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

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Abstract

This paper identifies the mechanism through which financial crises exert long-term negative effects on output. Theory suggests 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 522 U.S. corporations responsible for 58% of industrial research and development. Exploiting exogenous variation in firm-level exposure to the Global Financial Crisis, I show that tight credit reduced investments in productivity-enhancement, and significantly slowed down output growth between 2010 and 2015. A partial-equilibrium aggregation exercise suggests GDP would be at least 3.2% higher today if productivity-enhancing investment intensity had remained at its pre-crisis level.

JEL-Codes: E320, E440, O300, O470.

Keywords: financial crises, endogenous growth, innovation, business cycles.

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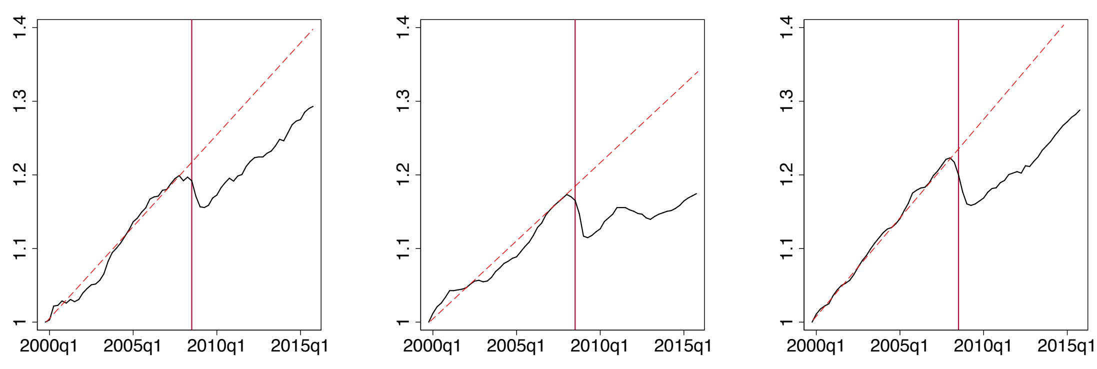
1. Introduction

Recovery from the Global Financial Crisis and the ensuing “Great Recession” has been weak. In the United States, GDP has deviated 10% from the level that an extrapolated trend between 2000 and 2007 predicts. Similar deviations are observed across developed economies, as Figure 1 illustrates. The gap between GDP and its pre-crisis trend is illustrative for the general lack of recovery after systemic banking crises. For a sample of 117 systemic banking crises between 1960 and 2001, Cerra and Saxena (2008) show that output on average remains 7% below trend a decade after a crisis starts.[1] This is at odds with standard business cycle models, in which output eventually recovers to steady state. What makes financial crises different? A shortfall in productivity-enhancing investments may provide the answer. According to endogenous growth theory, a one-time reduction in such investments temporarily slows the rate of technological progress to levels below the balanced growth path, which has a permanent effect on the level of potential output. When the crisis fades and investments recover, technological progress regains its original growth rate. GDP does not catch-up to losses during the crisis, and remains on a lower trajectory (e.g. Comin and Gertler 2006, Anzoategui et al. 2016). Macro-level evidence in Figure 2 supports this hypothesis, as total factor productivity (TFP) has barely grown since 2010.[2] This follows two years after a strong decline in intangible investments. The magnitude of the decline in investments and the timing of the subsequent slowdown in productivity growth suggests the two are linked. Causal evidence on this premise, however, remains scarce.

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



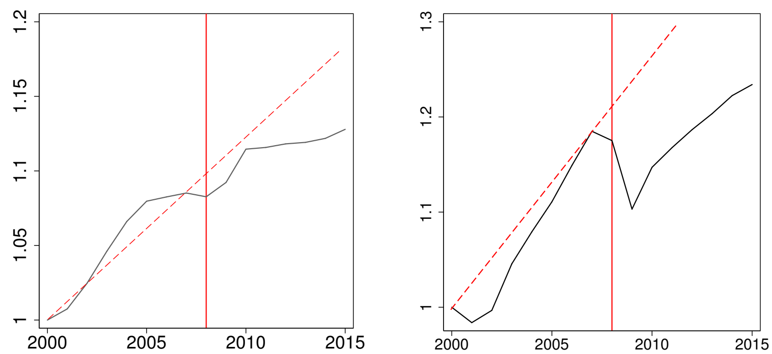
(a) United States (b) Euro Area (c) United Kingdom

Solid and dashed lines present actual and trend (log) GDP, respectively. Series are standardized such that 2000Q1 has value 1. Trends extrapolate growth rate between 2000 and 2007. Data: OECD.

[1] Similar evidence is found in, e.g., Furceri and Zdzienicka (2012), Reinhart and Rogoff (2014), and Teulings and Zubanov (2014).

[2] The post-crisis slowdown in TFP has been well-documented in various papers, including Hall (2014), Christiano et al. (2015), Ollivaud and Turner (2015) and Reifschneider et al. (2015).

Figure 2. U.S. Total Factor Productivity and Intangible Investments vs Trend, 2000-2015



(a) Total Factor Productivity (b) Intangible Capital Investments

Note: Total factor productivity from OECD. Intangible capital investments from Intan-Invest up to 2011, from Compustat afterwards (0.92 correlation in overlapping sample). TFP is measured as the part of labor productivity not explained by capital deepening. Intangible capital investments are the sum of investments in computerized information, innovative property and economic competencies. Trends extrapolate average growth between 2000 and 2007.

This paper fills that void by empirically identifying the effect of the Global Financial Crisis on productivity-enhancing investments and medium-term growth at the firm level. The analysis is conducted using a linked lender-borrower micro dataset on 522 medium- to large-sized firms in the United States. These firms are responsible for 58% 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 tight credit around the financial crisis.[3] 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 and costs when obtaining credit during the Global Financial Crisis. This reduces the optimal quantity of productivity-enhancing investments directly if financed by credit, or indirectly if firms prioritize short-term capital investments (Garicano and Steinwender 2016). 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 projects. These measures are then used as instrumental variables when estimating the effect of productivity-enhancing investments during the Global Financial Crisis on output growth in subsequent years. If exposure to tight credit through bank-links and debt maturity do not affect a firm's potential output growth through other channels than productivity-enhancing investments, this yields a causal test of the endogenous growth hypothesis.

[3] By analyzing the effect of shocks to productivity-enhancing investments on within-firm growth, this paper does not incorporate the effect of financial crises on inter-firm allocation of resources (e.g. Gopinath et al., 2015) or firm entry and exit (e.g. Clementi and Palazzo, 2016).

I find evidence of a significantly positive relationship between exposure to the Global Financial Crisis and reductions in productivity-enhancing investments. Using a novel measure of asset soundness 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 investment intensity by 2 percentage points per standard deviation decline in soundness. This relationship also appears when using established proxies for bank-exposure to the Global Financial Crisis, such as pre-crisis 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 intensity, annual output growth drops by 0.3 percentage points. Results are robust to the inclusion of control variables for firm age, size, pre-crisis growth and profitability, cash holdings, book-to-market ratios, and impact of the 2008 recession, as well as detailed sector and state fixed effects. The estimates are of an economically relevant magnitude: a partial equilibrium aggregation exercise suggests that GDP would be at least 3.2% higher by 2014 if investment intensity had remained constant. This implies that a substantial fraction of the recent slowdown in productivity is an endogenous effect of the crisis.

