Investment in Productivity and the Long-Run Effect of Financial Crises on Output*

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Abstract

This paper analyzes the channels through which financial crises exert long-term negative effects on output. Recent models suggest that a shortfall in productivity-enhancing investments temporarily slows technological progress, creating a gap between pre-crisis trend and actual GDP. This hypothesis is tested using a linked lender-borrower dataset on 519 U.S. corporations responsible for 54% of industrial research and development. Exploiting quasi-experimental variation in firm-level exposure to the 2008-9 financial crisis, I show that tight credit reduced investments in productivity-enhancement, and has significantly slowed down output growth between 2010 and 2015. A partial-equilibrium aggregation exercise suggests GDP would be be between 2.3 and 6.4% higher today if productivity-enhancing investments had grown at pre-crisis rates.

Keywords: Financial Crises, Endogenous Growth, Innovation, Business Cycles

JEL classification: E32, E44, O30, O47

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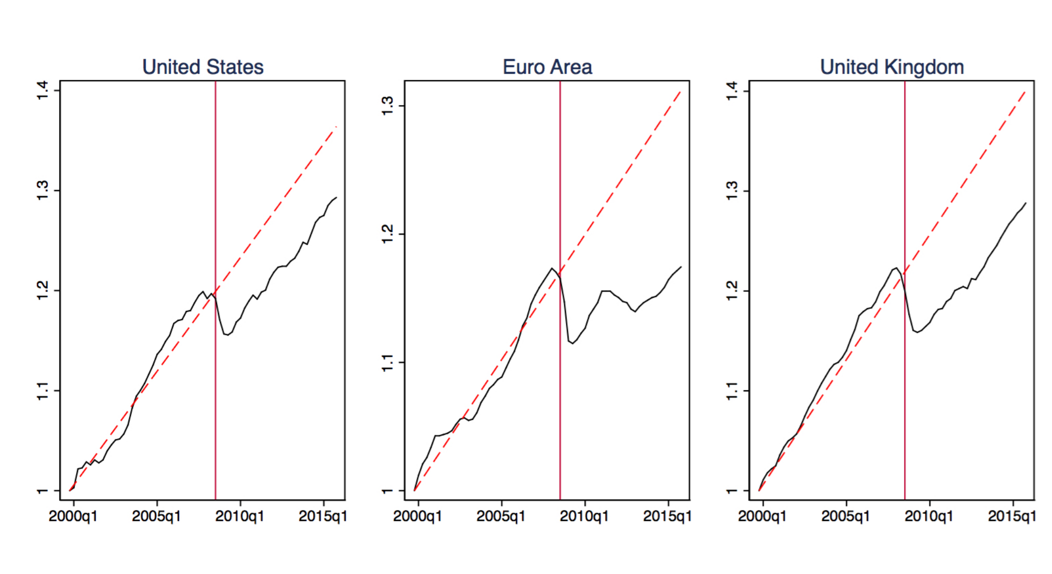
1. Introduction

A growing empirical literature shows that the effect of financial crises on output is not transitory. Crises are characterized by severe recessions during which a decline in output of 10 to 15% is not uncommon. In contrast to what standard macroeconomic models predict, these losses are often not reversed. While growth rates recover to levels similar to the pre-crisis trend within 2 to 3 years, there is no boom with above-average growth in which the level of output is able to recuperate. As a result, there is a permanent gap between the economy's original projected path and actual output (Boyd et al., 2005; Cerra and Saxena, 2008; Furceri and Zdzienicka, 2012; Reinhart and Rogoff, 2014; Teulings and Zubanov, 2014). Recovery from the recent global financial crisis and the ensuing "Great Recession" has followed a similar pattern. In the United States, industrial production declined by 17% between 2007 and 2009, while real GDP fell by 4.3%. This sharp reduction in activity was not followed by an episode of high growth. To the contrary, average output growth between 2010 and 2016 was only 2.5% per year, which is 0.3 percentage points lower than growth between 2002 and 2007. Consequently, GDP in 2016 has deviated by 10% from the level that an extrapolated trend between 2000 and 2007 predicts. This implies that annual per capita income would on average be $5000 higher today if no crisis had occurred. This experience is not unique to the United States. Output fell below trend-levels after 2007 across developed economies, as Figure 1 illustrates. In the United Kingdom, per capita GDP has deviated over 10% from trend, while output in Germany and France has fallen behind by 5 and 12%, respectively. Ball (2014) documents that deviations in GDP were accompanied by an 8% reduction in OECD potential output. This means that the aggregate loss of output in the aftermath of the crisis is roughly the size of the economies of the United Kingdom, Austria, Denmark, and Ireland, combined.

Standard business cycle models, even with financial frictions, predict that the economy always returns to steady state. Recessions and expansions are mere transitory deviations from a long-term trend. Why does mean reversion not happen after financial crises? A small but growing theoretical literature suggests that a shortfall in productivity-enhancing investment is the answer. Investments in, for instance, research and development (R&D) and intangible capital are particularly affected by financial crises as they are risky, pay off with substantial delays, and have poor collateral value (e.g. Hall and Lerner, 2010). Endogenous growth models predict that a temporary reduction in such investments slows the rate of technological progress to levels below the balanced growth path, which has a persistent effect on potential GDP. When the crisis fades and investments recover, technological progress regains its original

Figure 1. Real Gross Domestic Product vs Trend, 2000-2015



Solid and dashed lines present actual and trend (log) GDP, respectively. Series are standardized such that 2000Q1 has value 1. Trends extrapolate output growth between 2000 and 2007. Source: Author's calculations using OECD national accounts data.

growth rate. GDP does not catch-up to losses during the crisis, and is on a permanently lower trajectory. While intuitive, there is no causal evidence on the validity of this explanation.[1]

The 2008-9 financial crisis presents a unique opportunity to fill that void. By comparing firms that exogenously faced different degrees of exposure to the economy-wide tightening of credit, I assess whether reductions in productivity-enhancing investments at firm-level explain why growth in the aftermath of the crisis has been sluggish. This hypothesis is tested using a linked lender-borrower micro dataset on 519 medium- to large-sized firms in the United States. These firms are responsible for 54% of industrial R&D with total sales measuring 28% of 2007 GDP. Following Chodorow-Reich (2014), I exploit the long-term nature of relationships between firms and banks to obtain exogenous variation in the extent to which firms are exposed to credit tightening around the financial crisis. Firms that rely on loans from banks that held high credit-risk assets in 2007, underestimated the credit-risk of their portfolio, were strongly affected by the Lehman Brother's bankruptcy, the subsequent collapse of interbank markets or had higher leverage are expected to face greater difficulty financing productivity-enhancing investments during the crisis. Similarly, firms with a large fraction of their long-term debt due for refinancing during the crisis are exogenously limited in their ability to engage in new

[1]Descriptive evidence exists for the recovery from the 2008-9 financial crisis, in papers that analyze developments of total factor productivity (TFP) during the Great Recession: e.g., Hall (2014), Christiano et al. (2015), Ollivaud and Turner (2015) and Reifschneider et al. (2015). Alternatively, Fernald (2014) warns that comparing pre- and post-crisis trends in TFP may result in an overestimation of the decline in TFP due to excess growth before 2007. He also notes that the decline in TFP growth pre-dates the Great Recession.

projects. I then use measures of crisis-exposure as instruments for productivity-enhancing investments, to assess their effect on firm-level output growth between 2010 and 2014.

By focusing on the 2008-9 financial crisis in the U.S., I exploit three favorable characteristics of this episode. First, recovery from the financial crisis exhibits the typical gap between the original trend path and actual GDP, as shown in Figure 1. Second, the 2008-9 financial crisis is the largest financial crisis since the waive of bank failures between 1931 and 1933. The magnitude of the crisis is important, as identification requires that exposed firms are unable to compensate short-term credit disruptions with internal funds to finance productivity-enhancing investments. The strong decline in credit availability after the bankruptcy of Lehman Brothers in September 2008, which is used as the crisis' starting point, suggests that the disruption was sufficiently large. In the months after September, supply of new loans to corporations fell by 47%, while supply fell by 79% compared to the pre-crisis peak (Ivashina and Scharfstein, 2010). Third, the 2008-9 financial crisis provides a source of quasi-experimental variation in the extent to which individual firms were affected. As the crisis did not originate in the market for commercial loans, exogenous variation in the impact of the financial crisis on firms can be derived through comparing the banks from which they usually obtain funds.[2] The suddenness of the collapse of Lehman Brothers in September of 2008 furthermore allows a firm's long-term debt maturity at the onset of the crisis to be used as a second source of exogenous variation.

I find evidence of a significantly positive relationship between exposure to the 2008-9 financial crisis and reductions in productivity-enhancing investments. Using a novel measure of asset quality based on the distribution of bank assets across Basel I risk categories, I find that firms relying on banks with low-quality assets in 2007 reduce investments during the crisis by 8 percentage points per standard deviation decline in quality. Similar results are found for the decline in a bank's asset quality between 2007 and 2010, which captures the extent to which banks underestimated risks. This relationship also appears when using established proxies for bank-exposure to the 2008-9 financial crisis such as 2007 leverage and deposits or exposure to the bankruptcy of Lehman Brothers, although results are stronger with the new measure. Difference-in-difference regressions show that the negative effect of exposure to the crisis first appears in 2008, and persists for the remainder of the sample. In the main analysis, I find that firms whose investments in productivity-enhancement decline during the crisis experience lower output growth between 2010 and 2014. For each percentage point decline in investment, annual output growth drops by roughly 0.08 percentage points. Results are robust to the inclusion of control variables for firm age, size, pre-crisis growth and impact of the 2008 recession, as well as detailed sector and state fixed effects. The estimates are highly significant in all specifications and are of an economically relevant magnitude: a partial equilibrium aggregation exercise suggests that output amongst sampled firms would be

[2] For an elaborate discussion, see Gorton (2008) and Chodorow-Reich (2014).

12% higher in 2014 if productivity-enhancing investments had grown along pre-crisis trends. Investments in capital, while negatively related to crisis-exposure, cannot explain growth in the medium term. Placebo tests and an assessment of the timing of the effect are used to show that the estimates are likely to be causal.

This paper's primary contribution is the provision of causal evidence on the premise that reduced credit supply during financial crises affects productivity-enhancement and subsequent growth. That is of particular importance to a growing theoretical literature that aims to explain the long-term effects of financial crises on output in microfounded models. These models are usually built around endogenous growth theory. Following the tradition sparked by Romer (1990), Aghion and Howitt (1992), and Grossman and Helpman (1993), long-term growth is driven by technological progress which is the outcome of profit-maximizing investment in innovation. A number of papers hypothesize that financial crises reduce such investments as innovative projects are risky, pay off with lags and are bad-collateral, such that banks are unwilling or unable to provide the needed funds. In Aghion et al. (2010), for instance, short run liquidity shocks move firms away from long-term productivity-enhancing investments in favour of short run production capital if credit constraints are tight.[3] Garcia-Macia (2015) claims that firms are unable to fund investment in intangible assets during financial crises, as their collateral value is hard to collect. Similarly, the models in Ates and Saffie (2013, 2014) claim that financial turmoil affects technological progress through the ability of banks to observe project quality under imperfect information. In Queraltó (2013), financial crises increase the costs of financial intermediation through balance sheet deterioration á la Gertler and Kiyotaki (2010), which reduces the entrance of entrepreneurs that need to fund entry costs. Schmitz (2014) adds that the effect of crises on innovation is amplified by the fact that small and young firms are particularly affected by credit tightness, as these produce more radical innovation.[4] A related literature explains the long-term effects of financial crises through non-financial channels. Crises reduce the profitability of productivity-enhancing investments because demand and prices are low. Examples include Fatas (2000), Comin and Gertler (2006), Benigno and Fornaro (2015) and Anzoategui et al. (2016).[5] In these models, financial crises are effectively large recessions. Results in this paper provide support for models in which financial crises are distinct from large recessions, as restricted loan supply is the source of declines in productivity-enhancing investments and medium-term growth. Reductions in the profitability of investments could form a complementary channel.

This paper's second contribution is the conclusion that productivity-enhancing investments are affected by disruptions to bank lending. Existing evidence on the importance of bank loans for investments in R&D and intangible assets is mixed. Hall and Lerner (2010) argue that

[3] Empirical support for this channel based on French micro data is provided in Aghion et al. (2012).

[4] This is somewhat at odds with Garcia-Macia et al. (2015), who find that incumbent firms are more important for innovation than entrants in the U.S.

[5] Economic activity is also related to endogenous growth in Bianchi and Kung (2014).

firms vastly prefer to finance such investments internally using cash flow or equity because intangible capital has poor collateral and because it is difficult for lenders to estimate the quality of projects, which raises the cost of loans. In line with this, Brown et al. (2009) find that young firms tend to finance R&D expenditures almost entirely without debt. Alternatively, Nanda and Nicholas (2014) show that innovative firms in the Great Depression that operated in the same county as banks which suspended depositor payments produced fewer patents in following years. Patents at affected firms were also less frequently cited, less general and less original, as derived from patent citations. For the 2008-9 financial crisis, Kipar (2011) shows that German firms were more likely to cancel innovative projects if firms borrowed from credit unions rather than commercial banks. Garicano and Steinwender (2013) use Spanish data to show that crises change the composition of investments towards short-term instead of long-term capital. An emerging literature, surveyed by Nanda and Kerr (2015), furthermore finds that bank deregulation during the 1980s benefited innovation.[6]

The empirical strategy builds on a number of papers that use firm-exposure to lending shocks to assess the real effects of financial crises. Firm-level data is well suited to analyze this paper's question because firms differ exogenously in the extent to which they are exposed to the financial crisis, facilitating causal interpretation of results. This is one of the main reasons that micro data has become increasingly popular in macroeconomic work. Particularly relevant examples include Chodorow-Reich (2014), Acharya et al. (2015), Bentolila et al. (2015) and Giroud and Mueller (2015), who analyse the employment effects of credit shocks by considering variation in firm-level crisis-exposure. Franklin et al. (2015) conduct a similar exercise for the United Kingdom, and add that credit thightning negatively affected labor productivity in 2008-9. It is similarly related to Almeida et al. (2012), Greenstone et al. (2014), Adelino et al. (2015), Aghion et al. (2015), and Paravisini et al. (2015). These papers use exposure to credit shocks to analyse the effect on employment, investments, exports and short-term output. To my knowledge, this is the first paper to apply that methodology to study the effect of credit shocks on productivity-enhancing investments and subsequent growth over the medium run.

This paper is also related to papers on episodes of slow recovery from recessions. Shimer (2012) develops a model with rigid wages and show that shocks to capital stocks have persistent effects on the level of output. Galí et al. (2012) show that recovery from recessions in the U.S. has been slow after the 1990s, and suggest that an increase in risk premiums in the recessions' wake is likely responsible. Others have used financial frictions as a source of persistently low output in the aftermath of shocks (e.g. Hall, 2010; Gertler and Kiyotaki, 2010). These models predict that GDP will eventually recovery to its original trend. This paper does not address the empirical question whether the effect of financial crises is permanent or fades over long horizons, as such an analysis requires decades of data.

[6] This paper is also related to a long literature on the effect of innovation and R&D on output growth. An elaborate discussion of past work and empirical strategies is provided in Cohen (2010).

The remainder of this paper is structured as follows. Section 2 outlines the empirical strategy and introduces the linked lender-borrower dataset, while Section 3 provides measures of exposure to the 2008-9 financial crisis. Results are presented in Section 4, while an aggregation exercise is discussed in Section 5. Section 6 concludes.

2. Empirical Methodology

This section explains the empirical strategy used to test whether investment in productivity by firms can explain the long-term effects of financial crises on output. The identification problem and estimation equations are outlined in Section 2.1. Section 2.2 introduces the dataset and measures of investments and output growth, while summary statistics and a discussion of sample representativeness are provided in 2.3.

2.1. Identifcation Strategy

A firm's decision to invest in productivity-enhancement depends on the profits which it expects to gain from investing, which are directly affected by exposure to the 2008-9 financial crisis. Reductions in the supply of new bank loans raise interest rate costs, especially for investments in assets that are poor collateral (Garcia-Macia, 2015). Credit rationing may even prevent firms from obtaining adequate funds at all. While credit tightens throughout the economy during a crisis, firms differ in the extent to which their access is impeded. As shown by Chodorow-Reich (2014), there is a strong relationship between the supply of loans to firms and health of the banks from which they obtained their loans prior to the 2008-9 financial crisis. Similarly, Almeida et al. (2012) show that firms which had a smaller percentage of their long-term debt due during the crisis were more able to sustain capital investments.

These firm-level differences are expected to determine the change in productivity-enhancing investments during the 2008-9 financial crisis. If differences can be captured in exogenous variables, they enable an instrumental variable analysis on the effect of such investments on output growth in subsequent years. Instruments are needed because a simple regression of output growth on productivity-enhancing investments is impeded by endogeneity. Firms that expect output to grow irrespective of the crisis have an incentive to invest in, for instance, the efficiency of production processes or to expand their line of products. Alternatively, firms that foresee declining sales might invest in the development of new goods and services in an attempt to regain growth. These channels create a positive or negative correlation between productivity-enhancing investments and output growth irrespective of whether firms were affected by the crisis. An instrumental variable strategy will yield unbiased estimates of the coefficients if the instruments satisfy the exogeneity condition: they may not affect a firm's ability or desire to undertake productivity-enhancing investments other than through its ability to obtain loans under acceptable conditions. If this condition holds, the following equation describes the first stage:

$$Invest_i = \alpha + \beta Exposure_i + \mu' X_i + \phi_k + \psi_s + \epsilon_{i,k} \quad (1)$$

where $Invest$ denotes the ratio of average productivity-enhancing investments after the Lehman Brothers bankruptcy over average i§nvestments during pre-crisis base years for firm i, X is a vector of firm-level control variables while ϕ and ψ are industry and state fixed effects, respectively. This metric corrects for unobserved time-invariant heterogeneity that determines the amount that firms invest in productivity. It also corrects for the fact that not all firms require equal expenditure to increase productivity. *Exposure* is a set of measures that determine to what extent firms are exposed to credit tightening during the 2008-9 financial crisis. To verify that $Invest$ is unaffected by *Exposure* before 2008, (1) is also estimated in difference-in-difference form.

