptions

5.1 Relationship Lending

The purpose of the paper is to examine the impact of credit supply frictions on the innovative activity of firms. To the extent that relationship lending is important in the process of obtaining access to bank credit, the relationship under study is meaningful. Therefore, I provide a concise review of the literature that highlights the importance of relationship lending and I demonstrate through an elementary specification evidence of bank-firm stickiness.

There is a large literature that supports the ability of strong bank relationships to mitigate informational asymmetry concerns and agency problems (Diamond (1984); Boyd and Prescott (1986); Boot(2000)). James (1987) and Billett et al. (1995) highlight the fact that there is a positive stock price reactions in the announcement of bank loan commitments providing evidence of relaxing informational concerns. Rajan (1992), Petersen and Rajan (1994), Berlin and Mester (1998) and Cole (1998) document that relationships are valuable as strong and persistent ties between a firms and creditors have a beneficial impact on both the availability and the cost of funding, while Berger and Udell (1995) focus on the impact of relationship lending on relaxation of collateral requirements. Puri (1996) and Drucker and Puri (2005) demonstrate the relation between bank-firm relationships and obtaining favorable terms in bond issues underwritten by relationship banks, and Bharath et al. (2011) show that relationship lending is accompanied by a significantly lower interest rate. However, there is evidence of a detrimental effect of bank-firm relationship in the presence of informational holdup problems (Santos and Winton (2008)), while Gopalan et al. (2011) provide evidence of switching lenders using data on syndicated loans.

Therefore, in order to examine the potential existence of relationship lending, I use the following specification that examines the propensity of a lender to be either the lead arranger or participant in a new syndicated loan having already assumed the same role in a previous commitment of the same borrower:

$$Lead_{i,b} = \alpha + \beta PreviousLead_{i,b} + \gamma PreviousParticipant_{i,b} + FE_{lender} + FE_{industry-lender} + u_{i,b} \quad (5)$$

$$Participant_{i,b} = \alpha + \beta PreviousLead_{i,b} + \gamma PreviousParticipant_{i,b} + FE_{lender} + FE_{industry-lender} + u_{i,b} \quad (6)$$

The period considered is from 2003 to June 2009 and the sample consists of loan commitments that correspond to a borrower that has already used the syndicated loan market before. For each loan related to a borrower that has already obtained a loan commitment, I match the lenders that are currently active in the syndicated loan market. Then the dependent variable $Lead_{i,b}$ or $Participant_{i,b}$ is equal to one in case the corresponding lender is either the lead arranger or the participant respectively in the current loan commitment, while the independent variables $PreviousLead_{i,b}$ and $PreviousParticipant_{i,b}$ account for the existence of a repeated borrower-lender relationship. The specification is augmented with lender fixed effects and industry-lender fixed effects to account for an industry specialization effect. The results provide evidence of a potential relationship lending channel as the significant coefficients of the regressors reveal the higher propensity of a lender having either the lead arranger or the participant role in a previous loan of a borrower to assume the same role in the subsequent commitment of the same borrower. In particular, there is 65% higher likelihood that a lead arranger in a previous syndicate is going to assume a lead role in case of re-accessing the lending market, while the probability of a previous participant to provide financing in the issuance of new bank debt is around 50%. The results provide support to the previous literature (e.g. Sufi(2007)) that focus on the mitigation of asymmetric information concerns to explain the structure of syndicates.

5.2 Borrower Characteristics

The crucial assumption that allows me to identify a causal relation between relationship lending and corporate innovation is that the supply changes in the lending activity before and after the Lehman collapse are unrelated to pre-crisis borrowers' characteristics. I have documented that the lenders that are highly exposed to the shock - as captured by the co-syndication exposure to Lehman at the time of the collapse - involve in a contraction in the lending activity; however the absence of controls for borrowers characteristics may lead to confounding effects with contemporaneous credit demand shocks. Therefore, I proceed with considering observable borrower characteristics as controls in my subsequent empirical specifications. Specifically, I control for the public or private status of a firm, size, the interest rate spread of the last pre-crisis loan as a means to capture the imputed level of credit risk of the borrower, the type of the loan, and indicator variable for borrowers that have loans due amidst the crisis to account for rollover risk during crisis and the potential need for financing. Besides, I employ a large set of fixed effects - including industry and year - so as to control for variation driven by the aforementioned factors.