The results are robust to three tests on causal validity. First, the analysis has been repeated with controls for capital and labor. If either is affected by exposure to tight credit, their inclusion is needed to satisfy the exclusion restriction. The estimated effect of productivity-enhancing investments becomes larger when adding changes in capital labor between 2007 and 2014. Second, time-varying estimates on the effect of investments on output where obtained. These become significant from 2013 onwards, suggesting a 3 year lag in the effect of investments on growth. This is in line with previous estimates of the lag with which productivity-enhancing investments become operational. Third, placebo regressions on growth after the 2001 recession are insignificant in all specifications. Jointly, these results firmly corroborate the hypothesis.

Related Literature 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. In Aghion et al. (2010), for instance, liquidity shocks move firms away from long-term productivity-enhancing investments in favour of short-run production capital if credit constraints are tight.[4] Garcia-Macia (2015) claims that firms are unable to fund investment in intangible assets during financial crises, as these investments are hard to collateralize. The models in Ates and Saffie (2013, 2014) claim that financial turmoil affects technological progress through the ability of banks to observe project

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

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. Similar mechanisms are described in a New Keynesian framework by Garga and Singh (2016). 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, which produce more radical innovation. A related literature suggests that crises reduce the profitability of productivity-enhancing investments because demand and prices are low. Financial crises are effectively large recessions. Examples include Fatas (2000), Comin and Gertler (2006), Ikeda and Kurozumi (2014), Benigno and Fornaro (2015) and Anzoategui et al. (2016).[5] Results in this paper provide support for models in which financial crises are distinct from large recessions, as restricted loan supply is a source of the decline in productivity-enhancing investments and medium-term growth. Reductions in the profitability of investments could form a complementary channel.

More broadly, this paper lends evidence to the notion that productivity growth as a consequence of productivity-enhancing investments like R&D and intangible investments. This hypothesis is at the heart of endogenous growth theory, in the tradition of Romer (1990), Aghion and Howitt (1992), Grossman and Helpman (1993) and Jones (1995). I am able to identify the existence of this mechanism causally, as the Global Financial Crisis provides exogenous variation in credit tightness.

This paper's second contribution is the finding 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. The conventional wisdom is that firms prefer to finance such investments internally using cash flow or equity because intangible capital is poor collateral and because it is difficult for lenders to screen the quality of projects, which raises the cost of loans (Hall and Lerner 2010). In line with this, Brown et al. (2009) find that young firms tend to not finance R&D expenditures with debt. This paper is in line with a growing body of recent work that does find an effect of bank lending on these investments. Nanda and Nicholas (2014) for instance 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. 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. Peia (2016) shows that R&D in financially constraint industries declined more during the Global Financial Crisis. Garicano and Steinwender (2016) use Spanish data to show that crises change the composition of investments towards short 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]

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

[6] This paper is also related to the 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).

This paper also contributes to the recent debate on causes of the post-crisis slowdown in productivity growth.[7] Fernald (2014) shows that the growth of TFP started to fall in the early 2000s. This suggests that the Global Financial Crisis is not responsible for the reduction in growth. Similar evidence is provided by Reifschneider et al. (2015) from a state-space model and by Fernald et al. (2017) from a growth accounting exercise. In line with this secular view of the decline in TFP growth, Bloom et al. (2017) provide aggregate and sector-level evidence that the effort required to attain productivity growth has increased over time. According to Gordon (2016), the recent slowdown of productivity grows is part of a longer trend of diminishing innovation, which he expects to be permanent. Others have argued that the slowdown in productivity growth is the product of measurement error. Aghion et al. (2017) quantify understatement of growth due to imputation of outdated goods in the GDP deflator, which increased by only 0.28 percentage points per year during the Great Recession. While significant, this increase does not explain the large shortfall in output and productivity.[8] Results in this paper imply that while a secular decline in productivity growth may be present, some part of the slow post-crisis growth is an endogenous affect of the fall in productivity-enhancing investments.

The empirical strategy builds on papers that use firm-exposure to lending shocks to assess the real effects of financial crises. Firm-level data is suited to analyze this paper's question because firms differ exogenously in the extent to which they are exposed to the crisis, facilitating causal interpretation of results. Relevant examples include Chodorow-Reich (2014), Acharya et al. (2015), Bentolila et al. (2015) and Giroud and Mueller (2015), who analyze the employment effects of credit shocks using firm-level crisis-exposure. Franklin et al. (2015) conduct a similar exercise for the United Kingdom, and add that credit tightening negatively affected labor productivity in 2008-9. It is similarly related to Amiti and Weinstein (2011), 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 analyze the effect on 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.[9]

Outline The remainder of this paper is structured as follows. Section 2 outlines the analytical framework, derives the estimation equation, and presents the empirical strategy. The dataset is discussed in Section 3, while results are presented in Section 4. The aggregation exercise is discussed in Section 5. Section 6 concludes.

[7]A complete review is provided in Adler et al. (2017).

[8]A further discussion on the role of measurement explanation for the productivity slowdown is provided by Byrne and Sichel (2017).

[9]A recent paper by Duval et al. (2017) confirms this paper's main findings using an international sample of firms.

2. Analytical Framework and Identification

This section presents a formal discussion on how the financial crisis affected investment in productivity and subsequent output growth. The analytical framework is presented in Section 2.1 and the empirical strategy is discussed in Section 2.2.

2.1. Analytical Framework

A financial crisis can permanently affect the level of output in a simple real business cycle model with endogenous growth. Under standard assumptions, optimal productivity-enhancing investments are proportional to current productivity, implying shocks to investments do not mean-revert. To see this, consider the optimal investment decision for a continuum of firms that monopolistically produce varieties of intermediate goods.[10] Production occurs along a Cobb-Douglas production function with capital $k_{j,t}$, labor $l_{j,t}$, and firm-specific total factor productivity $a_{j,t}$. Firms sell their output to the competitive wholesale sector, which combines intermediate goods to a final good using a constant elasticity of substitution (CES) technology. Demand for the variety produced by firm j follows:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t}\right)^{-\varepsilon} Y_t$$

where $y_{j,t}$ is firm j's output, $p_{j,t}$ is its price, ε is the elasticity of substitution, P_t is the price index, and Y_t is aggregate output. As this paper analyzes developments in medium-term growth, I abstract from nominal frictions and adjustment costs. The optimal real price is therefore a constant markup $\varepsilon/(\varepsilon-1)$ over real marginal costs, such that:

$$y_{j,t} = \left(\frac{\varepsilon}{\varepsilon-1} mc_{j,t}(a_{j,t})\right)^{-\varepsilon} Y_t \tag{1}$$

Firms can increase productivity $a_{j,t+1}$ by engaging in innovative projects $rd_{j,t}$. By investing in projects at time t, firms increase the level of productivity for all periods from $t+1$ onwards. Higher productivity increases the firm's output as it lowers marginal costs, which reduces the optimal prices and raises demand for the firm's variety. This is a reduced-form characterization of the channels through which output might increase from investing in innovative projects. Actual channels are likely a combination of enhanced production processes, human capital accumulation, and the development of new and better products.[11] The growth rate of firm-specific productivity is a function of expenditure on productivity-enhancing projects along:

[10] This section describes the firm side, while the complete model is summarized in Appendix A.