The second stage of the estimation measures the effect of developments in investments on medium-term output growth. At the macro-level, endogenous growth models suggest that investments in productivity affect steady state output through total factor productivity. Firm-level total factor productivity and potential output cannot be measured accurately, because production functions differ across firms and factor utilization is not observable. Growth in actual output is used instead, measured through real sales. Sales are a common measure in work that studies determinants of firm growth.[7] As a robustness check I also analyse the effect of productivity-enhancing investments on labor productivity, which yields similar results. Actual output is a good approximation for developments in potential output when the economy is in steady state, but might be far off if the economy experiences a recession. The 2008-9 financial crisis was joined by the largest decline in economic activity since the Great Depression of the 1930s. This is problematic, because the initial recession might obscure the correlation between productivity-enhancing investments and medium-term growth. To correct for this, I analyze developments in growth once firms have, on average, recovered from the demand shock. This is defined as the point where their sales are equal to the peak level prior to the crisis. If firms were producing at their potential rate, further growth has to come from growth in potential output, which is more likely to be driven by productivity-enhancing investments.[8] The second stage estimation equation reads:

$$\Delta Output_i = \alpha + \gamma \widehat{Invest}_i + \mu' X_i + \phi_k + \psi_s + \eta_i \quad (2)$$

where $\Delta Output$ denotes the growth rate of medium-term output after the average firm has recovered for firm i in industry k with headquarters in state s. $\widehat{Invest}_i$ denotes the fitted

[7] Examples include Gabaix (2011), Bloom et al. (2013), and Kogan et al. (2016).
[8] A detailed motivation is provided in Section 2.2.2.

values from first-stage equation (1). A significantly positive estimate of γ is consistent with the hypothesis. Causal inference requires that productivity-enhancing investments are the only channel through which exposure affects medium-term growth. Falsification tests using other types of investments are provided to assess whether this exclusion restriction is satisfied. To assess the timing of the effect of investments, a projection along equation (2) is estimated for annual developments in output.

2.2. Dataset and Variable Construction

Data on firm variables for investments, output growth and covariates are taken from S&P's Compustat. Compustat contains balance sheet and income statement data for all publicly listed firms in the U.S. It is the largest public firm-level micro dataset for the United States and the only dataset containing R&D investments. The latter implies that larger datasets which include private firms, such as the Longitudinal Business Database, are not suitable. I start from the annual file and keep firms that engaged in R&D at least once in the three years prior to the crisis. I drop observations with missing or negative total assets and sales, as well as firms that leave or enter the dataset between 2002 and 2014.[9] Firms that first appear in the data after 2001 are excluded to allow sufficient years to calculate a pre-crisis growth trend and to exclude very young firms. Firms in finance, insurance and real estate (FIRE), as well as firms in government and regulated utility sectors are excluded. All variables are deflated to 2009 USD using the BAE's GDP deflator and are winsorized at bottom and top 3% tails.

The resulting dataset is merged with a 2015 extract of Thomson Reuters' DealScan. DealScan contains loan-level information on the characteristics of large commercial loans, including the amount, conditions, collateral requirements, the purpose of loans, and most importantly: the name of borrowers and lenders. Reuters obtains this information primarily from SEC filings, complemented by sources such as news reports and from contacts inside borrowing and lending institutions.[10] Loans in DealScan account for over 75% of commercial loans in the U.S., making it the most complete overview of debt transactions available and the primary source of bank loan data for research.[11] To select the sample of loans from DealScan, I roughly follow the criteria in Sufi (2007), Ivashina and Scharfstein (2010) and Chodorow-Reich (2014). Loans with start dates prior to 1995 are not included as DealScan's coverage increased substantially from that year onwards. Loans with extraordinary purposes, such as

[9] 2014 is the final year because a number of firms did not have data for 2015 at the time of writing.

[10] Information obtained from non-official sources is verified at the relevant firm before inclusion in the dataset.

[11] Carey and Hrycray (1999) find that between 50 to 75% of the volume of commercial loans is included in the dataset, and a large majority of large loans. Chava and Roberts (2008) suggest that coverage has been even higher from the late 1990s onwards. Examples of studies using DealScan data include Dennis and Mullineaux (2000), Sufi (2007), Ivashina and Scharfstein (2010), De Haas and Van Horen (2012). Chava and Roberts (2008) and in particular Chodorow-Reich (2014) link DealScan to firm-level data in similar ways to mine.

management buyouts, are also excluded.[12] Following Chodorow-Reich (2014), I also require that at least one of the lenders for each loan is part of the top 43 of overall lenders and drop lenders without any loans two years prior to the crisis, to allow balanced matching with bank data later on. Finally, 260 loans with values below $10,000 are excluded. The samples are merged using a linking table by Chava and Roberts (2008). The merged Compustat-DealScan sample of R&D performers contains 519 firms whose total sales equal 28% of GDP and are responsible for 54% of corporate R&D in 2007.

2.2.1. Measures for Productivity-Enhancing Investments

For these firms I create two variables to measure investment in productivity-enhancement. The first is total R&D expenditures (Compustat item *xrd*). These include all the costs incurred for the development of new products and services, including software costs. They also include R&D activities undertaken by others for which the firm paid. This is particularly important as firms increasingly rely on external sources for R&D (e.g. Arora et al. 2016 and Chesbrough et al. 2006). The second measure also includes advertisement and marketing expenditures (Compustat item *xad*). This variable is referred to as intangible capital investments.[13] Ideally, a measure of investment in productivity would also contain efforts to increase production efficiency like employee training. Data on such expenses is unfortunately not available. Past literature suggests however that these are likely correlated with other intangible investments as their gains interact (see e.g. Michie and Sheehan 1999, Thornhill 2006). My measures are therefore proxies for changes in the total effort of firms to become more productive. $Invest$ is calculated by taking the ratio of average annual investments in productivity in 2009 and 2010 to average annual investments in the three years prior to the crisis. 2009 and 2010 are used to measure investments during the crisis because most firms reduced investments in those years compared to their peak in 2008. The ratio with investments three years prior the crisis is taken as it makes the measure robust to volatile year-to-year differences in expenditure, keeps firms without expenditures in specific years in the sample, and corrects for unobserved heterogeneity.[14]

2.2.2. Measures for Medium-Term Growth

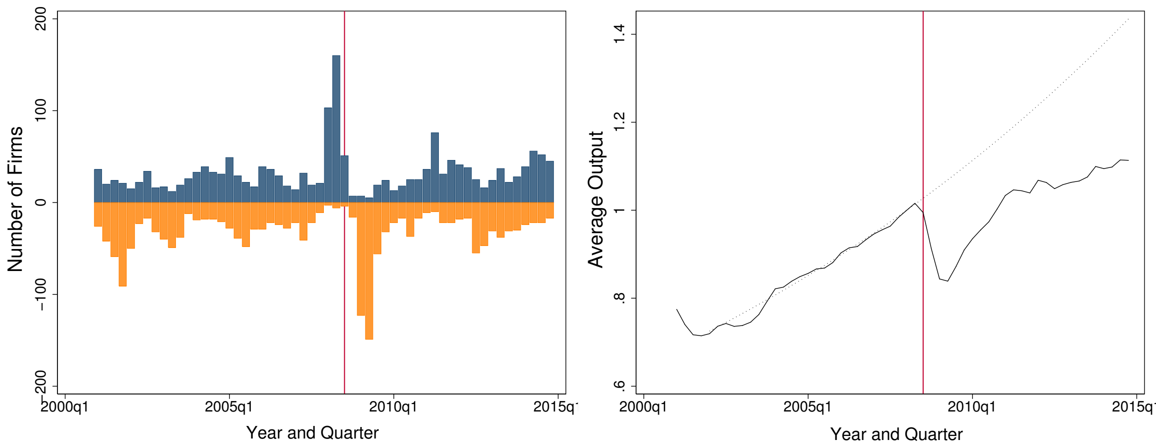
To measure $\Delta Output$ I use the percentage increase in real sales between 2010 and 2014. Growth between these years is likely to capture the effect of the crisis over the medium horizon, for three reasons. Firstly, the vast majority of firms experienced their trough in

[12] Specifically, loans for general corporate purchases, asset acquisitions, aircraft finance, credit enhancement, debt refinancing, project, hardware and software financing, equipment purchases, real estate financing, ship finance, telecoms build outs, trade finance and working capital are included.

[13] Chen (2014) use sales, general and administrative investments to measure intangible investments. This is problematic when assessing the drivers of sales growth, as components of these expenses are variable costs.

[14] Sensitivity checks on definitions of $Invest$ in Section 4 show that results are robust to using different years.

Figure 2. Firm-Level Output Turning Points and Growth, 2002-2014



Note: Left figure presents the number of firms reaching the peak (dark, upper half) and trough (light, lower half) of output cycles in a given quarter. Calculated using turning point dating algorithms described in text. Right figure: average real output standardized to 1 for the third quarter of 2008. Vertical line marks the quarter of Lehman Brother's bankruptcy.

output before the end of 2010. To show this, the left graph of Figure 2 plots the distribution of turning points over time. Turning points are defined as quarters in which the direction of a firm's output growth changes from expansionary to recessionary (at the peak) and vice versa (at the trough). Turning points are obtained for each firm using a simple dating algorithm.[15] The figure shows that output amongst most firms peaked between the second and fourth quarter of 2008. Over half the sampled firms reach their trough in 2009, while by the end of 2010 most firms have regained growth. Growth after 2010 is therefore likely to capture crisis-recovery rather than the crisis-impact. Secondly, 2010 is the year in which firm-output had, on average, recovered to pre-crisis levels. The right graph in Figure 2 plots an index of mean output within the sample, which exceeds its pre-crisis peak in the first quarter of 2011. Growth beyond that level is more likely to reflect increases in potential output due to productivity-enhancing investments, as demand shocks from the crisis have worn off. Thirdly, investments in R&D start paying off after at least 2 or 3 years (Mansfield et al., 1971). Because investments first declined in 2009, the first year in which a treatment effect is expected is 2011. Patents are not used as outcomes because available data ends in 2010 (Kogan et al., 2016).

[15]The algorithm works as follows. First, quarterly sales for each firm are obtained from the Compustat quarterly file. These series are seasonally adjusted using the X-11 procedure. Second, short term volatility is smoothed by taking a three-month centred moving average of the output series. Third, local minima and maxima are identified using a script by Philippe Bracke that implements methods from Harding and Pagan (2002). Their method imposes restrictions on the number of quarters between turning points. In my calibration, each turning point must be at least 2 quarters long, while a complete cycle (from through to through or from peak to peak) must be at least 6 quarters long.

2.3. Descriptive Statistics

Summary statistics for the resulting dataset are provided in Table 1. The upper panel summarizes firm characteristics prior to the financial crisis, in 2007. The median firm employs over 5000 employees, holds $230 million in capital and sold over $1.3 billion in 2007. This implies that sampled firms are much larger than average U.S. corporations. Return on assets and sales, measured as the ratio of net income and real total assets and sales, lie around 5%. Yearly output growth, measured as percentage change of real sales, was highest prior to 2008 when the median firm grew more than 7% per year. The bottom panel of Table 1 summarizes the main variables of interest: investment growth in R&D and intangible capital. Note that median growth of both variables is slightly positive despite the decline in investments during the crisis. This is driven by a large increase in investments between 2005 and 2008.[16]

Although companies in the sample are much larger than average American firms, their productivity-enhancing investments are highly correlated with national values. Figure 3 shows that indices of both investments in R&D and investments in intangible capital co-move closely with the OECD index of U.S. enterprise R&D. The associated correlation coefficients are 0.87 and 0.83, respectively. This is expected as sampled firms are responsible for 54% of aggregate industrial R&D in 2007. Consequently, even though firms in the sample are not a random sample of the universe of American firms, they form a significant population on their own.

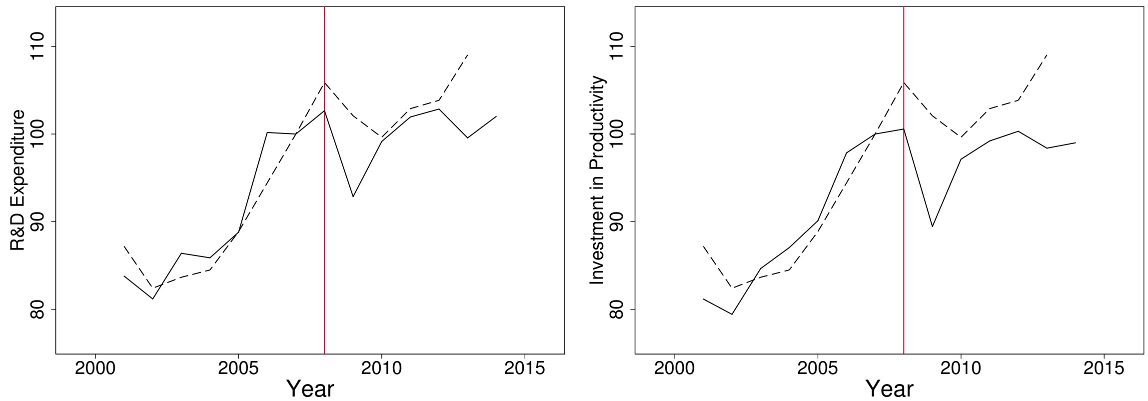
Table 1: Descriptive Statistics Firm Characteristics

Variable	Median	Mean	St. Dev.	10th Pct.	90th Pct.	Obs.	Notes
Characteristics, 2007							
Capital	231.88	1234.61	2522.76	9.81	3653.71	519	Mil. '09 USD
Sales	1360.09	5379.26	10275.32	94.21	14702.00	519	Mil. '09 USD
Employment	5.14	15.83	26.89	.32	46.00	519	Thousands
Return on Assets	5.48	4.14	9.10	-5.42	13.19	519	Percentage
Return on Sales	5.65	4.30	10.32	-6.90	15.20	519	Percentage
Annual Sales Growth							
Average 2003-2007	7.18	10.70	13.42	-3.31	25.16	518	Percentage
Average 2008-2009	-11.77	-11.76	16.07	-32.93	7.52	518	Percentage
Average 2010-2014	3.23	4.06	8.67	-9.10	14.34	519	Percentage
Investment Growth Crisis							
R&D Investment	3.96	14.11	64.13	-46.34	77.18	519	Percentage
Intangible Investment	3.01	13.46	53.52	-41.40	79.46	519	Percentage

Descriptive statistics for the merged Compustat-DealScan sample. Includes all non-FIRE firms continuously present in the dataset from 2003 to 2014 that had positive R&D expenditures in at least one year between 2004 and 2007.

[16] In 2009, for instance, median R&D investments were 7% lower than in 2008 while intangible investments declined by 8%.

Figure 3. Sample and Aggregate Investment in R&D and Intangible Assets, 2002-2014



Note: Solid and dashed lines present productivity-enhancing investments in the sample and at the aggregate level, respectively. Aggregate investments use OECD business and enterprise broad R&D expenditures. Correlation between aggregate investments and R&D (left figure) is 0.87 and 0.83 for intangible investments (right figure).

3. Measuring Exposure to Crisis

Firms face greater exposure to the 2008-9 financial crisis if they suffered an above-average restriction in credit supply. The extent to which firms have access to credit cannot be inferred from the amount of loans they take out or the interest rate charged, because these variables are also determined by firms' solvability and demand for loans. Instead, I rely on indirect measures of firm-level exposure to the crisis. I first summarize these measures in Section 3.1. Data sources are discussed in Section 3.2 while descriptive statistics are provided in 3.3.

3.1. Measures

To measure *Exposure* in first-stage equation (1), variables are composed that quantify exogenous exposure to credit tightening. Exogeneity requires that these do not affect a firm's ability or desire to undertake productivity-enhancing investment, other than through its ability to obtain loans under acceptable conditions. Measures are grouped into two categories: bank relationships and debt structure.

3.1.1. Measures using Relationship Banking

The main measures use the health of banks from which firms usually borrowed prior to the crisis to measure exposure. Firms tend to borrow from a limited number of financial institutions because of the benefits to relationship banking. By repeating interaction with borrowers, banks are able to monitor and screen loans more closely, which helps to solve problems of asymmetric information.[17] Measures of exposure that use bank health explicitly rely on relationship banking, as firms should not be able to perfectly substitute loans from

[17] A review of theory and evidence is provided in Boot (2000).

affected banks with loans from alternative, unaffected banks. Chodorow-Reich (2014), on which this part of the empirical strategy is based, shows that the health of banks from which firms obtained loans was an important determinant of firm-level employment growth between 2008 and 2009. This is in line with the importance of relationships in bank-loan provision.