Table 4 provides the distribution of characteristics of the pre-crisis borrowers that I control for in the baseline regressions based on the measure of exposure to the Lehman collapse. The sample appears to be

balanced among the aforementioned observable characteristics as borrowers across quantiles do not differ in terms of size and access to alternative financing sources and public or private status. Only credit spread is distributed in a U-shape form among the quantiles with the financial institutions that experience a shock in the middle of the distribution to be matched to ex-ante less risky borrowers.

However, there is still the concern that unobservable firm characteristics may be responsible for both the credit supply and the exposure to the shock. In order to accommodate issues relevant to firm unobservables, I employ a specification that relies on the Khwaja and Mian (2008) within-firm estimator so as to provide convincing evidence against a correlation between pre-crisis borrower characteristics and loan supply changes. In particular, Khwaja and Mian (2008) document that the inclusion of borrower fixed effects is able to purge firm-specific demand shocks and identify the lending channel effects, as changes in credit supply and firm-specific components are likely to be positively correlated leading to biased estimators. Therefore, the borrower fixed effects approach test whether a firm borrowing from multiple banks experiences a larger decline in lending from the bank that is highly exposed to the shock. However, the usefulness of the within-firm estimator is tested only in the sample of firms with multiple-banking relationships that obtained a loan commitment during the crisis. Therefore, the sample is restricted to the borrowers that accessed the syndicated loan market after the Lehman collapse and, hence an observation corresponds to a borrower-lender pair in the last pre-crisis loan. The specification that I consider is the following:

$$\Delta Lending_{i,b} = \alpha + \beta \Delta \tilde{L}_{-i,b} + FE_i + u_{i,b} \tag{7}$$

$\Delta Lending_{i,b}$ is the dollar amount change in lending obtained during the crisis from lender b by borrower i and the last pre-crisis loan of the same borrower with the same lender weighted by the participation percentage of each lender in the loan commitment and $\Delta \tilde{L}_{-i,b}$ is the loan supply change by the financial institution b to the rest of the borrowers. The results are reported in column (1) of Table 5 and existence of a positive coefficient implies that borrowers with multiple banking relationships in the pre-crisis syndicate experienced higher contraction in access to bank credit by financial institutions that were highly exposed to Lehman collapse.

Following Chodorow-Reich (2014), running the previous specification without the borrower fixed effects but including the observable borrower characteristics mentioned above is able to provide evidence of the magnitude of unobserved borrower characteristics that may be able to explain the differential response to the shock for both lenders and borrowers. If the unobserved characteristics were correlated with the lending measure, I expect the point estimate to change to reflect the omitted variables. Instead, Column (2) of

Table 5 demonstrates that the point estimate is identical indicating strong evidence against a bank-firm matching explanation.

5.3 Credit Demand Concerns

As a means to consider the potential impact of a credit demand shock, I focus on loan level analysis and examine the intensive margin effects using the following linear regression specifications:

$$\Delta LoanTerms_{i,s} = \alpha + \beta \Delta \tilde{L}_{i,s} + \gamma X_i + u_{i,b} \tag{8}$$

$$\Delta LoanTerms_{i,b} = \alpha + \beta \Delta L_{i,b} + \gamma X_i + u_{i,b} \tag{9}$$

The sample is restricted to borrowers that have initiated a loan commitment during the crisis that is of the same type of the last pre-crisis loan commitment. The aforementioned approach to match loans of the same type for the same borrower before and after the Lehman collapse closely follows the existing literature examining syndicated lending (Hubbard et al. (2002); Lin and Paravisini (2011); Santos (2011); Irani (2012)). As a result, the β estimate captures the heterogeneous impact of credit supply disruptions on lending terms. The contractual terms that I consider include maturity, the credit spread and the loan amount. Therefore, the dependent variable in the intensive margin specifications is the difference in the loan terms between a loan obtained by a borrower during the crisis and the last loan of the same type obtained by the same borrower prior to the Lehman collapse. Following Petersen (2009), I cluster standard errors by both firm and bank so as to account for potential correlation across banks lending to the same firm, and across firms obtaining lending by the same bank. Besides, I consider industry and loan-year fixed effects so as to mitigate concerns for the impact of industry characteristics and the timing of the loans. The control variables in the regressions are the ones described in the previous section and account for observable borrower characteristics that have an impact on the contractual terms. I expect borrowers that maintained relationships with financial institutions that were highly affected by the 2007-2009 financial crisis to exhibit an increase (decrease) in the interest rate spread (maturity, loan amount) in the case of attempting to access syndicated loan market during the crisis.