[11] A limitation of this approach is that the role of entrants is not considered. Data limitations prohibit the inclusion of entrants in the main analysis, which motivates the current specification. It is supported by the finding of Garcia-Macia et al. (2016) that own-product innovation by incumbent firms is the main source of growth in the U.S. Productivity-enhancing investments are assumed to yield positive spillovers due to the presence of Y_t in (1).

$$g_{j,t+1} = \zeta \left(\frac{rd_{j,t}}{a_{j,t}} \right)^{\phi} \tag{2}$$

where research-effectiveness parameter $\zeta > 0$ while returns to scale are determined by $\phi \in (0,1)$. The presence of $a_{j,t}$ reflects that firms must raise productivity-enhancing expenditures in proportion to current productivity in order to maintain a constant growth rate.[12]

Financial shocks enter the model through the costs of external funding. Firms are assumed to incur a proportional financing cost $\mu^c_{j,t}$ when investing in productivity-enhancing investments. Shocks to $\mu^c_{j,t}$ reflect changes in the costs of obtaining bank loans, bond issuance, satisfying collateral requirements, or indirect costs from credit rationing or tightening of credit constraints. There is a financial intermediary that has perfect information about the firm's profits and the technology to enforce repayment without costs. The timing in each period is as follows. After production has occurred, firms repay the intermediary the principal and interest due on loans for productivity-enhancing investments. Remaining profits are transferred to the household in lump sum. Firms then decide how much to invest in next period's productivity-enhancement and secure the necessary loans, after which next period's production occurs.

The firm's optimal investment decision involves choosing expenditure on innovative projects $rd_{j,t}$ such that the marginal increase in discounted profits equals the marginal costs of investments, $1+\mu^C_{j,t}$. The Bellman equation for discounted profits reads:

$$V(a_{j,t}, Y_{j,t}) = \pi(a_{j,t}, Y_{j,t}) + E_t \mathcal{M}_t V(a_{j,t+1}, Y_{j,t+1})$$

where $\pi(a_{j,t}, Y_{j,t})$ is the firm's profit function under optimal prices, while $\mathcal{M}_t$ is the stochastic discount factor for period $t+1$ at t. The first order condition with respect to $rd_{j,t}$ gives:[13]

$$\frac{rd_{j,t}}{a_{j,t}} = E_t \left[\left(\frac{\zeta\phi}{1+\mu^C_{j,t+1}} \right)^{\frac{1}{1-\phi}} \left(\frac{\partial\pi(a_{j,t+1}, Y_{t+1})/\partial a_{j,t+1}}{1-\mathcal{M}_{t+1}\frac{\partial a_{j,t+2}}{\partial a_{j,t+1}}} \right)^{\frac{1}{1-\phi}} \right] \tag{3}$$

which yields that optimal investments increase in expected profitability, the discount factor, and the effectiveness of productivity-enhancing investments, while they fall with financing costs. A financial crisis temporarily raises financing costs, leading to a reduction in optimal spending on productivity-enhancement. In the steady state, the right hand side of (3) does not contain current productivity. This means that investment intensity $rd_{j,t}/a_{j,t}$ does not depend on current productivity $a_{j,t}$. A temporary increase in $\mu^C_{j,t}$ will therefore cause a temporary reduction in productivity growth, resulting in a permanent shift in the level of output.

[12] This assumption gives rise to a steady state where firms have the same investment intensity rd_j/a_j irrespective of their level of productivity. It is a standard assumption in the literature that is widely confirmed in the empirical finance literature. See Cohen and Klepper (1996) or Cohen (2010) for a review.

[13] Derivations are provided in Appendix A2.

2.2. Empirical Strategy

The previous section yields two predictions about productivity-enhancing investments and output around the Global Financial Crisis. First, restrictive supply of credit during the crisis reduces the optimal expenditure on productivity-enhancement. In the months after Lehman Brothers failed in September 2008, supply of new loans fell by 79% compared to the pre-crisis peak (Ivashina and Scharfstein, 2010). This was associated with an increase in funding costs ($\mu^C_{j,t}$), as there was a sharp increase in corporate bond spreads and commercial loan rates. Second, a reduction in optimal productivity-enhancing investments during the crisis temporarily reduces the growth rate of output after the crisis, causing a permanent shift in the level of output.

2.2.1. Identification Problem

To test these predictions, I analyze the effect of credit shocks during the Global Financial Crisis on productivity-enhancing investments and subsequent growth across firms. Firms that faced greater exposure to credit shocks are hypothesized to reduce productivity-enhancing investments relatively more, and subsequently grow less. The latter part of this analysis is subject to a clear reverse causality problem: the decision to invest depends on the expected profitability of doing so. 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 spurious positive or negative correlation between productivity-enhancing investments and medium-term output growth.

2.2.2. Strategy

To solve this endogeneity problem, I isolate the exogenous component of exposure to credit shocks, and use it to instrument for investments during the crisis. Exogenous exposure is measured through variables that capture the degree to which a firm faced a contraction of credit, but do not correlate with unobserved heterogeneity in firm-level potential output growth. The Global Financial Crisis gives rise to two sources of variation in exogenous exposure. First, firms differ in their exposure through the banks with which they established a relationship prior to the crisis. Firms tend to borrow from a limited number of financial institutions, as repeated interaction improves the ability of banks to screen and monitor lenders.[14] Firms that borrowed from banks *prior* to the crisis that were relatively restrictive in lending *during* the crisis therefore faced a stronger reduction in the supply of new loans. Differences in lending behavior across banks were primarily driven by the extent to which the crisis affected the health of their balance sheet, for instance through a fall in the value of mortgage backed securities and the poor functioning of interbank markets. These variables are unlikely to correlate with the expected profitability and growth potential of firms to

[14] A review of theory and evidence on relationship lending is provided in Boot (2000).

which these banks lend.[15] Measures that capture the extent to which banks were exposed to the crisis therefore create exogenous variation in credit supply to firms. Chodorow-Reich (2014), on which this part of the empirical strategy draws, shows that the health of banks on which firms rely was an important determinant of firm-level access to credit and employment growth between 2008 and 2009. A variety of measures is used to capture the exposure of a bank's to the financial crisis, including the 2007 composition of its balance sheet, reliance on interbank markets, and exposure to the bankruptcy of Lehman Brothers.

The second source of variation in firm-exposure to restrictive credit supply uses variation in debt structure. Specifically, it measures the percentage of a firm's long-term debt due the year after Lehman Brother's bankruptcy. Firms with a large fraction of their long-term debt due in middle of the credit crisis faced increased rollover risk and higher interest rates, reducing the optimal amount of productivity-enhancing investments. This measure is valid if having a large percentage of long-term debt due does not reflect poor managerial practices, which may be an unobserved driver of long-term growth. Firms with high amounts due exogenously face greater exposure to the crisis, as decisions on long-term debt payable right at the crisis' onset were made well before the crisis. A similar measure was first used by Almeida et al. (2012) who show that firms with large portions of debt due were similar to other firms prior to the crisis in a number of dimensions, but displayed different investing behavior afterwards.

2.2.3. Empirical Specification

The empirical analysis proceeds in two steps. First, the effect of exposure to tight credit on productivity-enhancing investments is estimated. This estimation serves a double purpose: it assesses whether financial factors were responsible for the shortfall in productivity enhancing investments during the crisis, and forms the first stage in the main estimation. The estimation equation is a linear approximation of first order condition (3):

$$\frac{rd_j}{a_j} = \Omega' Exposure_j + \mu' X_j + \epsilon_j \tag{4}$$

where rd_j/a_j denotes the intensity of productivity-enhancing investments during the Global Financial Crisis, *Exposure* is a set of measures that capture the extent to which firms are exposed to credit tightening (μ_j^C) during the 2008-9 financial crisis. X is a vector of control variables, which are added to control for non-financial factors that determine optimal investments, such as expected growth and the productivity of research. The specification is cross-sectional because the measures for *Exposure* are constants. To verify that investments are unaffected by *Exposure* before 2008, (4) is also estimated in difference-in-difference form.

[15]This premise is tested using balance checks and placebo regressions in Section 4. Results show that firms which borrowed from banks with higher exposure to the crisis did not grow at different rates prior to the Global Financial Crisis and initially displayed similar investing behavior.