The relationship between each firm and bank in the sample is derived from the share that bank h contributed to the last loan taken out by firm i in the DealScan sample prior to June 2007. This share is usually smaller than one because the majority of loans in DealScan (73%) is syndicated.[18] Such loans are the primary source of bank loans for U.S. corporations.[19] In contrast to standard loans, syndicated loans are provided by a group (the syndicate) rather than an individual lender. The choice to divide loans amongst participants is usually driven by the desire to diversify on the side of banks, as syndicated loans can be very large. They take the form of fixed term loans, bridge loans, credit lines, leases, or most other conventional forms. Firms seeking a syndicated loan arrange the basic terms with a lead arranger, also known as the underwriting bank. Once the loan amount, interest rate and additional requirements like collateral and fees have been agreed upon, the lead arranger recruits other investors to participate in the loan.

The primary measure of bank-level exposure to the financial crisis captures the soundness of bank assets, in a novel way. I use the distribution of assets across risk weighing categories for Basel 1 capital requirements. Under the original Basel Accord, banks were to classify assets in 5 categories along credit risk. Assets such as cash and U.S. treasury notes carry risk weights of 0%. Securities with excellent ratings, including AAA-rated mortgage-backed securities, carry a weight of 20%. Residential mortgages fall under the 50% risk category, provided that they are fully first lien and accruing on schedule. Commercial loans and most non-performing assets fall under the 100% risk category.[20] Risk-weighted assets are calculated by multiplying the dollar amount of assets in each category with the weight-percentage. Because higher percentages imply greater credit risk, these categories measure the soundness of the bank's asset portfolio. Specifically, banks with high risk-weighted assets compared to total assets hold lower quality assets than firms with less risk-weighted assets. To measure the overall soundness of assets, I therefore calculate:

$$Asset\ Quality = Assets/Risk\text{-}Weighted\ Assets \tag{3}$$

for each bank. To my knowledge, this is the first paper to use this measure for firm-exposure to the financial crisis. Banks with low-quality assets in 2007 are expected to face greater difficulty satisfying capital requirements during the financial crisis, and hence to decrease

[18] Loans after June 2007 are not considered because turmoil on financial markets commenced around the summer of 2007 BNP Paribas blocked withdrawals from three hedge funds engaged in asset-backed security investment in early August.

[19] This explanation draws on Sufi (2007).

[20] Full reporting requirements for U.S. banks are available via this link.

supply of loans.[21] A second measure of bank balance sheet health is the percentage change in *Asset Quality* between 2007 and 2009.[22] Because assets need to be reclassified to higher risk categories when not performing, exposure to failing mortgages or asset-backed securities leads to an increase in risk-weighted assets and a decline in asset quality.[23]

Alternative measures of bank-exposure to the crisis capture the extent to which banks were affected by the credit-supply shock and the collapse of interbank markets. Most of these measures are taken from past work. The first measure quantifies a bank's relationship with Lehman Brothers, following Ivashina and Scharfstein (2010). This variable is calculated as the fraction of the total amount of syndicated loans that Lehman Brothers played a lead role in. Banks with high exposure to Lehman provided less new loans during the 2008-9 financial crisis.[24] The second measure quantifies a bank's exposure to the collapse of asset-backed securities (ABS), for which data is taken from Chodorow-Reich (2014). He derives ABS exposure from the correlation between a firm's daily stock returns with an index that tracks the price of ABS securities issued in 2005 with, at the time, a AAA-rating.[25] This is preferred over the use of balance-sheet derived measures of ABS-exposure, as foreign banks do not report such items consistently. The third measure is the ratio of deposits over assets. Deposits capture the stability of bank funding, because it is less volatile than, for instance, short term loans on interbank markets which eroded during the crisis (e.g. Brunnermeier 2009). In line with this, Ivashina and Scharfstein (2010) show that banks with higher levels of deposits reduced lending supply less than banks with other funding sources. The final measure of credit-shock exposure is a dummy equal to 1 if the financial institution ceased to exist in its current form during the crisis. To identify these banks, the sample is first restricted to banks that stop reporting financial data between 2007 and 2010. These banks are hand-classified as failed if they filed for bankruptcy during the crisis or if they merged to a healthier institution under, for instance, regulatory pressure. The most important bank in the first category is Lehman Brothers, while Bear Stearns and Washington Mutual are examples of the second. To measure the health of bank balance sheets in 2007, two standard measures are used. The first is the ratio of bad loan provisions over total loans, which is a proxy for the quality of the bank's loan portfolio. The second is leverage, defined as the ratio of liabilities over equity. Higher leverage is associated with higher risk, as small changes in asset values can swiftly turn equity negative.

[21] In line with this premise, Das and Sy (2012) find that firms with higher risk-weighted assets experienced greater declines in stock prices during the 2008-9 financial crisis.

[22] The main results are similar if using change between 2008 and 2009 or 2008 and 2010.

[23] To alleviate endogeneity concerns, I asses the effect of new loans to firm i during the crisis on change in asset quality: these are subtracted from total and risk-weighted assets assuming the highest risk weight. Correlation with the original measure exceeds 0.99.

[24] Ivashina and Scharfstein (2010) argues that this resulted from the decision by firms that borrowed from a syndicate with Lehman to increase their usage of existing credit lines from other banks in the syndicate after Lehman's failure, to prevent having inadequate liquidity. A similar measure has also been used by De Haas and Van Horen (2012), Chodorow-Reich (2014), and Acharya et al. (2015).

[25] He notes that the use of alternative ABS indices yield similar results.

The measures for crisis-exposure and balance sheet health above are calculated at the level of financial institutions. To translate measures into firm-level variables, their weighted average over the share of banks in the firm's last pre-crisis loan syndicate is taken:

$$Exposure_i = \sum_{h=1}^{H} \psi_{i,h} \left(Exposure_h\right) \tag{4}$$

where $Exposure_h$ represents each of the bank-level exposure variables, while $\psi_{i,h}$ denotes the share of bank h in firm i's final loan.[26]

3.1.2. Measures using Debt Structure

The final measure of firm-exposure to the 2008-9 financial crisis explores quasi-experimental variation in a firm's debt structure. Specifically, it measures the percentage of long-term debt due in the peak year of the financial crisis: 2008. Firms with a large fraction of their long-term debt due in middle of the credit crisis faced lower availability and higher costs of capital such that their ability to invest in productivity enhancement was hindered. As decisions on long-term debt payable right at the crisis' onset were made well before signs of the financial crisis appeared, firms with high amounts due face exogenously greater exposure to the financial crisis than others. A similar measure was first used by Almeida et al. (2012), who show that firms with large portions of debt due were not significantly different from other firms prior to the crisis in a number of dimensions, but displayed different investing behavior afterwards.

3.2. Data

The Compustat-DealScan dataset of R&D performers is merged with bank balance sheet variables using Bureau Van Dijk's Bankscope and Federal Reserve FR Y-9C tables. Bankscope is used for data on international banks and investment banks, while Y-9C data is used for American depository institutions. The datasets are merged using a script kindly provided by Gabriel Chodorow-Reich. His file creates links for 258 banks which are responsible for the creation of 85% of loans in the year prior to the crisis. Amongst the remainder, I hand-match 90 large lenders to Bankscope and Federal Reserve identifiers.[27] Combined, matched banks are responsible for issuing over 93% of DealScan loans. For Y-9C data, deposits are calculated as the sum of total demand deposits (item 2210), total non-transaction saving deposits (item 2389) and total time deposits (the sum of items 2604 and 6648). For Bankscope data, the sum of consumer and bank deposits (items 2031 and 2185) are used. Asset quality is only

[26] If multiple loans were taken at the same date, shares are calculated over all loans. Because ψ is only available for a minority of loans in DealScan, it is imputed using the structure of syndicates. Following Chodorow-Reich (2014), shares of lead-arrangers and participants are based on average shares of both types in loans with the same number of leads and participants for which shares are available.

[27] The main results are similar when only using identifiers from Chodorow-Reich, while first stage F-statistics are larger when including additional banks.

calculated using Y-9C data because Bankscope's risk weighted assets use Basel II internal weights, which differ from Basel I's.[28]

3.3. Descriptive Statistics

Descriptive statistics are provided in Table 2. The upper panel provides standard summary statistics while to bottom panel provides a correlation matrix. All variables are winsorized at the bottom and top 3% tails. A number of results stand out. First, it seems that banks which were involved in many syndicated loans with Lehman Brothers were more heavily exposed to mortgage backed securities, held lower-quality assets and had higher leverage ratio's. Firms with higher bad loan provisions were also more than averagely affected by mortgage-backed securities and Lehman Brothers, although they are less likely to fail during the crisis. The latter suggests that such provisions are also a measure of bank prudence. There is no strong correlation between bank-relationship measures and the share of debt due after 2008. This is expected if firms do not anticipate the relevance of bank health.

4. Results

This section presents estimation results for the empirical strategy discussed in Section 2. Section 4.1 presents results of the first stage regressions on the effect of crisis exposure on productivity-enhancing investments. Section 4.2 presents reduced form estimates on the effect of exposure on $\Delta Output$, while Section 4.4 presents estimates for the second stage. Identification assumptions are tested in Section 4.5.

4.1. First Stage Results

4.1.1. Effect of Exposure on Investment in Productivity

To estimate the effect of the 2008-9 financial crisis on productivity-enhancing investments, univariate regressions along first-stage equation (1) are run using each measure of crisis exposure. Results are presented in Table 3. The left panel presents results using R&D investments for *Invest* as the dependent variable, while the right panel uses intangible investments. Standard errors are clustered by two-digit industry. All measures are standardized to have unit standard deviations. Results show that higher exposure to the financial crisis results in lower productivity-enhancing investments. Firms that rely on loans from banks with high-risk asset portfolios in 2007 or whose asset quality fell strongly during the crisis invested significantly less in research and development. Similarly, greater exposure to Lehman Brothers' bankruptcy,

[28]A dummy is added to the instruments for firms that only rely on loans from banks with no Y-9C data available, which applies to 17 firms. The main results are similar if asset quality is calculated for Bankscope banks using Basel II risk weights, although the results are less significant in some specifications. Results are available upon request.

Table 2: Descriptive Statistics Firm Exposure to 2008-2009 Financial Crisis

Summary Statistics	Median	Mean	St. Dev.	10th Perc.	90th Perc.	Obs.	Notes
Bank's Asset Quality							
Asset Quality	6.40	6.88	3.34	4.22	12.54	519	See Text
Δ Asset Quality	-32.90	-41.73	24.86	-76.73	-27.56	519	Percentage
Bank's Crisis Exposure							
Lehman Lead Share	2.15	2.11	0.91	0.13	2.68	519	Percentage
Abx Exposure	1.08	1.04	0.24	0.28	0.24	519	Stock Loading
Deposit Ratio	45.91	45.28	13.03	30.18	68.15	519	Perc. of Assets
Bankruptcy Dummy	0.00	4.72	1.30	0.00	14.70	519	Percentage
Bank's Balance Sheet							
Bad Loan Prov.	0.90	0.86	0.37	0.41	1.26	519	Perc. of Loans
Leverage Ratio	12.50	13.96	7.51	8.54	25.57	519	Debt-to-equity
Firm's Characteristics							
Debt due after 2008	3.89	12.64	21.76	0.00	33.56	456	% of LT Debt

Correlation Matrix	Asset Q.	Δ A. Q.	Lehman	Abx	Deposits	Bankr.	BLP	Lev.
Bank's Asset Quality								
Asset Quality	1							
Δ Asset Quality	0.61*	1						
Bank's Crisis Exposure								
Lehman Lead	-0.43*	-0.13*	1					
Abx Exposure	-0.43*	0.08	0.60*	1				
Deposit Ratio	0.63*	0.21*	-0.47*	-0.42*	1			
Bankrupt	-0.21*	-0.26*	0.01	0.17*	0.15*	1		
Bank's Balance Sheet								
Bad Loan Prov.	-0.10*	0.46*	0.33*	0.28*	-0.43*	-0.18*	1	
Leverage	-0.23*	0.01	0.35*	0.33*	-0.10*	-0.11*	0.16*	1
Firm's Characteristics								
Debt Due in '08	0.04	-0.00	-0.08	-0.21*	0.08	-0.05	-0.02	-0.09

Summary statistics for the merged Compustat-DealScan sample. Includes all non-FIRE firms with continuous presence in the dataset from 2003 to 2014 that had positive R&D expenditures in at least one year between 2004 and 2007. Bank variables are averages weighted by bank shares in the firm's last pre-crisis loan syndicate.
* indicates that pairwise correlation coefficients are significantly different from 0 at the 5% level.

low deposits or high leverage ratios is associated with a decline. For intangible investments the effect of asset quality, deposits, bankruptcy, and leverage are significant. The size of coefficients is economically relevant: a one standard deviation decline in asset quality results in an 8.4 percentage point decline in R&D. Coefficients for leverage and deposits are of similar size, while a standard deviation increase in exposure to the bankruptcy of Lehman Brothers reduces investments by 5 percentage points. The effect of having a greater share of debt due after 2008 is also highly significant on both types of investments: a one standard deviation increase reduces investments in R&D and intangibles by 6.4 and 7.3 percentage points, respectively. Coefficients for exposure to mortgage backed securities and bad loan provisions run in the expected direction, but are insignificant.

Table 3: First Stage: Effect of Crisis-Exposure on Firm-Level Investment in Productivity

	R&D Investments				Intangible Investments			
Variable	Coeff.	Const.	R^2	F-val.	Coeff.	Const.	R^2	F-val.
Bank's Asset Quality								
Asset Quality	0.084***	-0.031	0.020	10.5	0.056***	0.019	0.000	16.1
	(0.026)	(0.071)			(0.014)	(0.038)		
Δ Asset Quality	0.057**	0.980***	0.016	3.3	0.026	0.060	0.002	1.3
	(0.022)	(0.062)			(0.023)	(0.058)		
Bank's Crisis Exposure								
% Lehman Lead	-0.049**	0.256***	0.006	4.5	-0.020	-0.017	0.001	0.66
	(0.023)	(0.048)			(0.021)	(0.044)		
ABX Exposure	-0.026	0.255*	0.001	0.7	-0.013	0.191	0.001	0.2
	(0.032)	(0.130)			(0.013)	(0.122)		
Deposits/Assets	0.074***	-0.116	0.001	12.1	0.037***	0.004	0.005	7.7
	(0.021)	(0.092)			(0.013)	(0.064)		
Bankruptcy Dummy	-0.029*	0.152***	0.002	3.7	-0.029**	0.144***	0.003	4.4
	(0.015)	(0.036)			(0.014)	(0.032)		
Bank's Balance Sheet								
BLP/Loans	-0.014	0.173***	0.000	0.2	-0.015	0.168***	0.000	0.5
	(0.028)	(0.063)			(0.022)	(0.044)		
Leverage Ratio	-0.080**	0.290***	0.020	5.3	-0.049*	0.225***	0.009	2.9
	(0.035)	(0.077)			(0.029)	(0.063)		
Firm's Characteristics								
Share 1 year	-0.073***	0.014	0.016	28.5	-0.064***	0.163***	0.016	24.0
	(0.014)	(0.043)			(0.013)	(0.037)		

Note: Dependent variable is the ratio of real productivity-enhancing investments in 2009-2010 to 2005 -2007. 519 observations. Estimates obtained from univariate OLS. Standard errors clustered by industry and given in parentheses. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.

4.1.2. Difference-in-Difference Estimates

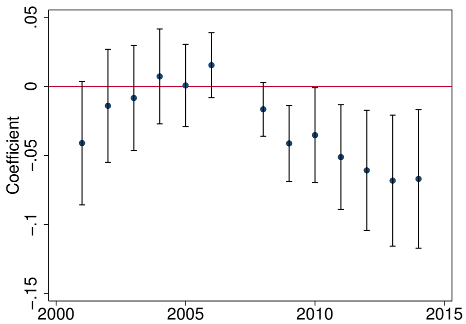
I next assess whether results in Table 3 are driven by exogenous exposure to the financial crisis, and not by inherent differences between firms. To do so, first-stage regressions are estimated in difference-in-difference form with time-varying coefficients. The estimation equation reads:

$$Invest_{i,t} = \alpha + \mu_t + \gamma_t Exposure_i + \epsilon_{i,t} \tag{5}$$

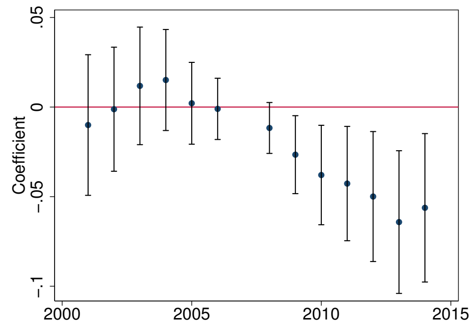
where $Invest_{i,t}$ measures the ratio of productivity-enhancing investments in year t over investments in 2007. The equation is estimated for all exposure measures that significantly affect one of the investment variables. Results are graphed in Figure 4. Graphs in the left column report coefficients for the effect of crisis-exposure on R&D investments, while intangible capital investments are used in the right column. Coefficients for asset quality, the change in asset quality and the deposit-to-asset ratio are multiplied by (-1). Standard errors are clustered by firm while 2007 is used as the base year. Results show that asset quality has a positive effect on productivity-enhancing investments after 2007. Oppositely, it has has no significant effect on developments in investments prior to the crisis. Graphs on the effect of Lehman exposure, deposit-to-asset ratios, bankruptcy, leverage and the share of debt due have similar profiles. This is in line with the notion that firms are not ex-ante different for varying degrees of exposure. In years after the 2008-9 financial crisis, the negative effects of *Exposure* do not diminish. Consistent with theory, productivity-enhancing investments do not mean-revert to compensate for low investments during the crisis. Rather, coefficients remain significant and often exceed 2009-10 values by the end of the sample. The persistent effect could arise endogenously: if firms grow slowly because of inadequate investments in productivity-enhancement, their ability to increase such investments later on is reduced. First-stage results in Table 3 are based on investments in 2009 and 2010, which are unlikely to be affected by an endogenous lack of firm-growth in those years.[29]

[29] Evidence on this is provided in Section 4.2.