The first specification focuses on the borrowers that obtained a loan during the crisis, through without matching by lender as well. In other words, the first specification captures the change in lending terms of borrowers that accessed the syndicated loan market even by switching lenders. The results are presented

in Panel A of Table 6 and, indeed, indicate that pre-crisis borrowers of less exposed financial institutions obtained a loan with favorable terms compared to the ones that maintained pre-crisis relationships with lenders that were highly exposed to the liquidity shock. However, the preferential treatment is mostly apparent in lower credit spreads, while there is evidence of securing longer maturities as well.

Nevertheless, comparing loan terms for borrowers without matching with the lender as well, may raise the concern of a bank-firm matching so that firms with certain characteristics are likely to borrow from financial institutions with characteristics that are correlated with the level of exposure to the shock. As a result, the second specification considers only the subsample of firms that borrowed during the crisis from the same lender. Therefore, the estimate of loan supply changes is identified only by bank-firm variation alleviating any bank-firm matching concerns. The results of the within-relationship specification are presented in Panel B of Table 6 and are in tandem with the results reported previously. In particular, the strong effect in credit spreads is still apparent, while contrary to the prior significant impact on maturity the results exhibit no significant effect.

Although within-relationship results are consistent with a credit supply-side shock, results are not informative of the impact on extensive margin of lending. Therefore, I consider the following probit specification to shed further light on credit demand concerns:

$$P(AccessToSyndicatedMarket_{i,s} = 1) = G(\alpha + \beta \Delta \tilde{L}_{i,s} + \gamma X_i + u_{i,b}) \tag{10}$$

The dependent variable in the extensive margin specification is an indicator variable that equals 1 in case a firm has obtained a loan during the crisis, while borrower-level covariates are as of the last pre-crisis loan taken by each borrower. The coefficient of interest is β and measures the impact of the change in bank lending activity on both the probability to obtaining access to the syndicated loan market and the change in the loan terms. I expect borrowers that maintained relationships with financial institutions that were highly exposed to the 2007-2009 financial crisis to exhibit a decrease in the probability of obtaining a syndicated loan during the crisis. Indeed, borrowers that maintain relationship lending with financial institutions less exposed to the liquidity shock are more likely to access to syndicated market during the crisis. Specifically, a standard deviation increase in the lending supply measure corresponds to 10% higher probability of accessing bank financing.

6 Empirical Methodology and Results

6.1 Credit Supply Frictions and Innovation Measures

Having tackled the concern that changes in the lending activity before and after the Lehman collapse are unrelated to pre-crisis borrowers' characteristics, thus excluding a contemporaneous credit demand shock, I am able to use the loan supply measure $\Delta\tilde{L}_{i,s}$ as a continuous treatment in a difference-in-differences setting so as to identify the impact on corporate innovation for firms with heterogeneous responses to the exogenous credit supply shock. In other words, based on the assumptions that pre-crisis borrower characteristics are orthogonal to the loan supply measure and that the loan supply measure is representative of the differential impact of the exogenous liquidity shock on the borrowers ability to be provided access to bank credit due to relationship lending considerations, I am able to identify a causal relation between credit supply frictions and corporate innovation. As financial institutions decreased lending activity in the syndicated market for reasons that are independent of the quality of the pre-crisis loan portfolio, firms that were highly affected by the exogenous shock are expected to decrease both the quantity and the quality of innovative activity. In case there is no differential response to innovation among firms controlling for access to the bond market and ex ante credit risk levels, there is support for theories that point to the inappropriateness of bank credit for innovation purposes. However, there are rational reasons to expect that constraints in access to bank lending may impose restrictions to the ability of a firm to innovate. Indeed, limited access to bank financing or even the higher cost of obtaining bank credit due to the imposed liquidity constraints on financial institutions provide a rational channel to expect and justify an effect on corporate innovation.

Specifically, the empirical specification considered is the following:

$$InnovationMeasure_{i,b,t} = \alpha + \beta_0 Post + \beta_1 \Delta\tilde{L}_{i,s} + \beta_2 Post\Delta\tilde{L}_{i,s} + \gamma X_{i,t-1} + FE + u_{i,b,t} \qquad (11)$$

The primary innovation measures that are considered as dependent variables are the natural logarithm of patent counts and the natural logarithm of the number of non-self citations per patent adjusted for time and class. To account for the long-term nature of innovation process, our empirical tests use measures of innovation productivity 8 quarters before and after the collapse of Lehman Brothers. The focus is the coefficient on the interaction term β_2 that captures the average change in the innovative activity from the period before the collapse of Lehman Brothers to the post-period for firms exposed differentially to the supply shock. A significantly positive coefficient on the interaction term in the case of innovative activity would support the hypothesis that credit supply frictions are harmful for innovation. I account

for a battery of observable firm characteristics, while I alleviate the impact of unobservable time-invariant effects using industry and loan-year fixed effects.