The main empirical analysis relates productivity-enhancing investments during the crisis to output growth after the crisis. The associated estimation equation follows directly from the analytical framework. Start with the empirical counterpart of demand function (1):

$$y_{j,t} = \left(\frac{\varepsilon}{\varepsilon-1} mc(a_{j,t}, k_{j,t}, l_{j,t})\right)^{-\varepsilon} Y_t e^{\eta_{j,t}}$$

where $\eta_{j,t}$ is a normally distributed idiosyncratic error term with mean 0. If productivity is labor-augmenting in the Cobb-Douglas production function, marginal costs mc can be written as $a_{j,t}^{\alpha-1} \widetilde{mc}_{j,t}$ where α is the capital share in production and $\widetilde{mc}_{j,t}$ denotes the optimal marginal cost if total factor productivity equals 1. Inserting this into the empirical demand equation and taking log-differences between t and $t+1$ gives:

$$\log\left(\frac{y_{j,t+1}}{y_{j,t}}\right) = (1-\alpha)\varepsilon \log\left(\frac{a_{j,t+1}}{a_{j,t}}\right) - \varepsilon \log\left(\frac{\widetilde{mc}_{j,t+1}}{\widetilde{mc}_{j,t}}\right) + \log\left(\frac{Y_{t+1}}{Y_t}\right) + \eta_{j,t+1} - \eta_{j,t} \qquad (5)$$

where the change $a_{j,t+1}/a_{j,t}$ in productivity is determined by expenditure on productivity enhancing investments along (2). The estimation equation in the context of the Global Financial Crisis then reads:

$$\Delta y_j = \gamma\left(\widehat{rd_j/a_j}\right) + \delta' \chi_j + \widetilde{\eta}_j \qquad (6)$$

where Δy_j denotes output growth at firm j in the aftermath of crisis, $\widehat{rd_j/a_j}$ denotes the fitted value of investments during the crisis from first-stage equation (4), while χ is a vector of control variables. A significantly positive estimate of γ is consistent with the hypothesis.

The second stage's dependent variable is the growth rate of output, which is measured through sales. Output is a common outcome variable in the literature on firm-level effects of productivity-enhancing investments.[16] It is preferred over revenue productivity (TFPR) as the latter cannot be directly observed. Firms have different production functions and factor utilization, such that multiple-stage estimations are needed to approximate TFPR (e.g. Wooldridge, 2009). Output is also preferred over labor productivity, as in a number of models (e.g. Melitz 2003), higher productivity leads to a proportional increase in employment, resulting in constant labor productivity.[17]

Output growth is not driven by productivity growth if it reflects recovery from a crisis-borne demand shock. Firms in highly cyclical industries may experience greater post-crisis output growth irrespective of developments in productivity-enhancing investments and potential output. This is controlled for in two ways. First, firm-vector χ includes a control for the fall in cash flow between 2008 and 2009. Second, the dependent variable Δy_j measures output growth after 2010. By then, firms had on average recovered from the demand shock, as their sales equaled the peak in 2007. If firms were producing at their potential rate that year, further growth is more likely to be driven by productivity-enhancing investments. Further discussion is found in Section 3.2.

[16] Examples include Gabaix (2011), Bloom et al. (2013), Kogan et al. (2016), and Bloom et al. (2017). Garcia-Macia et al. (2016) derive productivity from employment.

[17] A discussion is provided in Bloom et al. (2017).

3. Data

3.1. Dataset 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, which are a main component of productivity-enhancing 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 2004 and 2014.[18] Firms that first appear in the data after 2003 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. Stock price and market capitalization data is obtained by merging the resulting dataset with CSRP. All variables are deflated to 2009 USD using the BEA'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.[19] Because Reuters takes data on loans from public sources, the majority of loans (73%) in DealScan is syndicated. 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 conditions like collateral and fees have been agreed upon, the lead arranger recruits other investors to participate in the loan. 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.[20]

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 in-

[18] 2014 is the final year because a number of firms did not have data for 2015 at the time of writing.

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

[20] 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.

cluded as DealScan's coverage increased substantially from that year onwards. Loans with extraordinary purposes, such as management buyouts, are also excluded.[21] 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 522 firms whose total sales equal 28% of GDP and are responsible for 58% of corporate R&D in 2007.

3.2. Variable Construction

In the analytical framework, productivity growth is determined by the intensity of productivity-enhancing investments rd_j/a_j. Productivity-enhancing investments rd_j are measured with two variables. The first is total research and development (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 is the sum of R&D, advertisement and marketing expenditures (Compustat item *xad*). This variable is referred to as intangible capital investments.[22] The optimal measure of investment in productivity would also contain efforts to increase production efficiency like employee training. As data on such expenses is unavailable, the measures used here should be thought of as proxies for a firm's total effort to increase productivity.

The firm-specific term a_j is derived from past productivity-enhancing investments. Because the parameters of the law of motion for productivity (2) are unknown, a_j is approximated by adding up past investments using the perpetual inventory method.[23] The intensity of investments during the Global Financial Crisis is found by taking the ratio of average average annual investments in productivity in 2009 and 2010 to the stock of investments in 2007. The years 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.[24]

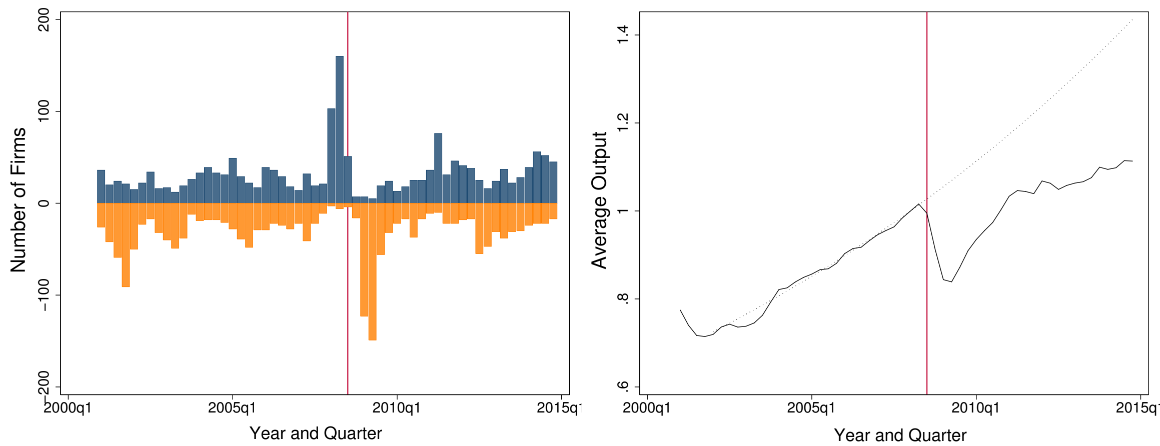
[21] Specifically, loans for general corporate purchases, asset acquisitions, aircraft finance, credit enhancement, debt refinancing, project, hardware and software financing, equipment purchases, real estate financing, ship finance, telecoms build outs, trade finance and working capital are included.

[22] 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.

[23] The stock then evolves along $a_{j,t+1} = a_{j,t}(1-\delta)+rd_{j,t}$. Past expenditures are assumed to depreciate along the BEA's 15% depreciation rate for intangible capital investments. The initial stock equals investments over the depreciation rate. For robustness, all estimations have been conducted where the ratio of rd_j to the average of rd_j for three pre-crisis years was used to approximate investment intensity. This yields similar results.

[24] Robustness checks using slightly different years yield similar results.