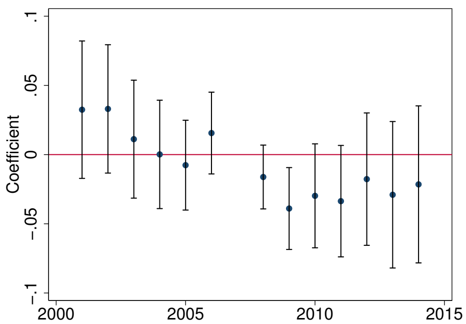
Figure 4. Time-Varying Effects of Exposure on Investments in Productivity



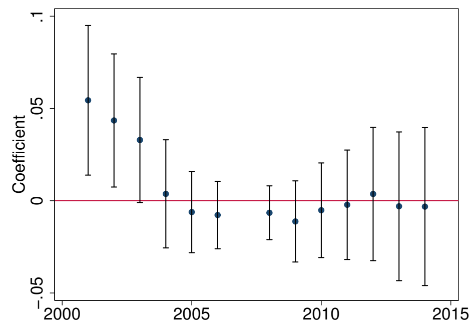
(a) Asset Quality, R&D



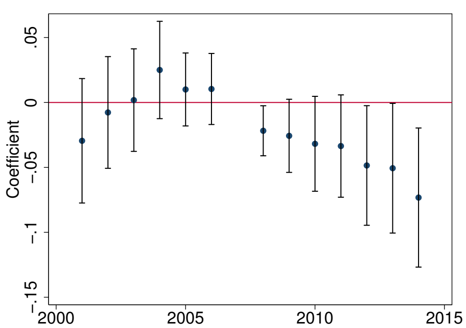
(b) Asset Quality, Intangibles



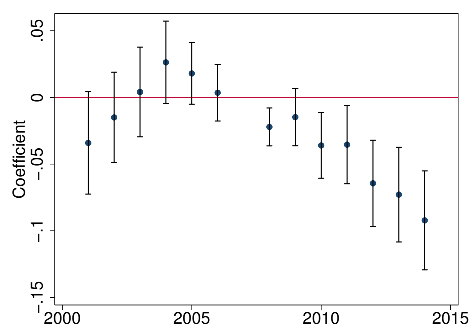
(c) Change Asset Quality, R&D



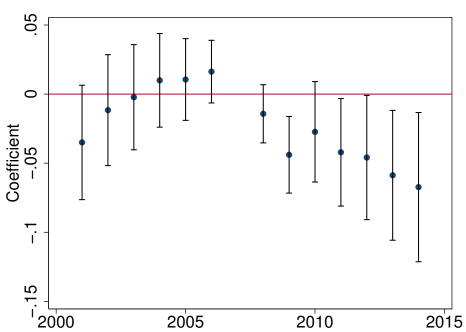
(d) Change Asset Quality, Intangibles



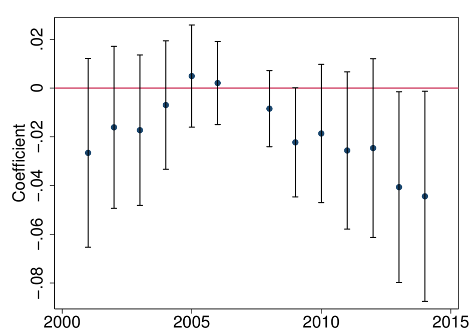
(e) Lehman Exposure, R&D



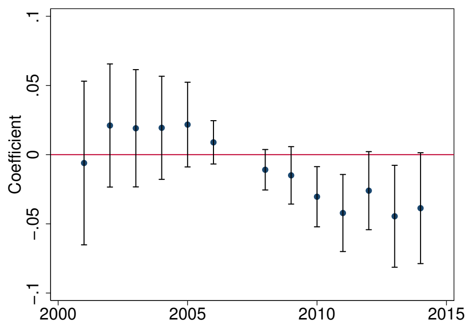
(f) Lehman Exposure, Intangibles



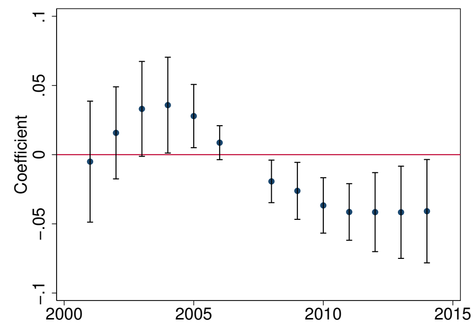
(g) Deposits-to-Assets Ratio, R&D



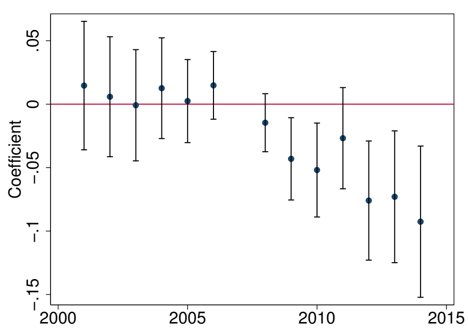
(h) Deposits-to-Assets Ratio, Intangibles



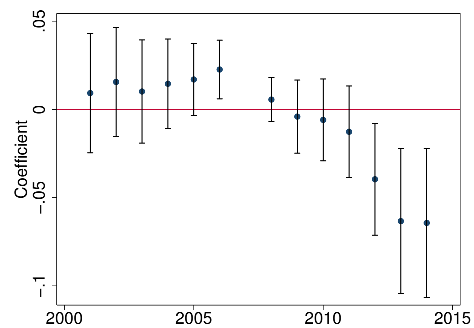
(i) Bankruptcy Dummy, R&D



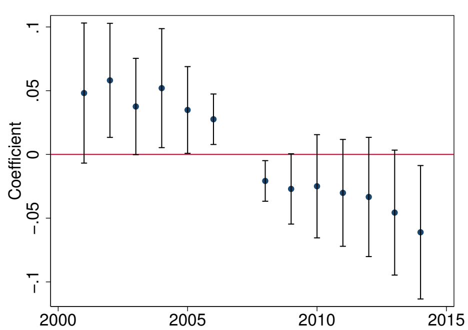
(j) Bankruptcy Dummy, Intangibles



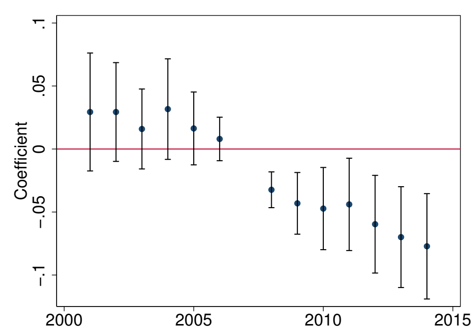
(k) Leverage Ratio, R&D



(l) Leverage Ratio, Intangibles



(m) Share of L.T. Debt Due, R&D

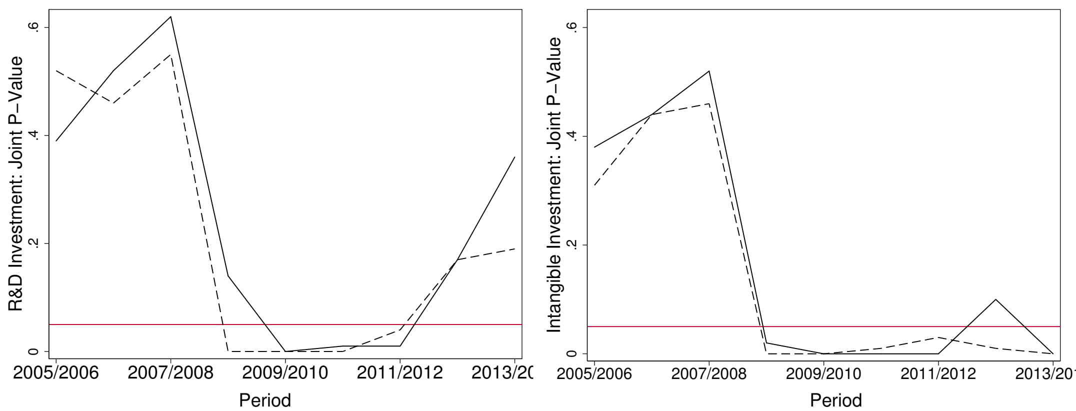


(n) Share of L.T. Debt Due, Intangibles

Note: Figures report point estimates for γ and 90% confidence intervals based on clustered standard errors. Base year is 2007.

The difference-in-difference results are robust to changes in the estimation. Alternatives include using the direct counterpart of *Invest* in Table 3 as the dependent variable: the ratio of a two-period moving average of investments to average investments in 2005, 2006, and 2007. This yields very similar results. Alternatively, equation (5) was estimated in levels using the log of spending as the dependent variable while adding firm fixed effects to control for time-invariant heterogeneity. This method is less efficient if productivity-enhancing investments follow a random walk and standard errors are larger. Results are available upon request.

Figure 5. Instrument Relevance at Alternative Investment Periods



Note: Solid lines present p-value of joint significance for bank health variables as instruments for R&D (left) and intangible (right) investment. Dashed lines add the share of a firm's long term debt due after 2008. The horizontal line marks the 5% significance level.

4.1.3. Instrument Validity

To use these measures as instruments the relevance condition of a non-zero correlation between instruments and endogenous regressors must hold. Table 3 shows that this is satisfied for most instruments, although some are 'weak'. Weak instruments can result in biased second-stage estimates as they distort the normality in coefficient and standard error distributions (e.g. Stock and Yogo 2002). Staiger and Stock (1997) suggest that as a rule of thumb, univariate F-statistics should at least equal 10. This condition only holds for asset quality and the share of debt due after 2008. To alleviate weak instrument concerns, I estimate the second stage using combinations of instruments, which increases overall relevance and significance of the first stage.[30] All instruments that are at least significant in univariate regressions on one type of investment are used, in two combinations. The first combination uses all significant measures that rely on bank relationships, while the second adds the share-of debt due after 2008. Because the share of debt due is only available for firms with positive long-term debt, the second combination has a reduced sample size of 456.

To assess the relevance and validity of the combined instruments, Figure 5 displays how the p-value of joint significance from an F-test over the instruments develops over time. If instruments capture the effect of exposure to the financial crisis on investments, they should be uncorrelated with change in investments prior to the crisis. The horizontal axis displays the years considered: 2009/2010 refers to the ratio of investments in those years to investments in three pre-crisis years, 2010/2011 refers to investments one year later, etc. Solid lines refer to bank-relationship measures of exposure using the full sample, while dashed lines include the

[30]Second-stage results using asset quality and the share of debt due after 2008 are provided in Appendix A. These results are in line with the hypothesis. The main results in this paper use the combination of instruments, as the associated results are more stable. Results with single instruments are more sensitive to changes in the estimation equation and show larger covariance imbalances, particularly in pre-crisis growth trends.

Table 4: Covariate Balance Check from Fitted Values

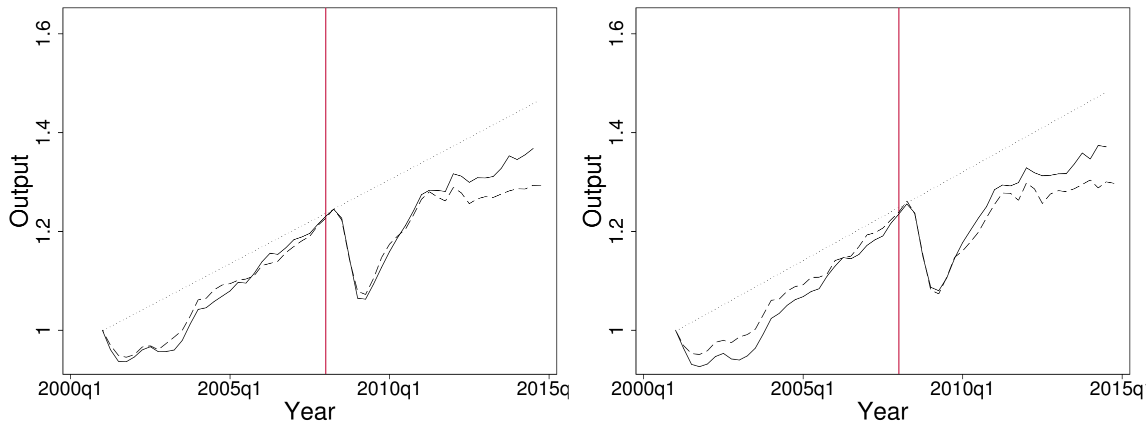
	Bank-Relationship Instruments				Incl. Share due after 2008			
	Low Exposure		High Exposure		Low Exposure		High Exposure	
Variable	N =259		N = 260		N = 226		N = 227	
Continuous Vars.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Pre-Crisis Assets (log)	6.40	1.52	7.93	1.80	6.85	1.48	7.89	1.94
Pre-Crisis Sales Gr.	0.11	0.12	0.10	0.12	0.11	0.11	0.10	0.12
Crisis Cash Flow Gr.	0.90	0.80	0.90	0.71	1.03	0.74	0.90	0.71
Age (log)	3.34	0.45	3.55	0.53	3.41	0.47	3.53	0.53
Fixed Effects	Spearman's Rank r		Product Mom. r		Spearman's Rank r		Product Mom. r	
Industry Code, 1-digit	0.85		0.95		0.89		0.96	
Industry Code, 2-digit	0.65		0.84		0.67		0.87	
Headquarter State	0.84		0.85		0.78		0.86	

Note: low and high exposure respectively refer to firms with fitted values of R&D and intangible investments above or below the median, from first stage regressions using bank characteristics, weighted by firm's last pre-crisis syndicate.

share of debt due after 2008. The figure shows that firm-exposure to the crisis has no significant effect on investments prior to 2008. After 2008, the instruments are highly significant and p-values are around 0.01 on most horizons between 2009 and 2012. This implies that the combined instruments have a prolonged effect on productivity-enhancing investments during the Great Recession while not affecting investments in earlier years, in line with Figure 4. The full first stage is provided in Tables X1 and X2 in the appendix. These tables contain the same control variables as those used in the second stage below. They show that when combining instruments, the largest coefficients appear for changes in asset quality, the deposits to asset ratio and the share of debt 1 year after Lehman Brother's failure, although there are substantial differences across specifications. Individual coefficients are often insignificant, which is in line with the high correlation between measures of crisis-exposure.

An additional test for instrument validity is provided in Table 4. It compares the mean values of covariates used in the second stage regressions. For both combinations of instruments, it compares firms for whom the fitted values in the first-stage equation were above (low exposure) and below (high exposure) the median. The left panel obtains fitted values from bank-relationship instruments while the right panel includes the share of debt due after 2008. It shows that average annual sales growth prior to the crisis and the decline in profits during the crisis is nearly identical for both groups. Values for fixed effects are also similar: the number of firms in each industry and state has correlation coefficients of at least 0.84, while the rank correlation is at least 0.65. Of some concern is the difference in mean age and pre-crisis asset size across both groups. Firms with higher exposure to the crisis are larger and slightly older, which means that some differences between both groups exist. Pre-crisis assets and age are therefore important control variables.

Figure 6. Development in Output at Firms with High and Low Crisis Exposure



Note: Solid and dashed lines represent developments in seasonally-adjusted output at firms with below and above median exposure to the crisis, respectively. Left figure obtains fitted values from bank-relationship instruments while right figure includes the share of debt due after 2008. Dotted lines present trend growth in output between 2002 and 2007. Vertical line marks Lehman Brothers' bankruptcy date.

4.2. Reduced Form Results

A potential objection to this paper's empirical strategy is that the exclusion restriction may be violated: exposure to the financial crises could affect medium-term output through alternative channels than productivity-enhancing investments.[31] Before proceeding to second stage results in Section 4.4, this section presents results in reduced form. By estimating the effect of exposure to credit tightening on medium-term output growth, I assess whether credit tightening affects medium-term growth independent of the channel through this runs.

In simplest form, this is achieved by graphing the development of output amongst firms with different degrees of exposure to the crisis. Figure 6 plots average real seasonally-adjusted output by quarter for firms with below-median (solid) and above-median exposure (dashed). Firms are grouped based on fitted values of *Invest*. The left figure uses measures on bank relationships while the right figure includes the share of debt due after 2008. Sales of each firm are indexed to unity in the first quarter of 2001. Three results stand out. First, firms have nearly identical trends prior to the crisis. Although the right hand figure shows some differences in output developments between 2002 and 2006, standardized output by the end of 2008 is roughly equal. Second, the decline in output during the crisis is similar for the two groups, both in timing and size. Third, and most importantly: growth after the trough in 2009 is stronger at firms with low exposure to the crisis. The similarity of both groups prior to the crisis marks a further validation of the empirical strategy, while diverging trends after the crisis are firmly in line with the hypothesis.

[31] The extent to which a violation is likely is addressed in Section 4.5.