The results are presented in Table 8 and consider both the full sample (Panel A) and only the subsample of firms that innovate (Panel B). The significantly positive coefficient of the interaction term $Post \times \Delta\tilde{L}_{i,s}$ supports the notion that credit supply frictions that hinder firm access to bank financing have a significant impact on corporate innovation and demonstrate that relationship lending is positively associated with innovation. The economic significance of the estimates above imply a 4.3% increase in the number of patents generated by the firm as compared to a mean patenting firm and a 5.5% increase in the number of non-self citations per patent. Besides, being in a lending relationship with a financial institution at the 90th percentile of the exposure as compared to one in a 10th percentile implies a patent increase by 7.2% and a citations increase by 9.1%. The effect is even more pronounced in case I consider only the subsample of borrowers that innovate. The economic significance of the estimates indicate a 10.1% and a 13.4% increase in the number of patents and citations respectively in case of borrowing from a financial institution in the 90th percentile instead of one in the 10th percentile.

6.2 Credit Supply Frictions and Innovative Efficiency

Moreover, I exploit cross-sectional variation in the innovative efficiency within the firms that were exposed to the supply-side credit shock in order to explain anecdotal evidence and validate existing empirical results (Almeida et al. (2013)) that support the notion that financial constraints may induce taking steps towards improving firm-level operational efficiency. Indeed, financially constrained firms may benefit innovation by leading to an increase in the level of innovative efficiency and alleviating agency problems of excess free cash flow that induce inefficient and unproductive R&D investment.

The empirical specification considered is the following:

$$InnovativeEfficiency_{i,b,t} = \alpha + \beta_0 Post + \beta_1 \Delta\tilde{L}_{i,s} + \beta_2 Post\Delta\tilde{L}_{i,s} + \gamma X_{i,t-1} + FE + u_{i,b,t} \qquad (12)$$

The primary innovation measures that are considered as dependent variables are patents or patent citations scaled by R&D investment. The focus is the coefficient on the interaction term β_2 that captures the average change in the innovative efficiency from the period before the collapse of Lehman Brothers to the post-period for firms exposed differentially to the supply shock. A significantly negative coefficient on the interaction term in the case of innovative activity would support the hypothesis that, in the presence of credit supply frictions that induce financial constraints, firms that are highly exposed are going to become

more efficient in the allocation and use of resources for corporate innovation. I account for a battery of observable firm characteristics, while I alleviate the impact of unobservable time-invariant effects using industry and loan-year fixed effects.

The results for the full sample are presented in Table 9. The significantly negative coefficient of the interaction term $Post \times \Delta\tilde{L}_{i,s}$ supports the notion that credit supply frictions that hinder firm access to bank financing have a significant impact on innovative efficiency. I find that the decrease in innovative efficiency following the liquidity shock is significantly higher, as for example, a one standard deviation increase in the lending activity by the financial institutions with which the borrower maintains relationship leads to patent citations per unit of R&D investment decrease by 12.3%.

7 Robustness Checks

7.1 Lehman Exposure Measure

In order to test further the validity of the results, I employ the difference-in-differences specification using as continuous treatment the exposure to Lehman variable that has been extensively used in the literature to account for the differential exposure of financial institution to the liquidity shock. The intuition is that the collapse of Lehman Brothers imposed a liquidity problem in the financial institutions with which Lehman had a co-syndication relationship, as the exposed financial institutions were forced both to replace the role of Lehman in the syndicated loan and to be confronted with additional drawdowns in case of maintaining credit lines with the borrowers. Besides, as the impact was heteregeneous among lenders based on the exposure on the failing institution, the exogenous variation is considered a supply-side effect unrelated to the pre-crisis characteristics of the borrowers, thus, providing an alternative measure of bank health.

The empirical specification considered is the following:

$$InnovationMeasure_{i,b,t} = \alpha + \beta_0 Post + \beta_1 LehmanExposure + \beta_2 Post \times LehmanExposure + \gamma X_{i,t-1} + FE + u_{i,b,t} \quad (13)$$

The results are presented in Table 10 and consider both the full sample (Panel A) and only the subsample of firms that innovate (Panel B). The significantly negative coefficient of the interaction term $Post \times LehmanExposure$ supports the notion that credit supply frictions that hinder firm access to bank financing have a significant impact on corporate innovation and demonstrate that relationship lending is positively

associated with innovation. The economic significance of the estimates above imply a 5.8% decrease in the number of patents generated by the firm as compared to a mean patenting firm and a 4.9% decrease in the number of non-self citations per patent. The effect is of a slightly higher magnitude in case I consider only the subsample of borrowers that innovate. Therefore, the use of an alternative measure of credit supply disruptions provides additional support for the causal relation between corporate innovation and relationship lending.