Figure 3. 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.

To measure Δy_j 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 output before the end of 2010. To show this, the left graph of Figure 3 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.[25] 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 3 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, Ravenscraft and Scherer 1982, Cohen 2010). Because investments first declined in 2009, the first year in which a treatment effect is expected is 2011.

[25]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.

Exposure to tight credit through banking relationships is derived from the share that bank h contributed to the last loan taken out by firm j in the DealScan sample prior to June 2007.[26] Define $Exposure_h$ is a variable that correlates with the extent to which bank h contracts its credit supply to firms. Then firm-level variable $Exposure_j$ approximates the extent to which firm j's access to credit is impeded when calculated as follows:

$$Exposure_j = \sum_{h=1}^{H} \psi_{j,h} \left(Exposure_h\right) \tag{7}$$

where $\psi_{j,h}$ denotes the share of bank h in firm j's final loan.

The primary measure of $Exposure_h$ captures the soundness of a bank's assets, in a novel way. It uses the distribution of assets across risk weighing categories for Basel 1 capital requirements. Under the original Basel Accord, banks classified assets in 5 categories along credit risk. The safest assets such as cash and U.S. treasury notes carry risk weights of 0%. 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.[27] 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:

$$Asset\ Soundness = Assets / Risk\text{-}Weighted\ Assets \tag{8}$$

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 supply of loans.

The second measure is the ratio of deposits to assets. Banks with a relatively high stock of deposits have a stable source of short-term funding. Alternative sources of funding, like short term loans from other banks, were volatile due to the erosion of interbank markets 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 short-term funding sources.

Two alternative measures of $Exposure_h$ from past work capture the extent to which banks were affected by the credit shock. 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 expo-

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

sure to Lehman provided less new loans during the 2008-9 financial crisis.[28] 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. This is preferred over the use of balance-sheet derived measures of ABS-exposure, as foreign banks do not report such items consistently.

Finally, two measures of $Exposure_h$ are used to capture the health of bank balance sheets in 2007. 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.

Data on the health of banks is obtained by merging the Compustat-DealScan dataset of R&D performers 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. Combined, matched banks are responsible for issuing over 93% of DealScan loans.[29]

3.3. Descriptive Statistics

Descriptive statistics for the firm variables are provided in Table 1. The upper panel of Table 1 summarizes the main variables of interest: investment intensity for R&D and intangible capital in 2009 and 2010, which both equal 0.185 for the median firm. Yearly output growth, measured as percentage change of real sales, is summarized in the middle panel. It was highest prior to 2008 when the median firm grew more than 7% per year. The bottom panel summarizes firm characteristics prior to the financial crisis, averaged for 2005 to 2007. The median firm employs almost 5000 employees, holds $1.2 billion in assets and sold over $1.3 billion prior to the crisis. This implies that sampled firms are much larger than average U.S. corporations. Return on assets, measured as the ratio of net income to real total assets, lies around 5%. Financial variables such as the book-to-market ratio are available for the sub-sample of firms on which data is available in CSRP. These firms have

[28] Ivashina and Scharfstein (2010) argue 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).

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

Table 1: Descriptive Statistics Firm Characteristics

Variable	Median	Mean	St. Dev.	10th Pct.	90th Pct.	Obs.	Notes
Investment Intensity during Crisis							
Research and development	0.185	0.209	0.128	0.079	0.360	522	See text
Intangible capital	0.185	0.207	0.113	0.088	0.354	522	See text
Annual Sales Growth							
Average 2003-2007	7.72	11.18	16.77	2.64	26.71	522	Percentage
Average 2008-2009	-11.79	-11.88	16.14	-32.94	7.43	522	Percentage
Average 2010-2014	3.23	2.98	8.98	8.52	14.34	522	Percentage
Characteristics, Avg. 2005-2007							
Assets	1220	5666	11347	93.99	15593.12	522	Mil. ’09 USD
Sales	1145	6602	22131	12840	76.94	522	Mil. ’09 USD
Employment	4.88	15.25	26.24	0.31	44.93	522	Thousands
Age (time since IPO)	3.37	3.43	0.51	2.77	4.16	522	Logarithm
Return on assets	5.09	3.86	7.90	-7.91	12.47	522	Percentage
Debt-to-assets	19.13	21.06	15.99	1.31	42.49	520	Percentage
Cash-to-assets	10.56	15.55	14.27	2.47	37.80	521	Percentage
Book-to-market ratio	-0.51	-0.53	0.66	-1.43	0.31	498	Logarithm
Price-earnings ratio	17.97	15.23	38.04	-26.42	47.68	501	Ratio

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.

an average price-earnings ratio of 18% and a book-to-market ratio of 0.6. The distribution of firms across SIC sectors is summarized in Appendix Table A2.

Descriptive statistics on credit contraction variables at the firm level 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. 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 more than averagely affected by mortgage-backed securities and Lehman Brothers. There is no strong correlation between bank-relationship measures and the share of debt due in 2009. This is expected if bank health is uncorrelated with firm characteristics.

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 provides an analysis of instrument validity for the second stage, on which results are presented in Section 4.3. Tests on the robustness of second-stage results, as well as reduced-form and time-varying estimations, are conducted from Section 4.4 onwards.

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

A. Summary Statistics	Median	Mean	St. Dev.	10th Perc.	90th Perc.	Obs.	Notes
Bank's Asset Soundness							
Asset Soundness	6.40	6.91	3.40	4.22	12.54	522	See Text
Bank's Crisis Exposure							
Deposit Ratio	45.77	45.31	13.10	30.21	68.15	522	Perc. of Assets
Lehman Lead Share	2.15	2.11	0.91	1.33	2.68	522	Percentage
sure	1.08	1.03	0.24	0.90	1.24	522	Stock Loading
Bank's Balance Sheet							
Bad Loan Prov.	0.89	0.86	0.37	0.41	1.26	522	Perc. of Loans
Leverage Ratio	12.50	14.04	6.10	8.54	21.50	522	Debt-to-equity
Firm's Characteristics							
% Long-Term Debt Due	3.89	12.82	22.00	0.00	33.96	458	% of LT Debt

B. Correlation Matrix	Asset S.	Deposits	Lehman	ABX	BLP	Lev.	Share Due
Bank's Asset Soundness							
Asset Soundness	1						
Bank's Crisis Exposure							
Deposit Ratio	0.6346*	1					
Lehman Lead Share	-0.4373*	-0.4718*	1				
sure	-0.4237*	-0.4232*	0.6051*	1			
Bank's Balance Sheet							
Bad Loan Prov.	-0.1130*	-0.4331*	0.3230*	0.2873*	1		
Leverage Ratio	-0.2148*	-0.1580*	0.4002*	0.4125*	0.2081*	1	
Firm's Characteristics							
% Long-Term Debt Due	0.0519	0.0897	-0.0851	-0.2087*	-0.0327	-0.129	1

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.