Table 5: Reduced Form: Effect of Crisis Exposure on Medium Term Growth

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014						
Panel A						
Exposure Partial F-Stat.	3.0**	3.4**	4.9***	4.0***	7.1***	6.5***
F-Stat.'s P-value	0.02	0.01	0.00	0.01	0.00	0.00
R-squared	0.030	0.112	0.193	0.139	0.214	0.214
Observations	516	516	515	516	515	515
Panel B						
Exposure Partial F-Stat.	2.1*	3.0**	3.4***	2.2*	2.4**	2.0*
F-Stat.'s P-value	0.08	0.02	0.01	0.07	0.05	0.09
R-squared	0.047	0.134	0.230	0.166	0.255	0.259
Observations	453	453	452	453	452	452
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Exposure variables in Panel A: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due after 2008. Panel B adds the share of debt due after 2008. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

A formal estimation of the reduced form is provided in Table 5. It reports results from equation:

$$\Delta Output_i = \alpha + \lambda' Exposure_i + \mu' X_i + \phi_k + \psi_s + \eta_i \tag{6}$$

where $Exposure_i$ is a vector of exposure-measures containing either bank-health variables or bank-health variables and the share of debt due after 2008, analogous to instruments in Figure 5. Because these measures are correlated, most elements of λ are insignificant. Results from Wald tests of joint-significance are therefore presented in Table 5. The estimations control for output growth between 2004 and 2007 to prevent differences in trend-growth from affecting results. Standard errors are clustered by two-digit industry to correct for arbitrary intra-sectorial correlation and heteroskedasticity. Column 1 presents the baseline estimations without additional controls. Column 2 adds industry fixed effects, while state fixed effects are added in Column 3. Column 4 and 5 add additional controls for pre-crisis asset size and age. Column 6 contains the preferred specification, which includes all control variables as well as the change in cash flow over 2008 to correct for differences in the impact of the crisis. Jointly, the effect of $Exposure$ on $\Delta Output$ is significant in all specifications.

Table 6: 2SLS: Effect of Productivity-Enhancing Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Output Growth '10-'14							
Panel A							
Δ R&D Investments	0.348***	0.373***	0.414***	0.370***	0.339***	0.322***	0.271***
	(0.111)	(0.134)	(0.114)	(0.0937)	(0.0954)	(0.0830)	(0.0942)
First Stage R^2	0.06	0.15	0.27	0.29	0.31	0.38	0.45
First Stage Partial R^2	0.04	0.03	0.04	0.04	0.05	0.06	0.05
First Stage F-Statistic	8.3	8.5	8.1	9.1	9.4	9.1	4.7
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.69	0.47	0.45	0.39	0.41	0.37	0.44
Observations	515	515	514	514	514	514	502
Panel B							
Δ Investment in Intan.	0.532***	0.562***	0.566***	0.473***	0.439***	0.414***	0.333**
	(0.174)	(0.191)	(0.137)	(0.121)	(0.110)	(0.116)	(0.152)
First Stage R^2	0.06	0.13	0.26	0.27	0.29	0.37	0.45
First Stage Partial R^2	0.02	0.02	0.03	0.03	0.04	0.04	0.03
First Stage F-Statistic	5.6	5.0	10.3	11.6	14.7	17.6	1.6
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.18
J-test Overid. P-value	0.51	0.56	0.58	0.61	0.67	0.68	0.56
Observations	515	515	514	514	514	514	502
Control Variables							
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	Yes	Yes	Yes
Δ Capital Investments	No	No	No	No	No	Yes	Yes
Δ Employment	No	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

4.3. Second Stage Results

This section estimates the second stage of the empirical strategy. Results based on bank-relationship instruments are presented in Table 6, while results that also use the share of debt due after 2008 are presented in Table 7. Both tables have the same structure. The upper panel reports results using the fitted value of R&D investments for $Invest$, while the bottom panel uses intangible investments. The estimations control for average output growth between 2004 and 2007 to prevent differences in trend-growth from affecting results. Standard errors are clustered by two-digit industry to correct for arbitrary intra-sectorial correlation and heteroskedasticity. Columns are ordered identically to Table 5.

Results in both tables firmly corroborate the hypothesis. Coefficients for productivity-enhancing investments are highly significant in all specifications and are of economically relevant magnitude. According to the preferred specification in Column 6 of Table 6, a one point decline in the ratio of crisis R&D expenditures to pre-crisis expenditures lowers out-

Table 7: 2SLS: Effect of Productivity-Enhancing Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Output Growth '10-'14							
Panel A							
Δ R&D Investments	0.345**	0.347**	0.396**	0.348***	0.366***	0.345***	0.244**
	(0.134)	(0.165)	(0.168)	(0.119)	(0.116)	(0.104)	(0.117)
First Stage R^2	0.07	0.17	0.31	0.34	0.37	0.41	0.47
First Stage Partial R^2	0.05	0.04	0.04	0.06	0.06	0.06	0.05
First Stage F-Statistic	9.0	9.0	8.8	11.7	10.8	9.9	4.0
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.50	0.47	0.48	0.66	0.73	0.75	0.83
Observations	452	452	451	451	451	451	440
Panel B							
Δ Investment in Intan.	0.501***	0.482***	0.503**	0.408***	0.481***	0.447***	0.282
	(0.180)	(0.187)	(0.208)	(0.142)	(0.162)	(0.142)	(0.184)
First Stage R^2	0.06	0.15	0.30	0.33	0.36	0.41	0.48
First Stage Partial R^2	0.03	0.02	0.03	0.05	0.05	0.05	0.03
First Stage F-Statistic	6.52	8.05	15.2	17.9	13.7	14.9	2.6
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.18
J-test Overid. P-value	0.54	0.63	0.58	0.74	0.81	0.86	82
Observations	452	452	451	451	451	451	440
Control Variables							
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	Yes	Yes	Yes
Δ Capital Investments	No	No	No	No	No	Yes	Yes
Δ Employment	No	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due after 2008. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

put growth between 2010 and 2014 by 0.34 percentage points. This translates to a decline in annual output growth of 0.08 percentage points. Based on first-stage estimates, a one standard-deviation change in exposure to the financial crisis would therefore implicitly lead to a decline in annual post-crisis growth by 0.2 to 0.6 percentage points, depending on the measure used. Point coefficients are stable across specifications, and differences never exceed the size of a standard error. This suggests that omitted variable bias is limited. First-stage F-statistics usually exceed the rule of thumb value of 10, while J-statistics for Hansen's test of overidentifying restrictions never reject the instrument exogeneity condition. Regressions using different years for investment in productivity and medium term output are provided in Appendix B. Results are robust to both.

4.4. Effect over Time

I next assess how the effect of productivity-enhancing investments on output develops over time. Because it takes two to three years for productivity-enhancing investments to affect a firm's potential output, the effect of investments on output in 2010 should be smaller than in subsequent years. To test this, the following projection is estimated annually:

$$Output_{t+h,i}/Output_{t,i} = \alpha_h + \gamma_h \widehat{Invest_i} + \mu_h' X_i + \phi_k + \psi_s + \eta_i \qquad (7)$$

for $h = 1, 2, 3, 4$ and $t = 2009$. The equation is estimated using the preferred specification in column 6 of Tables 6 and 7. Standard errors are clustered by industry. Results are presented in Table 8. Each column presents results from regressions at a separate point of the projection horizon. The upper panel uses the significant bank health measures as instruments for investments, while the bottom panel adds the share of long term debt due after 2008. In line with expectations, the effect of investments during the crisis on growth in 2010 is insignificant in all specifications. Coefficients vary between -0.11 and 0.10. By 2012, a one percentage point decline in investments comes with a 0.2 percentage point reduction in growth. The size of coefficients increases until the end of the sample in each specification. The monotonic increase of coefficients is consistent with two expectations. First, it is in line with estimates in Mansfield et al. (1971) on the time required from expenditures in R&D to become productive. Second, it is in line with endogenous growth models, in which a temporary shortfall in productivity-enhancing investments is not undone by an increase in investments after the crisis.

4.5. Falsification Tests

Results in the previous section provide evidence that firms with higher exposure to the financial crisis reduced productivity-enhancing investments and subsequently had lower medium-term growth. I next conduct two falsification tests to further establish whether these results are causal.

4.5.1. Investments in Other Production Factors

The first falsification test assesses whether investments in other type of production factors can explain medium-term growth. Firms with higher exposure to the crisis might invest less in physical capital or reduce employment, which could also affect growth after 2010. If this is the case, the instrument exogeneity condition is violated and results in Section 4.4 have no causal interpretation. Results remain valid if investments in other forms of intangible capital like on-the-job training are at play, because my measures are used as proxies for a firm's total effort to become more productive. From a theoretical standpoint it is unlikely that declines in physical capital could explain medium-term growth: if total factor productivity is unaffected

Table 8: Projection on Effect Producticity-Enhancing Investments During Crisis on Output

	(1) Output 2010	(2) Output 2011	(3) Output 2012	(4) Output 2013	(5) Output 2014
Instruments: Bank Health Variables (N = 513)					
Δ R&D Investments	0.101	0.153	0.187	0.387***	0.461***
	(0.0703)	(0.115)	(0.116)	(0.139)	(0.146)
R-squared	0.206	0.196	0.186	0.105	0.092
Δ Investment in Intangibles	0.0988	0.190	0.238*	0.352**	0.470***
	(0.0824)	(0.135)	(0.132)	(0.143)	(0.143)
R-squared	0.223	0.196	0.195	0.173	0.154
Instruments: Bank Health and Share of L.T. Debt Due (N = 450)					
Δ R&D Investments	-0.0140	0.107*	0.217***	0.353***	0.489***
	(0.0497)	(0.0573)	(0.0624)	(0.0921)	(0.125)
R-squared	0.220	0.242	0.199	0.169	0.120
Δ Investment in Intangibles	-0.114	0.0828	0.220*	0.239*	0.372**
	(0.0919)	(0.0928)	(0.117)	(0.144)	(0.178)
R-squared	0.138	0.251	0.235	0.246	0.238

Note: Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Control variables from column 6 of Tables 6 and 7.
Each cell presents results γ_h in a seperate regression.

by the crisis, firms have an incentive to increase investments until their marginal product equals the cost of capital. Similarly, employment should be increased until wages equal the marginal product of labor. Consequently, short-term credit disruptions should have no lasting effect.

To test whether this is confirmed by the data, estimations from Sections 4.1 and 4.4 are repeated using change in investments in physical capital, measured through capital expenditures (item *capex* in Compustat), and changes in employment (item *emp*). Results from first-stage regressions are presented in Table 9. The left panel uses growth in capital expenditures as the dependent variable, while the right panel uses growth in employment. Results show that exposure has the expected effect on capital expenditures. Coefficients are significant for exposure to mortgage backed securities, low deposit ratios, bad loan provisions, and the share of debt due in one year. Most coefficients are only marginally significant and F-values never exceed 5.6. This implies that the effect of my measures of exposure is weaker for capital investments than for investments in productivity-enhancement. Results on employment growth in the right panel are stronger. These regressions effectively replicate results in Chodorow-Reich (2014) on the Compustat sample. F-statistics exceed 10 for the deposits to assets ratio and asset quality, which are also important determinants of productivity-enhancing investments. Note that effects of exposure on employment could work through its effect on investments

Table 9: First Stage: Effect of Crisis-Exposure on Capital Expenditure and Employment

	Capital Investments				Employment			
Variable	Coeff.	Const.	R^2	F-val.	Coeff.	Const.	R^2	F-val.
Bank's Asset Quality								
Asset Quality	0.035	-0.075	0.000	0.8	0.046***	-0.054	0.017	13.5
	(0.040)	(0.105)			(0.013)	(0.036)		
Δ Asset Quality	-0.052	0.154	0.001	2.1	-0.001	0.046	0.000	0.0
	(0.036)	(0.131)			(0.015)	(0.059)		
Bank's Crisis Exposure								
% Lehman Lead	-0.028	0.061	0.001	0.7	-0.014	0.075	0.001	0.8
	(0.034)	(0.085)			(0.016)	(0.057)		
ABX Exposure	-0.063*	0.274*	0.001	3.0	-0.031*	0.180**	0.001	3.9
	(0.037)	(0.162)			(0.016)	(0.088)		
Deposits/Assets	0.062**	-0.219*	0.001	5.6	0.041***	-0.101*	0.013	11.0
	(0.026)	(0.115)			(0.013)	(0.058)		
Bankruptcy Dummy	0.026	0.152***	0.001	0.2	-0.015	0.047	0.002	1.2
	(0.054)	(0.053)			(0.014)	(0.032)		
Bank's Balance Sheet								
BLP/Loans	-0.059*	0.133	0.001	0.1	-0.036**	0.127**	0.011	6.7
	(0.033)	(0.091)			(0.014)	(0.050)		
Leverage Ratio	-0.041	0.074	0.000	2.0	-0.010	0.061	0.000	0.5
	(0.035)	(0.089)			(0.015)	(0.052)		
Firm's Characteristics								
Share 1 year	-0.060*	0.004	0.001	4.0	-0.042***	0.64**	0.016	25.9
	(0.030)	(0.051)			(0.008)	(0.031)		

Note: Dependent variable is the ratio of real productivity-enhancing investments in 2009-2010 to 2005 -2007. 519 observations. Estimates obtained from univariate OLS. Standard errors clustered by industry and given in parentheses. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.

in productivity-enhancement, as a reduction in spending on (e.g.) R&D comes with lower personnel requirements.[32]

Results for the second stage are provided in Table 10. The upper and lower panel present results for capital expenditures and employment, respectively. Because significance of the exposure variables is different for capital expenditures and employment, the second-stage regressions are estimated using different combinations of instruments. Columns I uses all significant bank-relationship instruments for either capital expenditures and employment. Columns II add the share of debt due after 2008. Columns III and IV use instruments from Section 4.4 excluding and including the share of debt due after 2008, to preserve comparability

[32]An alternative channel through which exposure to the crisis may affect growth is the ability of firms to acquire other firms. First stage regressions of crisis-exposure on the amounts that firms spend on acquisitions (Compustat item *aqc*) were however insignificant for all measures. Regressions on the change in the amount spent on acquisitions are significantly negative for the percentage of long-term debt due, but insignificant in difference-in-difference specifications.

Table 10: 2SLS: Effect of Capital Expenditure and Employment on Output

Output Growth	(1) I	(2) I	(3) II	(4) II	(5) III	(6) III	(7) IV	(8) IV
Panel A								
Δ Capital Inv.	0.000	-0.112	0.113	-0.075	0.035	-0.024	0.124	0.215
	(0.168)	(0.148)	(0.151)	(0.143)	(0.125)	(0.159)	(0.0950)	(0.139)
1st St. R^2	0.03	0.29	0.05	0.34	0.05	0.30	0.06	0.34
1st St. Part. R^2	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03
1st St. F-Stat.	3.2	1.2	4.7	2.1	6.7	4.0	3.8	4.6
F-Stat.'s P-val.	0.02	0.33	0.00	0.11	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.37	0.14	0.57	0.39	0.10	0.16	0.20	0.45
Observations	516	515	453	452	516	515	453	452
Panel B								
Δ Employment	0.234	0.483	0.170	0.588	0.145	0.620*	0.289	0.980**
	(0.242)	(0.336)	(0.212)	(0.366)	(0.217)	(0.348)	(0.207)	(0.448)
1st St. R^2	0.12	0.35	0.13	0.38	0.13	0.35	0.12	0.37
1st St. Part. R^2	0.03	0.02	0.04	0.03	0.03	0.03	0.04	0.02
1st St. F-Stat.	4.0	4.3	11.4	9.1	3.6	3.8	7.2	8.9
F-Stat.'s P-val.	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
J-test Overid. P-value	0.40	0.29	0.58	0.63	0.11	0.49	0.17	0.57
Observations	504	503	442	441	504	503	442	441
Control Variables								
Lagged Growth	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Eff.*	No	Yes	No	Yes	No	Yes	No	Yes
State *Fixed Eff.*	No	Yes	No	Yes	No	Yes	No	Yes
Firm Charact.	No	Yes	No	Yes	No	Yes	No	Yes
Impact 2008 Rec.	No	Yes	No	Yes	No	Yes	No	Yes

Note: Columns I: bank health instruments that are significant for investments in physical capital or employment (respectively). Columns II: adds share of debt due after 2008. Columns III: banking instruments used in R&D tables. Columns IV: adds share of debt due after 2008. Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate, share of long term debt due after 2008. Standard errors, clustered by industry,in parentheses. *, **, and *** denote significance at the 10, 5, and% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

with previous results. Standard errors are clustered by two-digit industry. The effect of capital expenditures on medium-term growth is insignificant in all specifications. Coefficients never exceed 0.22 and are negative in a number of regressions. This implies that, while affected firms reduce investments in both capital expenditures and productivity-enhancement, only the latter is significantly correlated with medium-term output growth. That confirms theoretical predictions and provides some evidence in favor of the instrument exogeneity condition. The effect of employment-declines in 2009 and 2010 on medium term growth is significant in two specifications, although F-values however are always below 10.

To address concerns that changes in employment during the crisis are responsible for results in Section 4.4, the dependent variable in the second stage is divided by employment. The resulting variable measures output per employee, which should be affected by productivity-enhancing investments. Results are provided in Appendix Tables A5 and A6, which are identical to Section 4.4's tables except for dependent variables. The estimated effect of investment in productivity are in line with the previously estimated effect on medium-term output growth. Results in Table A5 are similar in both significance and magnitude, which is expected if productivity-gains are the source of medium-term output growth. Regressions in Table A6 are significant if state fixed effects are taken into account.