7.2 Parallel Trends

In order for the loan supply measure to be a consistent continuous treatment variable, I assumed that innovative activity would have been similar absent the liquidity shock. As a means to invalidate that the experimental design separates the credit supply shock from contemporaneous firm-specific shocks that may impact corporate innovation, I conduct placebo regressions corresponding both to the 2001 recession and to a period that there is no explicit expected relation between corporate innovations and conditions in the lending market.

Panel A of Table 11 examines the 2001 crisis that shares the existence of recessionary effects which the recent financial crisis; however there is no supply-driven credit shock. The only concern is a potential matching of banks with countercyclical borrowers as financial institutions may specialize lending in specific borrowers, thus predicting a positive coefficient. Instead, the point estimates are either negative or positive but none are statistically significant. Panel B of Table 11 reports the results for the pre-crisis period 2003Q4-2007Q3. A significantly positive estimate would cast doubt on the orthogonality of the loan supply measure with the pre-crisis borrower characteristics. However, the results indicate that the loan supply measure has essentially no predictive power during this period. Therefore, the placebo regression results invalidate the soundness of the natural experiment design by providing support for the parallel trends assumption and indicate no false positives.

8 Conclusions

The results of the paper demonstrate the causal effect of disruptions in the bank credit market on both innovation output measured by the number of patents issued by a firm and the innovation impact captured by the number of non-self citations. In particular, firms that were maintaining a relationship with financial institutions that the liquidity shock induced a significantly less contraction in lending activity, increase innovative output relatively to firms that faced a higher credit supply decline. My evidence indicates that

relationship lending fosters corporate innovation and that bank financing is material for the investment in the innovative process, thus leading to technological progress. Besides, the results of the paper suggest that government policies that aim at bailing-out financial institutions and providing aggregate liquidity in the lending market may lead to positive spillovers in the economy by boosting innovative activity and, thereby, nurturing long-term economic growth.

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10 Tables

Table 1: Summary Statistics

The table reports summary statistics of the variables of interest. The sample includes borrowers with loan commitments reporting working capital or corporate purposes as the purpose of the loan and with non-missing state, industry, and public/private status identifiers. The sample excludes borrowers that are either real estate (SIC codes 1520-1600) or financial companies (SIC codes 6000-6799). Panel A reports summary statistics related to borrower characteristics and comparing the full Dealscan and the merged Dealscan-USPTO sample. Panel B focuses on summary statistics related to financial institutions and includes financial data at the period before the Lehman collapse and the main exposures of bank health used. Specifically, the variable $\%ChangeinNumberofLoans$ equals the change in the annualized number of loans initiated by the financial institution between the periods October 2005 to June 2007 and October 2008 to June 2009, while the variable $LehmanExposure$ is equal to the fraction of the syndication portfolio of a financial institution that Lehman Brothers had a lead role, and which is outstanding on September 15, 2008. Panel C provides summary statistics for the innovation measures that are considered, namely the number of patents and the number of citations splitting the sample in pre- and post-crisis periods, and focusing only on the subsample of borrowers that innovate.