4.1. Effect Tight Credit on Productivity-Enhancing Investments

To estimate the effect of the 2008-9 financial crisis on productivity-enhancing investments, regressions along first-stage equation (4) are run using each measure of crisis exposure. Results are presented in Table 3. The dependent variable in the upper panel is R&D intensity, while intangible investments (the sum of R&D and advertisement and marketing) are used in the lower. Standard errors are clustered by two-digit industries. All measures are standardized to have unit standard deviations, such that coefficients present the effect of a standard deviation shock in exposure. Coefficients for asset soundness and the deposit-to-asset ratio are multiplied by (-1). All regressions include controls for firm size, age and pre-crisis growth, as well as state and sector fixed effects. 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 invested significantly less in research and development. Similarly, greater exposure to Lehman Brothers'

Table 3: Effect of Crisis-Exposure on Productivity-Enhancing Investments

	Firm-Bank Relationship Measures						Debt Structure
	Asset Soundness	Deposits to Assets	Lehman Exposure	ABX Exposure	Leverage Assets	BLP to Assets	% Long-Term Debt Due
R&D Investments							
Coefficient	-0.023***	-0.023***	-0.009*	-0.002	-0.013*	0.000	-0.010**
	(0.004)	(0.008)	(0.005)	(0.004)	(0.008)	(0.004)	(0.004)
Observations	522	522	522	522	522	522	458
F-statistic	27.63	7.955	3.263	0.287	2.991	0.010	5.332
Intangible Inv.							
Coefficient	-0.019***	-0.015*	-0.001	-0.002	-0.011*	-0.004	-0.012**
	(0.004)	(0.007)	(0.003)	(0.004)	(0.006)	(0.003)	(0.005)
Observations	522	522	522	522	522	522	458
F-statistic	21.10	3.999	0.0430	0.222	3.532	1.092	5.694

Note: Dependent variable is average intensity of productivity-enhancing investments in 2009-2010. Estimates obtained from OLS. Controls for sector and state fixed effects, firm size, age, pre-crisis avg. growth. Standard errors clustered by industry and given in parentheses. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.

bankruptcy, low deposits or high leverage ratios is associated with a decline. For intangible investments the effect of asset soundness, deposits, and leverage are significant. The size of coefficients is economically relevant: a one standard deviation decline in asset soundness results in a 2.3 percentage point decline in R&D intensity. Coefficients for deposits are of similar size, while a standard deviation increase in leverage or exposure to the bankruptcy of Lehman Brothers reduces investment intensity by around 1 percentage point. The effect of having a greater share of debt due in 2009 is also highly significant on both types of investments: a one standard deviation increase reduces investments intensity in R&D and intangibles by 1 and 1.2 percentage points, respectively. These estimates are based on the subsample of firms that hold long-term debt. Coefficients for exposure to asset-backed securities run in the expected direction, but are insignificant.

4.2. Instrument Validity and Weakness

I next assess whether the instruments satisfy the relevance and exogeneity conditions for instrument validity. A first concern may be that firms which had relationships with poorly performing banks are inherently different from other firms, and invested less in productivity-enhancement regardless of the crisis. To test this, the first-stage regressions are re-estimated in panel form with time-varying coefficients. The estimation equation reads:

$$\frac{rd_{j,t}}{a_{j,t}} = \alpha_j + \mu_t + \gamma_t Exposure_j + \epsilon_{j,t} \tag{9}$$

where α_j and μ_t respectively denote firm and year fixed effects, while $rd_{j,t}/a_{j,t}$ is defined as the ratio of average investments in years t and $t+1$ to the stock at t-2, in line with the definition of

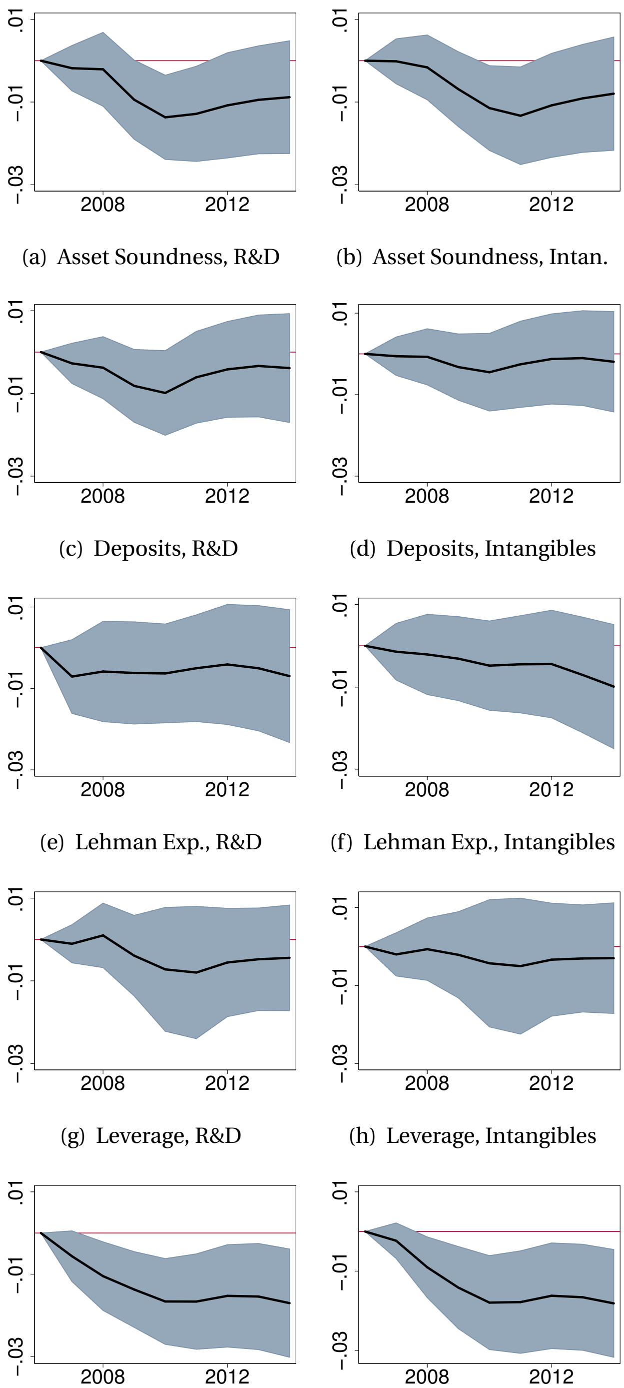
rd_j/a_j in Table 3. The equation is estimated for all exposure measures that significantly affect one of the investment variables. Results are graphed in Figure 4. The left column reports coefficients for the effect of crisis-exposure on R&D investments, while the right column plots intangible capital investments. Results show that asset soundness has a positive effect on productivity-enhancing investments after 2007, and no significant effect on developments in investments prior to the crisis. Graphs on the deposit-to-asset ratio, leverage and share of debt due look similar. This suggests that investment behavior across firms is not ex-ante different for varying degrees of exposure. The estimates in Figure 4 are insignificant for the deposits-to-assets ratio, Lehman exposure and leverage. This may be due to the inclusion of firm and year fixed effect on a relatively small sample. Results without firm effects are presented in Figure 5. Consistent with the analytical framework, investments do not accelerate post-crisis to compensate for low investments during the crisis.

A second concern may be that some instruments are 'weak'. The rule of thumb F-statistics of 10 is only attained by the soundness of a bank's assets in 2007. To alleviate weak instrument concerns, I therefore estimate the second stage using multiple instruments. All instruments that are at least significant for one type of investment in Table 3 are included, in two combinations. The first combination uses all significant measures derived from bank relationships, while the second adds the share-of debt due in 2009. The first stage results using the instruments jointly are provided in Tables A3 and A4 in Appendix B. Columns differ in terms of control variables, and follow the sequence in second stage regressions later on. The instruments are highly jointly significant in all specifications. The largest individual coefficients appear for changes in asset soundness, the deposits-to-assets 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 assessment of the similarity between firms with high and low exposure is provided in Table 4. It compares the mean values of second-stage covariates.[30] 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 bank-health as well as the share of debt due in 2009. It shows that average annual sales growth prior to the crisis and the decline in sales 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 ranging from 0.75 to 0.93, while the rank correlation ranges from 0.75 to 0.98. Importantly, firms with high and low fitted values also have similar book-to-market and price-earnings ratios, suggesting that financial markets expected their future profitability and growth to be similar. Of some concern is the difference in mean age, pre-crisis asset size and cash holdings across both groups. Firms with higher exposure to the crisis are larger, hold more cash and are slightly older, which means that some differences between both groups exist. These variables are therefore important controls.