4.5.2. Placebo Regressions

The second falsification test consists of running placebo regressions on growth after the recession of 2002. This is a test of selection rather than the exclusion restriction. If results in Section 4.4 present the causal effect of exposure to the 2008-9 financial crisis on medium-term growth, running the same regressions on growth after a different episode should yield insignificant coefficients. Results are presented in Tables 11 and 12, which replicate Tables 6 and 7, respectively. The dependent variable in both tables is growth in real output between 2002 and 2004. These years are considered because the pre-crisis trend variable used as a covariate in all prior specifications measures average growth between 2004 and 2007. Specifications are unchanged in terms of instruments and control variables. Results in both tables suggest that the empirical strategy is valid. Developments in productivity-enhancing investments during 2009 and 2010 have no significant effect on output growth between 2002 and 2004. In the full sample of Table 11 coefficients are less than half the size of estimates in Table 6. Coefficients in some specifications even turn negative when using the share of debt due after 2008 as an additional instrument in Table 12.

5. Aggregation

This section provides a back-of-the-envelope aggregation of the results in Section 4. To do so, the firm-level effect of exposure to the crisis on investments and subsequent growth is added up across sampled firms and compared to a counterfactual. This partial-equilibrium exercise is presented in Section 5.1. The exercise is of partial equilibrium nature because it is uncertain to what extent the estimated effect of investments captures the impact on firm i's growth alone, or firm i's relative growth to others. Throughout Section 5.1 it is assumed that the firm-level effect of exposure in growth translates one-on-one to aggregate output. A discussion on the validity of this assumption and the likely size of general equilibrium effects are provided in Section 5.2.

5.1. Partial Equilibrium Effects

The aggregation exercise under partial equilibrium involves three steps. First, I create a counterfactual scenario of output growth in absence of the crisis amongst sampled firms. To do so, I assume that average productivity-enhancing investments would grow at the same rate

Table 11: Placebo Effect of R&D Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2002-2004						
Panel A						
Δ R&D Investments	0.127	0.177	0.201	0.218	0.241	0.210
	(0.227)	(0.257)	(0.225)	(0.254)	(0.241)	(0.214)
First Stage R^2	0.06	0.15	0.27	0.17	0.29	0.31
First Stage Partial R^2	0.04	0.03	0.04	0.03	0.04	0.05
First Stage F-Statistic	8.3	8.5	10.2	14.7	12.6	12.5
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.24	0.25	0.31	0.54	0.79	0.79
Observations	516	516	515	516	515	515
Panel B						
Δ Investment in Intangibles	0.0747	0.193	0.286	0.134	0.201	0.184
	(0.475)	(0.547)	(0.438)	(0.356)	(0.351)	(0.315)
First Stage R^2	0.06	0.13	0.26	0.16	0.27	0.29
First Stage Partial R^2	0.02	0.02	0.03	0.02	0.03	0.04
First Stage F-Statistic	5.6	5.1	11.5	4.4	12.4	14.9
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.31	0.50	0.66	0.29	0.59	0.67
Observations	516	516	515	516	515	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$, 2002-2004. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

during the crisis as the last three years prior to the crisis.[33] Second, I use annual estimates from the projection in Table 8 to calculate a firm-specific path of output if investments had grown at the average pre-crisis rate.[34] The aggregate effect of productivity-enhancing investments is obtained by adding up the predicted path of output across sampled firms.

Before proceeding to the third step, Figure 7 plots results from step two. It graphs developments in quarterly real output from the start of the sample up to 2010. Afterwards, it plots developments in actual (solid) and counterfactual (long-dashed) output. The left figure plots results based on R&D investments, while the right figure uses investment in intangible capital. The predicted effects are substantial: if all firms in the economy move from the actual to the 90th percentile of productivity-enhancing investments, aggregate output of sampled

[33] Firms at the 90th percentile of investment growth during the crisis have similar growth rates prior to and during the crisis.

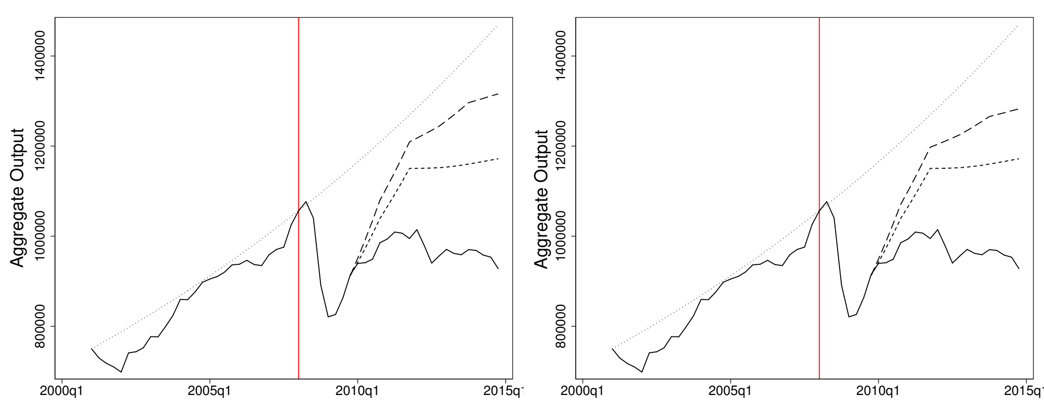
[34] Annual fitted growth is obtained by inserting the fitted values of productivity-enhancing investments at the counterfactual 90th percentile with firm-specific covariates and fixed effects: $\widehat{Output}_{i,t+h}/Output_{i,t} = \alpha_h + \gamma_h \widehat{Invest}_i^{90} + \mu_h' X_i + \phi_{k,h} + \psi_{s,h}$. The equation is estimated along preferred specification 6 in Tables 6 and 7 which includes all covariates and fixed effects at industry and state level.

Table 12: Placebo Effect of R&D Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2002-2004						
Panel A						
Δ R&D Investments	.049	-0.019	0.101	0.042	0.050	0.108
	(0.151)	(0.199)	(0.200)	(0.166)	(0.169)	(0.173)
First Stage R^2	0.07	0.17	0.32	0.21	0.34	0.38
First Stage Partial R^2	0.05	0.04	0.05	0.06	0.06	0.06
First Stage F-Statistic	9.0	8.8	17.4	9.9	21.6	17.0
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.16	0.25	0.12	0.32	0.38	0.56
Observations	453	453	452	453	452	452
Panel B						
Δ Investment in Intangibles	-0.035	-0.121	0.071	-0.053	-0.075	-0.003
	(0.213)	(0.323)	(0.322)	(0.176)	(0.202)	(0.208)
First Stage R^2	0.06	0.15	0.30	0.19	0.33	0.36
First Stage Partial R^2	0.03	0.02	0.03	0.05	0.05	0.04
First Stage F-Statistic	5.9	7.6	12.2	15.1	19.6	12.7
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.20	0.30	0.19	0.29	0.43	0.60
Observations	453	453	452	453	452	452
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due after 2008. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Figure 7. Aggregate Effect of Investments in Productivity from Fitted Values



Note: Solid lines present aggregate seasonally adjusted quarterly output in the sample. Long- and short-dashed lines present predicted path of output for firms at the 90th and 50th percentile, respectively, of fitted investment growth using estimates from col. 6 in Table 6. Left figure uses R&D investments, right figure uses intangible investments.

firms in 2014 would be 40% higher. This number is elevated by the fact that a number of large firms has faced both strong exposure to the crisis and low growth in recent years, which exacerbates the difference between actual and counterfactual growth. It is more robust to compare counterfactual output with the predicted path of output if all firms had allowed investments to grow at the median rate (short-dashed). This comparison suggests that output in absence of the crisis would have been 12% higher.[35]

The third step involves transforming the sample to facilitate an estimate of the aggregate effect on GDP. This requires two changes. First, output is multiplied by the average percentage value added in sales for each firm's 6-digit industry, to account for the use of intermediate goods in production.[36] Total value added amongst firms in the sample is 445 billion in the fourth quarter of 2007, which is equal to 11.9% of real GDP.[37] Second, I reweigh firms such that the distribution of R&D spending amongst firm-size classes in the sample is similar to the actual distribution in the U.S. in 2007.[38]

Results from aggregating developments in value added for the reweighted sample are plotted in Figure 8. A comparison of output from fitted values of investments growing at the pre-crisis trend and at the median suggests that value added amongst R&D performers would have been 11% higher if no crisis had occurred. This implies a 2.3% increase in GDP, or 16% of the gap between trend and actual GDP displayed in Figure 1. Comparing actual developments in value added and fitted values if investments had grown at the pre-crisis rates suggests a 6.4% increase, which translates to over 40% of the gap.

5.2. Limitations

The main concern with a partial equilibrium aggregation follows form the limitation that regressions capture the effect of crisis-exposure on productivity-enhancing investments at firms

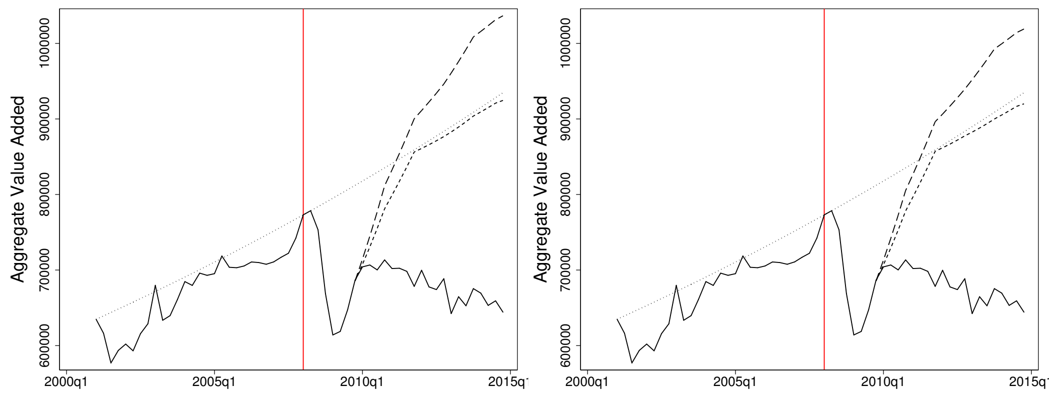
[35]This estimate implies that the gap between an extrapolated trend of growth between 2001 and 2007 would be 50% lower under the counterfactual of constant investments compared to median investments.

[36]Sector data is used because value added is not observed directly: Compustat does not contain data on wage and salary payments for most sampled firms. Data is obtained from the BEA's benchmark input-output table for 2007. Firms are matched to industries in IO-tables using the following procedure. First, firms with NAICS codes that match a 6-dixit industry code are matched straight to codes on the BAE conversion table. This creates a match for over 90% of firms. Second, firms with only 3,4 or 5 digit codes in Compustat are matched to all 6-digit sub-codes in the IO-tables. Value added is calculated by taking a simple average over all codes. Firms without matchable codes are removed. BEA data is successfully matched for 513 firms. Average value added is 44%, which is expected for a sample with a large share of manufacturing firms (Moro, 2012).

[37]The estimated output-fall of 12% in the previous section therefore suggests that the within-sample effect of the financial crisis on medium-term GDP in the U.S. is therefore 1.4%. This means that reduced investments amongst the 519 firms in my sample are responsible for almost 10% of the gap between trend and actual GDP displayed in Figure 1.

[38]This is needed because the merged Compustat-DealScan sample consists of publicly listed and active on the syndicated loan market, creating an over-representation of large firms. Appendix Table A7 shows that firms with less than 1000 employees account for only 1.1 percent of sampled R&D spending, while they accounts for 24.1% of spending at aggregate level. Oppositely, firms with more than 10,000 employees account for 87.1% of spending by sampled firms and only 52.3% of U.S. spending. As sampled firms are responsible for 54% of aggregate R&D expenditures, developments in value added for the reweighted sample are then divided by 54% to approximate the out-of-sample effect of investments on GDP.

Figure 8. Aggregate Effect of Investments in Productivity from Reweighted Sample



Note: Solid lines present aggregate seasonally adjusted quarterly value added in the re-weighted sample. Long- and short-dashed lines present predicted path of value added for firms at the 90th and 50th percentile, respectively, of fitted investment growth using estimates from specification 6 in Table 6. Left figure uses R&D investments, right figure uses intangible investments.

relative to others. This could lead to an overestimation of the general equilibrium effect. A financial crisis raises the costs of investments at given prices, which reduces demand for inputs like skilled labor and equipment. In a perfect market this reduces their price and partly offsets the effect of the rate hike. In the empirical sections, the effects of price changes are not captured because they apply to all firms equally. Consequently, the aggregation in 5.2 could overstate the general equilibrium effect of credit shocks on productivity enhancing investments.[39]

From a theoretical standpoint, it seems unlikely that the offsetting effect of price reductions would be substantial. Atkeson and Burstein (2015) show that the general equilibrium effects of policies that affect aggregate demand for productivity-enhancing investments are large in a baseline endogenous growth model. The size of an offsetting general equilibrium effect depends primarily on the elasticity of input prices to the demand for productivity-enhancing investments. If prices and wages are sticky, the difference between a partial and general equilibrium exercise is modest because the response R&D costs to a crisis is impeded. U.S. median wages rose moderately in 2008 and 2009, which suggests that costs of productivity-enhancing investments did not decline much. The well-documented lack of disinflation in the aftermath of the crisis (e.g. Gilchrist et al., 2015) lends further support to this notion. In line with this, the sticky price model in Anzoategui et al. (2016) replicates the slowdown in productivity around the Great Recession well. Note that the aggregation may also *understate* the general equilibrium effect of productivity-enhancing investments, because it does not consider spillovers. It is likely that companies which use the output of R&D performers as intermedi-

[39]The appendix contains a dynamic business cycle model with endogenous growth in order to quantify the likely magnitude of the difference between partial and general equilibrium effects. Results from this model suggest that under a conservative calibration, at most 44% of partial equilibrium effects do not translate to general equilibrium.

ary inputs are also affected by reduced technological progress. These indirect effects are not captured in the aggregation, which may result in an underestimation of the aggregate effect.

6. Conclusion

The financial crisis of 2008-9 and the ensuing Great Recession have led to a large decline in output throughout developed economies. Per capita output in the United States and Europe has deviated 10 to 20% from its pre-crisis trend. This is in line with the lack of recovery observed throughout financial crises over the last century. A growing theoretical literature suggests that crises have such long-term effects through endogenous growth channels. Crises reduce the ability of firms to finance productivity-enhancing investments, leading to a temporary slowdown in growth of potential output. This paper has aimed to provide causal evidence on that mechanism.

I exploit quasi-experimental variation in bank health and firm debt maturity to exogenously infer the extent to which firms were exposed to credit-tightening during the 2008-9 financial crisis. In particular, I assess whether the quality of a bank's assets, its exposure to Lehman Brothers' bankruptcy and its balance sheet health in 2007 affect investments in R&D and intangible capital during the crisis at firms that rely on its loans. Results show that the ratio of productivity-enhancing investments during the crisis to investments prior to the crisis reduces by 4 to 8 percentage points for each standard deviation increase in bank-exposure to the crisis. The main results show that investments have meaningful effects on output: annual growth between 2010 and 2014 is 0.08 percentage point lower for each percentage point decline in productivity-enhancing investments. That relationship is robust to the inclusion of various control variables as well as state and sector fixed effects. The validity of the empirical results have been verified in three ways. First, I use reduced form regressions to show that medium-term output growth is lower at firms with higher exposure to the crisis, irrespective of the channel through which this occurs. It is therefore likely that a part of the gap between actual and trend GDP in the U.S. is due to financial factors. Second, I assess whether developments in other production factors like physical capital and employment can explain medium-term growth, and find no relation. Third, I use placebo regressions on growth after the 2001 recession to show that exposure to the 2008-9 financial crisis does not explain growth over other horizons.

The results in this paper are relevant for policymakers. A partial-equilibrium exercise that aggregates the estimates suggests that output amongst sampled firms would be 12% higher by 2015 if no crisis had occurred. Based on an approximation of firm-level value added, this suggests that GDP would have been 2.3% higher. If trickle-down effects of innovation to firms lower in the value chain would be taken into account, the estimated effect would likely be larger. There are therefore substantial gains to public policies that can prevent firms from reducing productivity-enhancing investments due to financial constraints. Potential policies could include tax credits for R&D spending or the provision of subsidized loans.

My findings are in line with endogenous growth models in which crises affect the ability of firms to finance productivity-enhancing investments. The mechanism through which credit-tightening reduces investments differs across models. In the simplest case, crises reduce optimal productivity-enhancing investments because the associated profits decline with average interest rates. More complex channels might also apply, such as stricter collateral requirements or preferences for the timing of payoffs. An assessment of which mechanisms are at play remains an important avenue for future research.

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General Equilibrium Derivations

This appendix presents a simple business cycle model with endogenous growth. The model bears resemblance to RBC models with investments in human capital along Stadler (1990) and draws on endogenous growth models like Romer (1990) and Aghion et al. (2009). Firms employ skilled workers to enhance productivity. A market imperfection yields that firms cannot be forced to pay those wages at the end of each period. Workers therefore require assured payment in advance, which is provided by financial institutions. These have access to a costly technology to enforce debt repayment. Financial crises are modelled through an exogenous increase in enforcement costs. This leads them to raise interest margins on lending for innovative projects. Employment of skilled workers temporarily falls, leading to a slowdown in growth.