	N	Mean	Std Dev.	p10	p50	p90
	Panel A: Firm Variables					
Loan Amount						
Dealscan Sample	5,068	18.28	1.53	16.12	18.42	20.12
Merged Sample	1,715	18.49	1.65	16.12	18.48	20.62
Credit Spread						
Dealscan Sample	4,257	208.94	166.59	45	175	400
Merged Sample	1,465	180.81	149.64	35	150	350
Maturity						
Dealscan Sample	4,874	52.06	24.69	18	60	72
Merged Sample	1,657	51.86	24.51	15	60	72
Sales						
Dealscan Sample	3,574	20.17	1.86	17.91	20.11	22.58
Merged Sample	1,357	20.55	1.98	18.10	20.49	23.10
	Panel B: Bank Variables					
% Change in Number of Loans	61	-0.60	0.27	-0.88	-0.65	-0.21
Lehman Exposure (%)	60	0.8	1.96	0	0.26	1.46
Assets (in million $)	61	702.01	100.08	58.25	289.61	2,033.92
Deposits/Assets	61	0.39	0.20	0.15	0.35	0.64
Profitability (%)	61	-0.16	1.29	-1.60	0.25	0.94
Capital/Assets (%)	61	8.08	3.67	2.28	7.41	11.78
Real Estate Net Charge-Offs	61	0.0012	0.0019	0	0	0.0038
Loan Net Charge-Offs	61	0.004	0.005	0	0.0023	0.012
Trading Revenue	61	-0.0004	0.0051	-0.0033	0	0.0036
	Panel C: Innovation Variables					
Patents						
Pre-Crisis (Extensive Margin)	1,716	54.94	86.27	0	2	66
Pre-Crisis (Intensive Margin)	1,026	91.60	126.25	1	8	137
In Crisis (Extensive Margin)	1,716	38.67	45.50	0	1	47
In Crisis (Intensive Margin)	1,026	64.64	88.79	0	5	86
Citations						
Pre-Crisis (Extensive Margin)	1,716	57.94	382.99	0	1	75
Pre-Crisis (Intensive Margin)	1,026	113.16	491.62	1	11	221
In Crisis (Extensive Margin)	1,716	30.27	173.64	0	0	63
In Crisis (Intensive Margin)	1,026	47.02	194.62	0	3	86

Table 2: Aggregate Lending and Bank Characteristics

The table reports the results of the regressions that consider the impact of bank characteristics on the change in lending activity. The dependent variable is the change in the annualized number of loans initiated by the financial institutions of the last pre-crisis syndicate of the borrower between the periods October 2005 to June 2007 and October 2008 to June 2009 scaled by the participation percentage. The explanatory variable of interest is the variable *LehmanExposure* that is equal to the fraction of the syndication portfolio of a financial institution that Lehman Brothers had a lead role, and which is outstanding on September 15, 2008. Bank controls include deposit, profitability, equity, trading revenue and net charge-offs ratios. Standard errors are in parentheses. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

	(1)	(2)
Variables	Change in Lending Activity	
Lehman Exposure	-4.54***	-4.21**
	(1.20)	(1.71)
Deposits/Assets		0.51***
		(0.170)
Profitability		1.72
		(3.039)
Capital		-0.35
		(1.289)
Real Estate Net Charge-Offs		-13.44
		(27.789)
Loan Net Charge-Offs		7.58
		(11.403)
Trading Revenue/Assets		3.56
		(7.300)
Observations	61	61
R^2	0.11	0.28

Table 3: Relationship Lending

The table reports the results of the regressions that consider the existence of relationship lending in the syndicated loan market. The sample consists of loan commitments that correspond to a borrower that has already used the syndicated loan market before and the period under consideration is from 2003 to June 2009. The dependent variable is an indicator corresponding to whether the lender assumes either the role of the lead arranger or the role of participant in a loan. The interest is on the variables *PreviousLeadArranger* and *PreviousParticipant* that indicate whether the lender has assumed either the role of the lead arranger or the role of participant in a previous loan of the same borrower. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate and the borrower size measured by sales. Standard errors are in parentheses and clustered in the borrower level. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

	(1)	(2)	(3)	(4)
Variables	Participation as Lead Arranger		Participation as Participant	
Previous Lead Arranger	0.65***	0.59***	0.12***	-0.02***
	(0.009)	(0.009)	(0.008)	(0.010)
Previous Participant	0.012***	0.005***	0.54***	0.51***
	(0.001)	(0.001)	(0.007)	(0.007)
Lender Fixed Effects	Yes	Yes	Yes	Yes
Industry-Lender Fixed Effects	No	Yes	No	Yes
Year Fixed Effects	No	Yes	No	Yes
Borrower Controls	No	Yes	No	Yes
Observations	573,169	573,169	573,169	573,169
R^2	0.40	0.46	0.37	0.39

Table 4: Pre-Trends of Borrower Characteristics

The table reports summary statistics of borrower characteristics based on the last pre-crisis loan commitment. The sample is divided into three quantiles based on the exposure to the liquidity shock measure $\Delta L_{i,s}$ that is equal to the change in the annualized number of loans made by the borrowers last pre-crisis syndicate between the periods October 2005 to June 2007 and October 2008 to June 2009.