[30]The sample is split based on fitted R&D intensity in Table 4. Splitting the sample on fitted intangible capital investments yields similar results.

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



(a) Asset Soundness, R&D

(b) Asset Soundness, Intan.

(c) Deposits, R&D

(d) Deposits, Intangibles

(e) Lehman Exp., R&D

(f) Lehman Exp., Intangibles

(g) Leverage, R&D

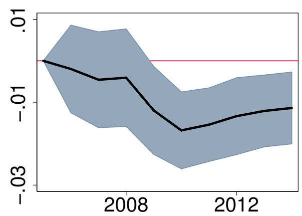
(h) Leverage, Intangibles

(i) Share Due, R&D

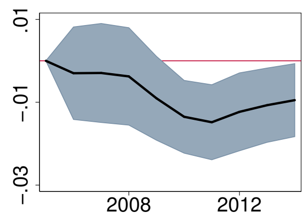
(j) Share Due, Intangibles

Note: Figures report point estimates for γ and 90% confidence intervals based on clustered standard errors. Control variables: time fixed effects, firm fixed effects.

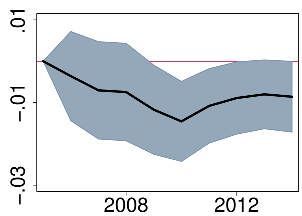
Figure 5. Time-Varying Effects of Exposure on Investments in Productivity



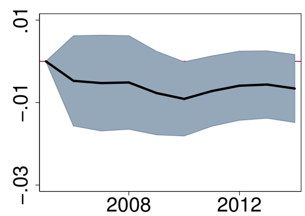
(a) Asset Soundness, R&D



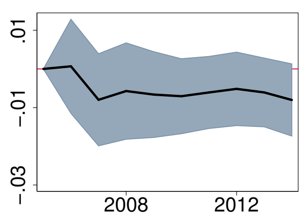
(b) Asset Soundness, Intan.



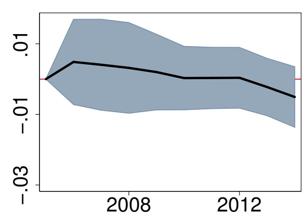
(c) Deposits, R&D



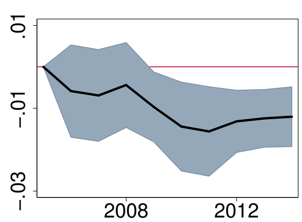
(d) Deposits, Intangibles



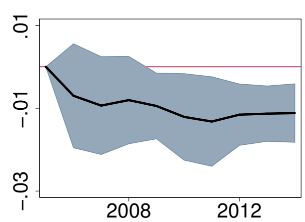
(e) Lehman Exp., R&D



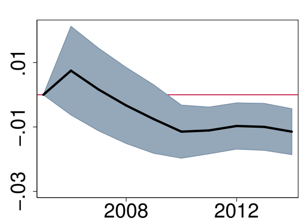
(f) Lehman Exp., Intangibles



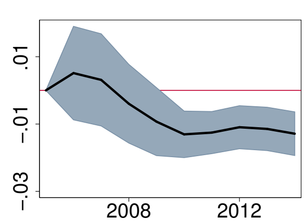
(g) Leverage, R&D



(h) Leverage, Intangibles



(i) Share Due, R&D



(j) Share Due, Intangibles

Note: Figures report point estimates for γ and 90% confidence intervals based on clustered standard errors. Control variables: time fixed effects.

Table 4: Covariate Balance from Fitted Values

	Bank-Relationship Instruments				Incl. Share due in 2009			
	Low Exposure N = 261		High Exposure N = 261		Low Exposure N = 229		High Exposure N = 229	
Variable								
Investments, Avg. 2005-2007	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Research and development	0.196	0.077	0.182	0.068	0.193	0.075	0.183	0.070
Intangible Capital	0.336	0.458	0.391	0.571	0.343	0.494	0.39	0.546
Annual Sales Growth								
Average 2003-2007	0.124	0.157	0.100	0.177	0.111	0.136	0.113	0.201
Average 2008-2009	0.885	0.178	0.878	0.143	0.885	0.173	0.877	0.146
Characteristics, Avg. 2005-2007								
Assets (log)	6.317	1.510	7.962	1.799	6.549	1.595	7.895	1.887
Age (log)	3.290	0.454	3.562	0.532	3.342	0.469	3.533	0.547
Profitability	0.028	0.110	0.043	0.086	0.030	0.106	0.043	0.089
Leverage	0.180	0.158	0.242	0.155	0.186	0.161	0.241	0.153
Cash-to-Assets	0.186	0.162	0.125	0.113	0.181	0.159	0.123	0.11
Book-to-market ratio (log)	-0.529	0.644	-0.529	0.685	-0.535	0.648	-0.522	0.686
Price-earnings ratio	15.49	39.67	14.98	36.40	15.43	40.25	14.99	35.09
Fixed Effects	Spearman's Rank r		Product Mom. r		Spearman's Rank r		Product Mom. r	
Industry Code, 1-digit	0.98		0.93		0.90		0.93	
Industry Code, 2-digit	0.77		0.80		0.75		0.80	
Headquarter State	0.81		0.75		0.79		0.79	

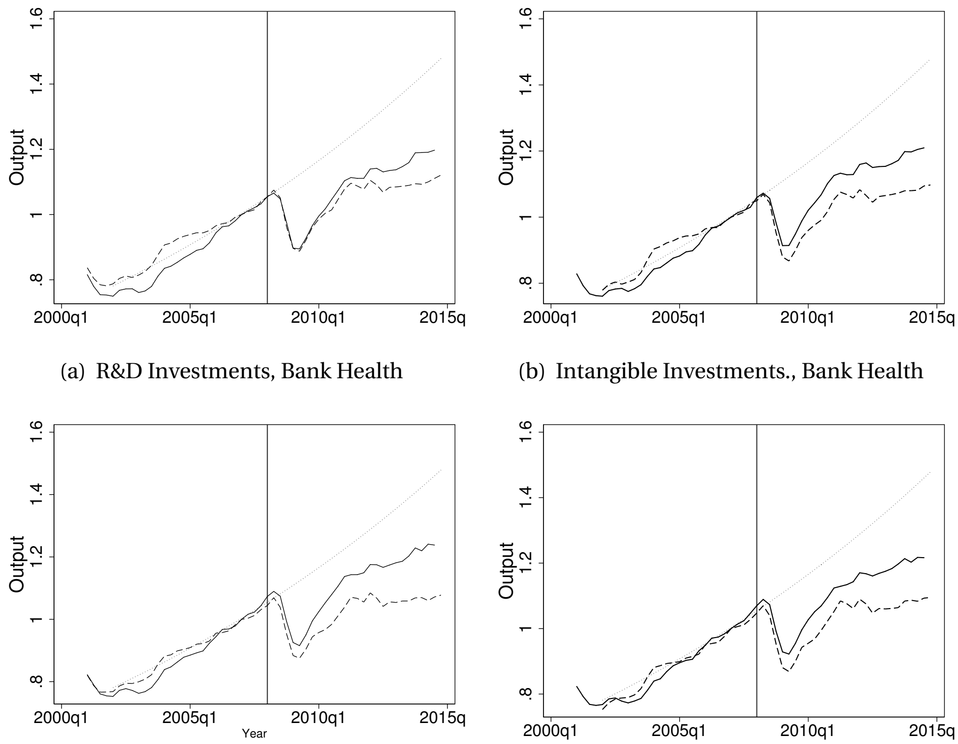
Note: low and high exposure respectively refer to firms with fitted values of R&D and intangible investments above or below the median, from first stage regressions using bank characteristics, weighted by firm's last pre-crisis syndicate.