A.1 Households

There is a continuum of identical households with unit measure. The representative household earns income by providing unskilled labor for the production of goods, skilled labor for the invention of technologies and by obtaining profits from good producers and the financial sector, which it owns. Households allocate consumption and labor supply over time to maximize the following lifetime utility function:

$$E_t \sum_{s=0}^{\infty} \beta^t \left[ln(C_{t+s}) - \frac{(H_{t+s})^{1+\psi}}{1+\psi} \right] \tag{1}$$

where C is a basket of consumption goods while H denote the supply of skilled labor. The budget constraint reads:

$$C_t = D_t(1+r_t) - D_{t+1} + W_{L,t}L_t + W_{H,t}H_t + \Pi_t \tag{2}$$

where D denotes deposits held by the household, Π_t denotes lump sum profit transfers, L denotes inelastically supplied unskilled labor, while W_L and W_H denote real unskilled and skilled wages. Intertemporal optimization with respect to consumption and future deposits yields the Euler equation:

$$\frac{E_t(C^i_{t+1})}{C^i_t} = (1+r_{t+1})\beta \tag{3}$$

Intratemporal optimization with to respect skilled labor supply yields:

$$C^i_t = W_{H,t}(H^i_t)^{-\psi} \tag{4}$$

A.2 Non-Financial Firms

The economy consists of a continuum of unit measure variety producers that sell goods to consumers. Each intermediate producer has in-house production technology to produce a consumption variety j, which it sells monopolistically. The production function reads:

$$Y_{j,t} = A_{j,t} L_{j,t}^{1-\alpha} \tag{5}$$

where Y_j denotes the quantity produced of variety j using unskilled employment L_j with firm-specific productivity A_j. After production in period t, firms decide how much to invest in labor productivity. These investments are financed with loans from financial intermediaries. To increase productivity, firms must hire skilled workers which invent labor-augmenting technologies. These increase A at a diminishing rate:

$$A_{j,t+1} = A_{j,t}(1 + \gamma H_{j,t}^{\lambda}) \tag{6}$$

where $0 < \lambda < 1$ governs returns to scale and $H_j \geq 0$. Firms are motivated to innovate because of profits generated by additional good production. These profits are the result of monopolistic competition among variety producers. Following Dixit and Stiglitz (1977), the following constant elasticity of substitution (CES) aggregator applies:

$$Y_t = \left[\int_0^1 (Y_{j,t})^{\frac{\mu-1}{\mu}} dj \right]^{\frac{\mu}{\mu-1}} \tag{7}$$

Optimization of good demand by consumers subject to the aggregator implies the following relationship between the price of variety p_j and aggregate price level P and GDP Y:

$$Y_{j,t} = Y_t \left(\frac{p_{j,t}}{P_t} \right)^{-\mu} \tag{8}$$

$$P_t = \left[\int_0^1 (p_{jt})^{1-\mu} dj \right]^{\frac{1}{1-\mu}} \tag{9}$$

The optimization problem of firms is twofold: they choose optimal pricing and optimal investment in future growth. The dynamic objective function reads:

$$V_{j,t} = E_t \sum_{s=0}^{\infty} \zeta_{t,t+s} \left(Y_{j,t+s} - \left[\frac{P_{t+1}}{p_{j,t+1}} \right] [W_{t+s} L_{j,t+s} + W_{H,t+s} H_{j,t+s}] \right) \tag{10}$$

which is optimized subject to constraints (5), (6), and (8). $\zeta_{t,t+s}$ denotes the firm's discount factor, which equals the consumer's marginal rate of substitution of consumption of period t

for period $t+s$ under balanced growth. The static optimization of prices yields first order condition:

$$p_{j,t} = \left[\frac{\mu}{\mu - 1} \left(\frac{1}{1-\alpha} \right) \frac{W_t}{P_t} \left(\frac{Y_t^{\alpha}}{A_{j,t}} \right)^{\frac{1}{1-\alpha}} \right]^{\frac{1-\alpha}{1-\alpha+\mu\alpha}} P_t \tag{11}$$

In the symmetric equilibrium $A_j = A$ which yields $p_j = P$, such that the real dynamic objective function reads:

$$V_{j,t}^{R} = E_t \sum_{s=0}^{\infty} \zeta_{t,t+s} \left[Y_{j,t+s} - W_{t+s} L_{j,t+s} - W_{H,t+s} H_{j,t+s} \right] \tag{12}$$

Denoting by J_j^H the value of hiring an additional researcher, the infinite-horizon incentive to hire an additional researcher is given by:

$$J_{j,t}^{H} = E_t \sum_{s=1}^{\infty} \zeta_{t,t+s} \left[\left(\frac{\partial A_{j,t+s}}{\partial H_{j,t}} \right) L_{j,t+s}^{1-\alpha} \right] \tag{13}$$

which simplifies to:

$$J_{j,t}^{H} = A_{j,t} \gamma \lambda H_{j,t}^{\lambda-1} \left(E_t \sum_{s=0}^{\infty} \zeta_{t,t+s} L_{t+s}^{1-\alpha} \right) \tag{14}$$

Then equilibrium requires that this value equals the costs of hiring an additional researcher. Firms pay salaries to researchers in advance, and therefore require loans. The costs of an additional researcher therefore equals the sum of interest and salary expenses:

$$J_t^H = (1 + r_{H,j,t}) W_{H,t} \tag{15}$$

where r_H denotes the interest rate paid on bank loans. The amount of loans demanded S_j equals salary expenses on scientists, such that $S_j = W_H H_j$.

A.3 Financial Institutions

Financial institutions in the model exist purely to assist in the cash-in-advance treatment of salary payments to skilled employees. The existence of advance payment constraints could rationally follow from an imperfection in contract enforceability where firms are able to elope with profits without paying their employees. As the specificities of the market imperfection are not essential to the empirical sections of this paper, they are not modelled explicitly.[40] Instead, it is assumed that financial institutions have access to a costly enforcement technology that enables the collection of debt at the end of each period, while households do not.

There is a continuum of financial institutions h with access to a contract enforcement technology specific to firm j. To enforce repayment at the end of each period, financial

[40] On similar grounds I do not impose a cash-in-advance constraint on salaries of unskilled workers, while the model could straightforwardly be extended in that direction.

institutions incur a cost $\nu_{j,t} x_t$ proportional to the amount outstanding with the borrowing firm. Other banks can purchase the screening technology for firm i giving rise to the standard zero-profit condition. The interest rate paid on loans by firm j is therefore equal to enforcement costs:

$$\nu_{j,t} x_t = r_{H,j,t} \tag{16}$$

Credit shocks enter the model as an idiosyncratic or systemic increase monitoring costs, which respectively evolve along AR(1) processes $\nu_t = exp(\epsilon_{\nu,t})\nu^* \nu_{t-1}^{\rho_\nu}$ and $x_t = exp(\epsilon_{x,t}) x^* x_{t-1}^{\rho_x}$.

A.4 Equilibrium

Consider the symmetric equilibrium where each firm has equal technology and enforcement technologies. Equilibrium on labor markets is obtained by adding production function (5) to (11), which gives the standard relationship between real wages, markups and employment:

$$W_t = A_t L_t^{-\alpha}(1-\alpha)\frac{\mu - 1}{\mu} \tag{17}$$

Equilibrium demand for unskilled labor is trivial as inelastic labor supply equals 1. Equilibrium on the market for skilled labor requires that the number of scientists is such that the increase in present value profits due to increases in productivity equal current costs of hiring an additional one. From equations (14) and (15) it follows that:

$$W_{H,t} = E_t\left(\left[\frac{1}{1+r_{H,t}}\right]_t H_{j,t}^{\lambda-1}\left[\frac{\lambda\gamma}{1-\zeta}\right] L^{1-\alpha}\right) \tag{18}$$

Equating this function with supply of skilled workers (4) and isolating H:

$$H_t = \left(\left[\frac{1}{1+r_{H,t}}\right]\frac{\gamma\lambda}{1-\zeta}\right)^{\frac{1}{1+\psi-\lambda}} \tag{19}$$

From this equation it is clear how a financial shock, modelled as an increase in interest rate, affects growth. Growth along the balanced growth path follows from inserting interest rates in (16) into this expression using that in the steady state $\eta_{j,t} x_t = \eta^* x^*$. From growth equation (6), it follows that the solution to Romer equation:

$$g_A^* = 1 + \gamma\left(\left[\frac{g_A^*}{g_A^* - \beta}\right]\left[\frac{\gamma\lambda}{1+\eta^* x^*}\right]\right)^{\frac{\lambda}{1+\psi-\lambda}}, \tag{20}$$

yields growth in the steady state. Observe that growth increases in the efficiency of R&D expenditures and the discount factor, while it decreases with contract enforcement costs.

A.5 General and Partial Equilibrium Effects

The general equilibrium effect of financial crises is mitigated by the fact that the costs of research declines during a financial crisis. This is modeled as a decline in wages when demand for skilled researchers is low. Firms that are not affected by the crisis are therefore motivated to increase productivity-enhancing investments. Consider a financial crisis which increases systemic monitoring costs from η to η^C. From equation (15) it follows that:

$$J^H_{j,t} = (1 + r_{H,j,t})W_{H,t} = A_t \gamma \lambda H^{\lambda-1}_{j,t} E_t \sum_{s=0}^{\infty} \zeta_{t,t+s} L^{1-\alpha}_{j,t+s}, \tag{21}$$

such that

$$H_{j,t} = \left[(1 + r_{H,j,t})W_{H,t} \left(\frac{1}{\gamma\lambda} \right) V^{-1}_{j,t} \right]^{\frac{1}{\lambda-1}}, \tag{22}$$

where $V_{j,t} = A_t E_t \sum_{s=0}^{\infty} \zeta_{t,t+s} L^{1-\alpha}_{j,t+s}$. Taking log differences under symmetry, (22) yields the equation governing firm-level investments in productivity growth:

$$\Delta h_{j,t} = -\left[\frac{1}{1-\lambda} \right] ln\left(\Delta[1 + r_{H,j,t}]\right) - \left[\frac{1}{1-\lambda} \right] \Delta w_{H,t} \tag{23}$$

where ΔX_t denotes the change in X at t compared to $t-1$ while lower cases denote logs. In a comparison of firms under partial equilibrium, the effect of higher interest rates on wages is not considered because these costs are identical across firms.[41] The partial equilibrium effect of financial crises on productivity-enhancing investments therefore simplifies to:

$$\Delta h^{PE}_{j,t} = -\left[\frac{1}{1-\lambda} \right] ln\left(\Delta[1 + r_{H,t}]\right) \tag{24}$$

The general equilibrium effect of a financial crisis on investments in productivity is found by taking log differences of equation (19). This yields the following counterpart of first stage regressions and partial equilibrium equation (23):

$$\Delta h^{GE}_{t}{}_{j} = -\left[\frac{1}{1+\psi-\lambda} \right] ln\left(\Delta 1 + r_{H,t}\right). \tag{25}$$

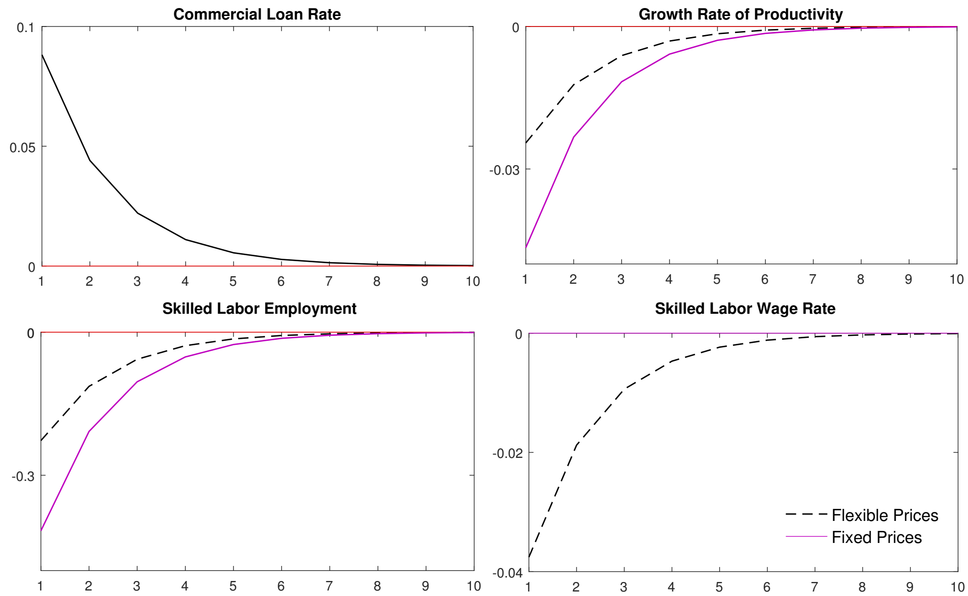
where the mitigating effect of wages runs through the inverse of the Frish labor supply elasticity ψ. The percentage difference between partial and general equilibrium effects of changes in interest rates on investments z is given by:

$$z = \left[\frac{1}{1-\lambda} \right] / \left[\frac{1}{1+\psi-\lambda} \right] \tag{26}$$

$$z = 1 + \frac{\psi}{1-\lambda}. \tag{27}$$

[41]This result can straightforwardly be derived by subtracting equation (23) of firm $g \neq j$ from (23) of j.

Figure A1. Simulated Effect of Financial Crisis



Figures draw deviation from balanced growth path level of respective variable. Horizontal axis: years from crisis. Deviations are absolute. Along the balanced growth path, corporate loan rates equal 6%, employment of skilled employees is 0.78, growth is 10% while the detrended pre-crisis skilled wage rate equals 0.72. Dashed and solid lines present impulse responses under flexible and sticky skilled wages, respectively.

Given that $\psi/(1-\lambda) > 0$, the partial equilibrium overestimates the effect. The overestimation decreases with elasticity of skilled labor supply, while it increases with R&D returns to scale.

A.5 Calibration

The model is calibrated with annual parameters using a combination of standard values from the literature and values that match characteristics of the merged Compustat-DealScan sample of R&D performers. In line with Smets and Wouters (2007), implicit labor share $1-\alpha$ is set to 0.8. Elasticity of demand μ is set to 6 for a mark-up of 20%. The inverse of the Frisch elasticity of skilled labor supply is set to 0.25. Research productivity γ is calibrated to 0.13 while returns to scale are set to 0.8 to match the average growth of 10.7% amongst sampled firms between 2003 and 2007. This calibration implies that the general equilibrium effect is 44% smaller than the partial equilibrium effect. Estimates of returns to scale vary widely in the literature, but firm-level estimates suggest they diminish "substantially" (Griliches and Mairesse, 2007; see also Cohen and Klepper, 1996 and Crépon et al., 1998). A returns to scale estimate of 0.8 is therefore conservative and may overestimate the difference between the partial and general equilibrium effect.

To simulate a financial shock, the model is detrended using growth along the steady state and is solved using Dynare. Approximations are of first order. The shock is calibrated to generate an increase in commercial loan spreads by almost 10 percentage points, in line with empirical events after 2007. Impulse response profiles are plotted in Figure A1. Responses in an economy with general equilibrium and perfectly competitive labor markets with flexible wages are drawn in black-dashed lines. Responses for the partial-equilibrium economy with fixed wages are solid purple. The upper left figure plots the development of commercial loan rates, which increase by 9 percentage points initially and return to steady state levels after 5 years.[42] The bottom left figure shows that skilled employment decreases by approximately 0.25 units in the flexible equilibrium and 0.35 units in the sticky wage equilibrium. This represents a decline of 32 and 45%, respectively. Interestingly, this difference is due to a wage cut amongst skilled employees of less than 6%. Growth in technology declines by 2.5 or 4.7 percentage points in the first year after the shock, and recovers at the same speed as corporate loan rates.

[42]The behavior of interest rates is determined entirely by monitoring costs which do not depend on the equilibrium considered.