Variables	**Quantile of Exposure Measure**		
	(1)	(2)	(3)
$\Delta L_{i,s}$	0.22	0.34	0.51
Public/Private Status	0.57	0.63	0.62
Mean Bond Access	0.40	0.48	0.30
Mean Credit Spread	209	125	175
Median Sales	20.52	21.32	20.06
Mean Due Crisis	0.11	0.10	0.14
Mean Year Open	2005.89	2006.10	2006.10

Table 5: Unobserved Borrower Characteristics

The table reports the results of the regressions that consider the impact of unobserved borrower characteristics potentially confounding the results of the identification strategy. The sample is restricted to borrowers that have signed a loan both before and after the Lehman collapse and the dependent variable is the change in the dollar amount of lending from a lender to the borrower. The interest is on the variable $\Delta L_{-i,b}$ that is equal to the change in the annualized number of loans initiated by the financial institution between the periods October 2005 to June 2007 and October 2008 to June 2009. The sample contains one observation for each financial institution participating in borrowers last pre-crisis syndicate. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Standard errors are in parentheses and clustered by the borrower and the lead lenders in the borrowers last pre-crisis loan syndicate. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

	(1)	(2)
Variables	Bank-Firm Change in Lending	
$\Delta L_{-i,b}$	1.77***	1.80***
	(0.25)	(0.28)
Borrower Fixed Effects	Yes	No
Industry Fixed Effects	No	Yes
Loan Year Fixed Effects	No	Yes
Borrower Controls	No	Yes
Observations	1,857	1,857
R^2	0.64	0.45

Table 6: Impact on Loan Contract Terms

The table reports the results of the regressions that consider the impact of credit supply frictions on loan terms. The dependent variable is the change in one of the credit spread, the maturity and the loan amount between a loan obtained in the crisis period between October 2008 and June 2009 and the last pre-crisis loan. The interest is either on the variable $\Delta\tilde{L}_{i,s}$ that is equal to the change in the annualized number of loans initiated by the financial institutions of the last pre-crisis syndicate of the borrower between the periods October 2005 to June 2007 and October 2008 to June 2009 or the variable ΔL_b that is equal to the change in the annualized number of loans initiated by the financial institution that the borrower has a loan agreement both before and after the Lehman collapse. The sample is restricted in Panel A to borrowers that have signed a loan during the crisis and in Panel B to borrowers that have signed a loan with the same lender both before and after the Lehman collapse. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Standard errors are in parentheses and clustered by the borrower and the lead lenders in the borrowers last pre-crisis loan syndicate. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

Panel A			
	Syndicate Level		
	(1)	(2)	(3)
Variables	Interest Rate Spread	Maturity	Loan Amount
$\Delta\tilde{L}_{i,s}$	-215.38***	11.34*	0.10
	(73.01)	(6.46)	(0.37)
Industry Fixed Effects	Yes	Yes	Yes
Loan Year Fixed Effects	Yes	Yes	Yes
Borrower Controls	Yes	Yes	Yes
Observations	320	316	320
R^2	0.09	0.20	0.08
Panel B			
	Bank Level		
	(1)	(2)	(3)
Variables	Interest Rate Spread	Maturity	Loan Amount
ΔL_b	-97.96***	-3.54	0.06
	(24.79)	(2.90)	(0.19)
Industry Fixed Effects	Yes	Yes	Yes
Loan Year Fixed Effects	Yes	Yes	Yes
Borrower Controls	Yes	Yes	Yes
Observations	193	191	193
R^2	0.15	0.22	0.08

Table 7: Impact On The Likelihood Of Accessing Bank Credit

The table reports the results of the regressions that consider the impact of credit supply frictions on the likelihood of obtaining bank credit during the crisis. The dependent variable is an indicator corresponding to whether the borrower obtained a new loan commitment between October 2008 and June 2009 and the interest is on the variable $\Delta\tilde{L}_{i,s}$ that is equal to the change in the annualized number of loans initiated by the financial institutions of the last pre-crisis syndicate of the borrower between the periods October 2005 to June 2007 and October 2008 to June 2009. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Standard errors are in parentheses and clustered by the borrower and the lead lenders in the borrowers last pre-crisis loan syndicate. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

	(1)	(2)
Variables	Access to Bank Credit	
$\Delta\tilde{L}_{i,s}$	0.59***	0.60***
	(0.15)	(0.23)
Industry Fixed Effects	No	Yes
Loan Year Fixed Effects	No	Yes
Borrower Controls	No	Yes
Observations	4,578	3,016

Table 8: Impact On Innovative Activity

The table reports the results of the baseline regressions that consider the impact of credit supply frictions on corporate innovation. The dependent variable is either the number of patents or the number of citations generated during the period under consideration and the interest is on the interaction term equal to $Post \times \Delta\tilde{L}_{i,s}$. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Panel A considers the full sample of borrowers, while Panel B is restricted to the subsample of borrowers that innovate. Standard errors are in parentheses and clustered in the borrower level. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