Appendix A: Additional Tables

Table A1: First Stage Results: Combined Instruments and Control Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ *R&D Investments*							
Asset Quality	0.004	-0.002	0.012	-0.010	-0.010	-0.008	-0.026
	(0.057)	(0.065)	(0.046)	(0.049)	(0.049)	(0.051)	(0.048)
Δ Asset Quality	0.080*	0.085	0.089*	0.105**	0.111**	0.134**	0.131***
	(0.042)	(0.051)	(0.046)	(0.050)	(0.050)	(0.052)	(0.047)
% Lehman Lead	-0.000	0.011	0.002	-0.005	-0.012	-0.024	-0.047
	(0.027)	(0.028)	(0.035)	(0.037)	(0.038)	(0.037)	(0.039)
Deposits/Assets	0.070	0.082*	0.080*	0.059	0.060	0.037	0.029
	(0.043)	(0.046)	(0.042)	(0.044)	(0.044)	(0.047)	(0.045)
Leverage Ratio	-0.009**	-0.008*	-0.008	0.002	0.002	0.004	0.006
	(0.004)	(0.004)	(0.005)	(0.008)	(0.008)	(0.007)	(0.007)
F-statistic	8.3	8.5	8.1	9.2	9.4	9.1	4.7
R^2	0.062	0.148	0.270	0.286	0.307	0.382	0.446
Observations	515	515	514	514	514	514	502
Δ *Investment in Intan.*							
Asset Quality	0.033	0.029	0.040	0.022	0.022	0.024	0.012
	(0.0393)	(0.042)	(0.030)	(0.031)	(0.032)	(0.037)	(0.031)
Δ Asset Quality	0.024	0.032	0.035	0.047	0.052	0.071*	0.062*
	(0.029)	(0.034)	(0.033)	(0.033)	(0.034)	(0.035)	(0.033)
% Lehman Lead	0.020	0.035	0.030	0.025	0.019	0.0096	-0.011
	(0.022)	(0.022)	(0.023)	(0.025)	(0.025)	(0.024)	(0.028)
Deposits/Assets	0.025	0.032	0.036	0.019	0.020	0.001	-0.010
	(0.027)	(0.031)	(0.027)	(0.030)	(0.029)	(0.033)	(0.030)
Leverage Ratio	-0.004	-0.004	-0.003	0.005	0.006	0.007	0.008
	(0.003)	(0.004)	(0.005)	(0.007)	(0.007)	(0.007)	(0.007)
F-statistic	4.7	5.5	5.0	10.3	11.6	17.6	1.6
R^2	0.060	0.134	0.257	0.273	0.292	0.366	0.446
Observations	515	515	514	514	514	514	502
Control Variables							
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	Yes	Yes	Yes
Δ Capital Investments	No	No	No	No	No	Yes	Yes
Δ Employment	No	No	No	No	No	No	Yes

Note: Dependent variable is *Invest*. F-statistics refer to joint significance of crisis-exposure variables. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A2: First Stage Results: Combined Instruments Including Share of Debt Due

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Δ *R&D Investments*							
Asset Quality	-0.011	-0.019	-0.023	-0.052	-0.057	-0.055	-0.065
	(0.064)	(0.075)	(0.055)	(0.057)	(0.056)	(0.059)	(0.061)
Δ Asset Quality	0.088*	0.071	0.085*	0.103*	0.116**	0.131**	0.127***
	(0.044)	(0.049)	(0.047)	(0.051)	(0.048)	(0.052)	(0.045)
% Lehman Lead	-0.021	-0.001	-0.017	-0.026	-0.035	-0.037	-0.060
	(0.024)	(0.021)	(0.034)	(0.036)	(0.039)	(0.041)	(0.045)
Deposits/Assets	0.070	0.076	0.069	0.049	0.048	0.036	0.030
	(0.048)	(0.050)	(0.047)	(0.049)	(0.049)	(0.052)	(0.051)
Leverage Ratio	-0.009**	-0.010**	-0.007	0.004	0.004	0.005	0.006
	(0.004)	(0.004)	(0.005)	(0.008)	(0.007)	(0.007)	(0.007)
Share 1 year	-0.078***	-0.077***	-0.069***	-0.094***	-0.077***	-0.067***	-0.053***
	(0.016)	(0.020)	(0.017)	(0.022)	(0.019)	(0.019)	(0.015)
F-statistic	9.0	9.0	8.8	11.7	10.8	9.9	4.1
R^2	0.060	0.134	0.257	0.273	0.292	0.366	0.446
Observations	452	452	451	451	451	451	440
Δ *Investment in Intan.*							
Asset Quality	0.022	0.017	0.017	-0.008	-0.012	-0.010	-0.013
	(0.045)	(0.049)	(0.037)	(0.039)	(0.038)	(0.042)	(0.041)
Δ Asset Quality	0.028	0.014	0.020	0.034	0.045	0.060*	0.047
	(0.027)	(0.030)	(0.032)	(0.033)	(0.030)	(0.035)	(0.033)
% Lehman Lead	0.007	0.029*	0.025	0.016	0.010	0.008	-0.011
	(0.017)	(0.015)	(0.024)	(0.024)	(0.026)	(0.028)	(0.036)
Deposits/Assets	0.018	0.020	0.023	0.004	0.004	-0.007	-0.018
	(0.029)	(0.032)	(0.026)	(0.028)	(0.027)	(0.031)	(0.029)
Leverage Ratio	-0.004	-0.005	-0.003	0.007	0.007	0.008	0.008
	(0.003)	(0.004)	(0.005)	(0.007)	(0.006)	(0.006)	(0.006)
Share 1 year	-0.063***	-0.062***	-0.062***	-0.083***	-0.070***	-0.061***	-0.044***
	(0.014)	(0.018)	(0.021)	(0.021)	(0.020)	(0.020)	(0.015)
F-statistic	6.5	8.1	15.2	17.9	13.7	14.9	2.6
R^2	0.061	0.153	0.299	0.330	0.360	0.408	0.483
Observations	452	452	451	451	451	451	440
Control Variables							
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	Yes	Yes	Yes
Δ Capital Investments	No	No	No	No	No	Yes	Yes
Δ Employment	No	No	No	No	No	No	Yes

Note: Dependent variable is *Invest.* F-statistics refer to joint significance of crisis-exposure variables. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A3: 2SLS: Effect of R&D Investment during Crisis on Growth

Output Growth 2010-2014	(1)	(2)	(3)	(4)	(5)	(6)
Δ R&D Investments	0.240*	0.319*	0.346***	0.307**	0.358***	0.331***
	(0.128)	(0.169)	(0.098)	(0.144)	(0.115)	(0.118)
First Stage R^2	0.05	0.13	0.26	0.15	0.27	0.29
First Stage Partial R^2	0.02	0.02	0.03	0.02	0.02	0.02
First Stage F-Statistic	7.6	5.4	6.5	8.5	4.7	5.5
F-Stat.'s P-value	0.00	0.01	0.00	0.00	0.02	0.01
Observations	516	516	515	516	515	515
Δ Investment in Intangibles	0.361**	0.483**	0.457***	0.483***	0.463***	0.424***
	(0.174)	(0.206)	(0.106)	(0.159)	(0.122)	(0.129)
First Stage R^2	0.06	0.13	0.25	0.15	0.26	0.28
First Stage Partial R^2	0.01	0.01	0.2	0.01	0.02	0.02
First Stage F-Statistic	8.1	4.9	13.8	6.1	10.4	11.4
F-Stat.'s P-value	0. 00	0.01	0.00	0.01	0.00	0.00
Observations	516	516	515	516	515	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instrument: Asset quality in 2007 and a dummy for firms that did not borrow from banks in Y-9C data. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10, 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A4: 2SLS: Effect of R&D Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014						
Δ R&D Investments	0.239	0.160	0.176	0.309*	0.329	0.452**
	(0.224)	(0.239)	(0.329)	(0.160)	(0.211)	(0.218)
First Stage R^2	0.04	0.15	0.30	0.19	0.32	0.35
First Stage Partial R^2	0.01	0.01	0.01	0.03	0.02	0.02
First Stage F-Statistic	18.9	10.5	12.9	18.9	20.7	16.0
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
Observations	453	453	452	453	452	452
Δ Investment in Intangibles	0.276	0.187	0.179	0.363*	0.357*	0.486**
	(0.250)	(0.271)	(0.320)	(0.185)	(0.215)	(0.222)
First Stage R^2	0.05	0.15	0.29	0.12	0.31	0.34
First Stage Partial R^2	0.01	0.01	0.02	0.03	0.03	0.02
First Stage F-Statistic	14.7	8.2	7.4	19.9	13.3	9.2
F-Stat.'s P-value	0.00	0.01	0.01	0.00	0.00	0.00
Observations	453	453	452	453	452	452
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instrument: Percentage of long term debt due after 2008. Standard errors, clustered by industry, in parentheses. * and ** denote significance at the 10 and 5% level, respectively. Firm characteristics: log of age and firm asset size in 2007.

Table A5: Alternative Dependent Variable: Labor Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
Productivity Growth 2002-2004						
Panel A						
Δ R&D Investments	0.117*	0.172***	0.177***	0.290***	0.285***	0.260***
	(0.0612)	(0.0607)	(0.0590)	(0.0838)	(0.0684)	(0.0621)
First Stage R^2	0.06	0.15	0.27	0.17	0.29	0.31
First Stage Partial R^2	0.04	0.03	0.04	0.03	0.04	0.05
First Stage F-Statistic	8.3	8.5	10.2	14.7	12.6	12.5
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	.15	.12	.16	.29	.43	.34
Observations	506	506	505	506	505	505
Panel B						
Δ Investment in Intangibles	0.245	0.438**	0.370***	0.540***	0.453***	0.422***
	(0.158)	(0.176)	(0.113)	(0.185)	(0.131)	(0.114)
First Stage R^2	0.06	0.14	0.28	0.17	0.29	0.31
First Stage Partial R^2	0.02	0.01	0.02	0.02	0.03	0.03
First Stage F-Statistic	5.1	4.4	7.1	3.9	7.6	8.3
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	.14	.26	.38	.79	.58	.56
Observations	506	506	505	506	505	505
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ 2002-2004. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A6: Alternative Dependent Variable: Labor Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2002-2004						
Panel A						
Δ R&D Investments	0.0537	0.0470	0.130***	0.111	0.172***	0.189***
	(0.0407)	(0.0604)	(0.0312)	(0.0719)	(0.0582)	(0.0567)
First Stage R^2	0.07	0.17	0.33	0.21	0.35	0.38
First Stage Partial R^2	0.05	0.04	0.04	0.05	0.05	0.06
First Stage F-Statistic	8.7	8.7	10.4	11.4	11.3	10.7
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	.13	.14	.18	.11	.32	.32
Observations	453	453	452	453	452	452
Panel B						
Δ Investment in Intangibles	0.117	0.102	0.252***	0.183*	0.247***	0.307***
	(0.0892)	(0.131)	(0.0817)	(0.102)	(0.0952)	(0.104)
First Stage R^2	0.06	0.16	0.30	0.20	0.33	0.36
First Stage Partial R^2	0.02	0.02	0.02	0.04	0.05	0.04
First Stage F-Statistic	5.7	5.8	6.6	11.2	6.0	5.2
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	.07	.10	.28	.10	.44	.48
Observations	453	453	452	453	452	452
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	No	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes	Yes
Impact 2008 Recession	No	No	No	No	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due after 2008. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A7: Distribution of R&D, U.S. Firms vs Compustat-DealScan Sample

	Percent of 2007 Spending	
Employees	All U.S. Firms (NSF)	Compustat-DealScan Sample
5 to 24	4.03	0.00
25 to 49	2.93	0.00
50 to 99	3.74	0.00
100 to 249	5.00	0.19
250 to 499	3.07	0.24
500 to 999	5.30	0.65
1000 to 4999	15.26	3.14
5000 to 9999	8.42	8.69
10000 to 24999	17.06	16.87
25000 or above	35.22	70.21

Source: Author's calculations using NSF data. Spearman's rank correlation: 0.93.

Appendix B. Robustness Checks Second-Stage Estimations

Tables A8 and A9 respectively repeat estimations in Table 6 and 7 using slightly different specifications for *Invest*. In main specifications, the ratio of average productivity-enhancing investments in 2009 and 2010 to 2005, 2006 and 2007 is taken to calculate *Invest*. In columns identified with I of Tables A8 and A9, *Invest* is calculated by taking the ratio of average investments in 2009 and 2010 to average investments in 2008, 2007 and 2006. In columns II, the ratio of investments in 2009 to average investments in 2006 and 2007 is used. In columns III, the ratio of average investments in 2009 and 2010 to average investments in 2004 to 2007 is used. The estimated effect of instrumented investments on medium-term growth in output is significantly positive in all specifications in both tables. The size of the estimates differ because base years have a large influence on average changes in investments. To assess the robustness of results to specification of the output horizon, Appendix Tables A10 and A11 respectively repeat estimations in Table 6 and 7 using different specifications for *Growth*.

Table A8: Effect of R&D Investment during Crisis on Growth for Various *Invest*

Output Growth 2010-2014	(1) I	(2) I	(3) II	(4) II	(5) III	(6) III
Panel A						
Δ R&D Investments	0.491***	0.484***	0.466***	0.451***	0.281***	0.287***
	(0.155)	(0.186)	(0.123)	(0.150)	(0.0955)	(0.0909)
First Stage R^2	0.04	0.28	0.03	0.23	0.06	0.44
First Stage Partial R^2	0.04	0.04	0.03	0.03	0.03	0.04
First Stage F-Statistic	7.4	7.6	10.2	6.8	7.4	11.4
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.78	0.60	0.84	0.57	0.79	0.41
Observations	508	507	508	507	516	515
Panel B						
Δ Investment in Intangibles	0.606**	0.503***	0.696***	0.643***	0.476***	0.362***
	(0.249)	(0.125)	(0.223)	(0.219)	(0.145)	(0.0818)
First Stage R^2	0.02	0.25	0.02	0.21	0.05	0.32
First Stage Partial R^2	0.02	0.04	0.02	0.02	0.01	0.03
First Stage F-Statistic	3.8	4.7	8.1	3.2	7.9	15.3
F-Stat.'s P-value	0.01	0.00	0.00	0.01	0.00	0.00
J-test Overid. P-value	0.54	0.70	0.76	0.89	0.64	0.60
Observations	508	507	508	507	516	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	No	Yes	No	Yes
State *Fixed Effects*	No	Yes	No	Yes	No	Yes
Firm Characteristics	No	Yes	No	Yes	No	Yes
Impact 2008 Recession	No	Yes	No	Yes	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A9: Effect of R&D Investment during Crisis on Growth for Various *Invest*

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014						
Panel A						
Δ R&D Investments	0.503***	0.599***	0.484***	0.489***	0.271**	0.310***
	(0.170)	(0.215)	(0.152)	(0.179)	(0.113)	(0.108)
First Stage R^2	0.05	0.34	0.04	0.29	0.06	0.53
First Stage Partial R^2	0.05	0.04	0.04	0.03	0.04	0.05
First Stage F-Statistic	8.9	3.4	7.3	6.6	6.4	10.6
F-Stat.'s P-value	0.01	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.55	0.90	0.40	0.90	0.58	0.73
Observations	508	507	508	507	516	515
Panel B						
Δ Investment in Intangibles	0.604***	0.639***	0.695***	0.692***	0.409***	0.363***
	(0.207)	(0.187)	(0.192)	(0.239)	(0.154)	(0.131)
First Stage R^2	0.03	0.31	0.03	0.28	0.0	0.39
First Stage Partial R^2	0.02	0.04	0.02	0.03	0.02	0.04
First Stage F-Statistic	4.1	14.7	5.5	7.2	5.9	17.0
F-Stat.'s P-value	0.01	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.67	0.84	0.53	0.79	0.52	0.78
Observations	508	507	508	507	516	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	No	Yes	No	Yes
State *Fixed Effects*	No	Yes	No	Yes	No	Yes
Firm Characteristics	No	Yes	No	Yes	No	Yes
Impact 2008 Recession	No	Yes	No	Yes	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A10: Effect of R&D Investment during Crisis on Growth for Various *Growth*

Output Growth Horizon:	(1) '11-'14	(2) '11-'14	(3) '10-'13	(4) '10-'13	(5) '11-'13	(6) '11-'13
Panel A						
Δ R&D Investments	0.424***	0.323***	0.347**	0.362***	0.449***	0.328***
	(0.110)	(0.102)	(0.136)	(0.117)	(0.167)	(0.119)
First Stage R^2	0.06	0.31	0.06	0.31	0.06	0.31
First Stage Partial R^2	0.04	0.05	0.04	0.05	0.04	0.05
First Stage F-Statistic	8.1	13.8	8.2	13.7	8.1	13.8
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.47	0.38	0.61	0.19	0.26	0.20
Observations	508	507	508	507	516	515
Panel B						
Δ Investment in Intangibles	0.638***	0.362***	0.586***	0.478***	0.700***	0.356***
	(0.163)	(0.129)	(0.222)	(0.129)	(0.221)	(0.117)
First Stage R^2	0.06	0.29	0.06	0.29	0.06	0.29
First Stage Partial R^2	0.02	0.04	0.02	0.04	0.02	0.04
First Stage F-Statistic	5.5	17.0	5.5	16.6	5.5	17.0
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.37	0.52	0.50	0.34	0.38	0.32
Observations	508	507	508	507	516	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	No	Yes	No	Yes
State *Fixed Effects*	No	Yes	No	Yes	No	Yes
Firm Characteristics	No	Yes	No	Yes	No	Yes
Impact 2008 Recession	No	Yes	No	Yes	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

Table A11: Effect of R&D Investment during Crisis on Growth for Various *Growth*

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth Horizon:	'11-'14	'11-'14	'10-'13	'10-'13	'11-'13	'11-'13
Panel A						
Δ R&D Investments	0.436***	0.388***	0.309**	0.339**	0.448***	0.372***
	(0.105)	(0.102)	(0.157)	(0.138)	(0.149)	(0.133)
First Stage R^2	0.07	0.38	0.07	0.37	0.07	0.38
First Stage Partial R^2	0.05	0.06	0.05	0.06	0.05	0.06
First Stage F-Statistic	8.5	13.6	8.5	13.7	8.5	13.6
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.66	0.26	0.71	0.52	0.71	0.42
Observations	508	507	508	507	516	515
Panel B						
Δ Investment in Intangibles	0.604***	0.418***	0.518**	0.490**	0.676***	0.422**
	(0.142)	(0.150)	(0.245)	(0.207)	(0.247)	(0.179)
First Stage R^2	0.06	0.36	0.06	0.35	0.06	0.36
First Stage Partial R^2	0.03	0.05	0.02	0.05	0.03	0.05
First Stage F-Statistic	6.5	12.8	6.5	12.3	6.5	12.8
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.59	0.42	0.62	0.67	0.66	0.64
Observations	508	507	508	507	516	515
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	No	Yes	No	Yes
State *Fixed Effects*	No	Yes	No	Yes	No	Yes
Firm Characteristics	No	Yes	No	Yes	No	Yes
Impact 2008 Recession	No	Yes	No	Yes	No	Yes

Note: Dependent variable is $\Delta Output$ between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due after 2008. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.