Panel A		
	Extensive Margin Results	
	(1)	(2)
Variables	Patents	Citations
Post	-0.26***	-0.95***
	(0.029)	(0.053)
$\Delta\tilde{L}_{i,s}$	-0.53***	-0.15
	(0.120)	(0.127)
$Post \times \Delta\tilde{L}_{i,s}$	0.22***	0.29***
	(0.052)	(0.094)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	26,832	26,832
R^2	0.11	0.26
Panel B		
	Intensive Margin Results	
	(1)	(2)
Variables	Patents	Citations
Post	-0.42***	-1.48***
	(0.055)	(0.084)
$\Delta\tilde{L}_{i,s}$	-0.09	-0.26
	(0.223)	(0.252)
$Post \times \Delta\tilde{L}_{i,s}$	0.32***	0.43***
	(0.105)	(0.170)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	16,080	16,080
R^2	0.27	0.28

Table 9: Impact On Innovative Efficiency

The table reports the results of regressions that consider the impact of the bank lending channel on innovative efficiency. The dependent variable is either the number of patents or the number of citations scaled by R&D and the interest is on the interaction term equal to $Post \times \Delta\tilde{L}_{i,s}$. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Standard errors are in parentheses and clustered in the borrower level. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

	(1)	(2)
Variables	Patents	Citations
Post	-0.14***	-0.40***
	(0.038)	(0.139)
$\Delta\tilde{L}_{i,s}$	0.09	1.06**
	(0.072)	(0.419)
$Post \times \Delta\tilde{L}_{i,s}$	-0.16***	-0.82***
	(0.070)	(0.395)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	5,683	5,683
R^2	0.09	0.06

Table 10: Lehman Exposure Regressions

The table reports the results of regressions that consider the exposure to Lehman Brothers as the measure of liquidity shock. The dependent variable is either the number of patents or the number of citations generated and the interest is on the interaction term equal to $Post \times LehmanExposure$. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Panel A considers the full sample of borrowers, while Panel B is restricted to the subsample of borrowers that innovate. Standard errors are in parentheses and clustered in the borrower level. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

Panel A		
	Extensive Margin Results	
	(1)	(2)
Variables	Patents	Citations
Post	-0.18***	-0.05***
	(0.020)	(0.008)
$LehmanExposure$	0.56	0.24
	(0.64)	(0.18)
$Post \times LehmanExposure$	-0.75***	-0.59**
	(0.28)	(0.22)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	26,832	26,832
R^2	0.11	0.12
Panel B		
	Intensive Margin Results	
	(1)	(2)
Variables	Patents	Citations
Post	-0.28***	-0.09***
	(0.03)	(0.01)
$LehmanExposure$	0.66	0.28
	(0.83)	(0.24)
$Post \times LehmanExposure$	-0.81***	-0.62**
	(0.31)	(0.26)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	16,080	16,080
R^2	0.10	0.18

Table 11: Placebo Regressions

The table reports the results of the placebo regressions in support of the parallel trend assumption. The dependent variable is either the number of patents or the number of citations generated in the placebo periods and the interest is on the interaction term equal to $Post \times \Delta\tilde{L}_{i,s}$. Borrower controls include the public or private status of the borrower, the credit spread in the last pre-crisis syndicate, the borrower size measured by sales, the type of the loan, an indicator variable for borrowers that have loans due amidst the crisis and borrowers that have access the bond market. Standard errors are in parentheses and clustered in the borrower level. *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 levels, respectively.

Panel A		
	2001 Crisis	
	(1)	(2)
Variables	Patents	Citations
Post	0.015	-0.268
	(0.022)	(0.228)
$\Delta\tilde{L}_{i,s}$	-0.145	0.047
	(0.126)	(0.212)
$Post \times \Delta\tilde{L}_{i,s}$	-0.046	0.009
	(0.044)	(0.058)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	18,896	18,896
R^2	0.25	0.18
Panel B		
	Period 2003Q4-2007Q3	
	(1)	(2)
Variables	Patents	Citations
Post	0.004	-0.228***
	(0.015)	(0.019)
$\Delta\tilde{L}_{i,s}$	-0.039	0.082
	(0.070)	(0.119)
$Post \times \Delta\tilde{L}_{i,s}$	0.029	0.025
	(0.038)	(0.040)
Industry Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Borrower Controls	Yes	Yes
Observations	37,088	37,088
R^2	0.27	0.28