A final assessment of the similarity across firms with high and low exposure to the crisis is provided in Figure 6. It 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 rd_j/a_j, as the first stage contains multiple variables for exposure. Upper figures use bank health instruments while bottom figures also include the share of debt due. Left and right figures use investments in R&D and intangible capital, respectively. Sales of each firm are indexed to unity in the first quarter of 2007. 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, in both timing and size. Third, 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 a first indication that the hypothesis is corroborated by the data.

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 5, while results that also use the share of debt due in 2009 are presented in Table 6. Both tables have the same structure. The upper panel measures productivity-enhancing investments through R&D, while the bottom panel uses intangible investments. All

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



(a) R&D Investments, Bank Health

(b) Intangible Investments., Bank Health

(c) R&D Investments, Incl. Share Due

(d) Intangible Investments., Incl. Share Due

Note: Solid and dashed lines represent developments in seasonally-adjusted output at firms with below and above median exposure to the crisis, respectively. Upper figures obtains fitted values from bank-relationship instruments while bottom figure includes the share of debt due in 2009. Dotted lines present trend growth in output between 2002 and 2007. Vertical line marks Lehman Brothers' bankruptcy date.

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. Results in Column 1 of Table 5 show that an increase in investment intensity by one percentage point raises medium-term output growth by 1.22 to 1.39 percentage points. This implies an effect on annual growth of 0.30 to 0.35 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 0.27 to 0.67 percentage points, depending on the measure used. Point coefficients are stable across specifications, and differences rarely exceed the size of a standard error. Industry fixed effects are added in Column 2, while industry and state fixed effects are included in Column 3. Column 4 adds controls for firm characteristics such as pre-crisis assets (log), age (log), cash-to-asset ratios and leverage, while column 5 adds controls for the book-to-market ratio and price-earnings ratios.[31] The latter yields point estimates of 1.26 and 1.52 respectively, or 0.31 and 0.38 on an annual basis. Because these estimates control for the book-to-market ratio, estimates in Column 5 robust

[31] The latter cause a 22 firm reduction in sample size as not all firms are matched to CSRP.

Table 5: Effect of R&D Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)
Output Growth 2010-2014					
Panel A					
R&D Investments	1.220*	1.356*	1.699***	1.205**	1.255***
	(0.672)	(0.722)	(0.513)	(0.541)	(0.482)
First Stage Partial R^2	0.039	0.049	0.064	0.057	0.058
First Stage F-Statistic	11.69	16.42	16.47	11.08	10.24
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.51	0.45	0.54	0.15	0.42
Observations	522	522	522	519	497
Panel B					
Investment in Intangibles	1.387**	1.647**	2.188***	1.491**	1.515***
	(0.658)	(0.779)	(0.607)	(0.656)	(0.547)
First Stage Partial R^2	0.036	0.042	0.048	0.045	0.059
First Stage F-Statistic	18.07	24.12	15.04	16.66	13.09
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.28	0.27	0.28	0.29	0.46
Observations	522	522	522	519	497
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset soundness, 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, resp.

to differences in expected future profitability. Even if banks with low exposure to the crisis lend to firms with high 'potential', estimates are valid as long as financial markets observe this. First-stage F-statistics usually exceed the rule of thumb value of 10, while J-statistics for Hansen's test of overidentifying restrictions do not reject the instrument exogeneity condition in any specification. The results in both tables show that for a variety specifications and instruments, the effect of productivity-enhancing investments on growth is economically and statistically significant.

The robustness of the second-stage results to changes in the definition of productivity-enhancing investments is analyzed in Tables A6 to Table A9 in Appendix B. In the previous tables, investment intensity rd_j/a_j is defined as the ratio of average investments in 2009 and 2010 to the stock of investments in 2007. Tables A6 and A7 estimate the regressions in Table 5 and 6 (respectively) using investments in either 2009 or 2008 and 2009 to measure rd_j. This has little effect on the estimated coefficients. Tables A8 and A9 use a different measure for the stock of past investments. Instead of deriving a_j from the perpetual inventory method, these tables use average investments from 2005 to 2007 to approximate the stock of past investments. Estimated coefficients are slightly larger than the main results, with similar levels of significance.

Table 6: Effect of R&D Investment during Crisis on Growth, Incl. Share Due

	(1)	(2)	(3)	(4)	(5)
Output Growth 2010-2014					
Panel A					
R&D Investments	1.472**	1.554**	1.796***	1.675**	1.841***
	(0.701)	(0.747)	(0.690)	(0.709)	(0.642)
First Stage Partial R^2	0.047	0.054	0.0622	0.055	0.050
First Stage F-Statistic	13.86	11.24	11.90	11.55	6.63
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.56	0.63	0.59	0.70	0.62
Observations	458	458	458	457	439
Panel B					
Investment in Intangibles	1.601***	1.899***	2.346***	2.275**	2.374***
	(0.608)	(0.662)	(0.817)	(0.986)	(0.837)
First Stage Partial R^2	0.042	0.048	0.046	0.039	0.048
First Stage F-Statistic	11.23	27.47	15.95	13.60	6.10
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.46	0.64	0.68	0.80	0.45
Observations	458	458	458	457	439
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, (change in) asset quality, leverage, share of long term debt due in 2009. 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.

4.4. Exclusion Restriction: Capital and Labor

I next test whether the results are driven by changes in the use of other production factors. Firms with greater exposure to the crisis may also reduce employment and investments in physical capital, which could also affect growth after 2010. If this is the case, the instrument exogeneity condition is violated and results in Section 4.3 are not causal. Note that according to the analytical framework in Section 2, a crisis-induced reduction in capital investments could affect medium-term growth only if total factor productivity is also affected. If not, firms have an incentive to increase investments post-crisis until their marked-down marginal product equals the cost of capital. Consequently, short-term credit disruptions should only have a lasting effect through this channel if total factor productivity was also affected. Also note that productivity-enhancing investments beyond this paper's measures (like on-the-job training) do not cause a violation of the exclusion restriction, as the measures are proxies for a firm's total effort to become more productive.[32]

[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 7: Exclusion Restriction: Capital and Employment as Control Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014						
Panel A						
R&D Investments	1.625*	1.976***	1.817**	3.163***	2.514***	1.782*
	(0.845)	(0.645)	(0.740)	(0.992)	(0.891)	(1.045)
First-Stage Angrist-Pischke F						
Prod. Enhancing Inv.	12.18	14.76	10.48	2.85	4.27	2.57
Capital Investments	26.22	51.82	20.43	16.27	69.94	15.15
Δ Employment	-	-	-	1.695	8.30	2.23
Observations	522	522	497	510	509	489
Panel B						
Investment in Intangibles	1.575**	2.401***	1.792**	4.970*	4.479**	2.303
	(0.755)	(0.662)	(0.780)	(2.872)	(1.980)	(1.633)
First-Stage Angrist-Pischke F						
Prod. Enhancing Inv.	17.86	12.26	16.69	5.27	2.52	2.78
Capital Investments	27.28	54.62	8.22	13.67	84.15	6.92
Δ Employment	-	-	-	1.37	6.13	1.38
Observations	522	522	497	510	509	489
Endogenous Controls						
Capital Investments	Yes	Yes	Yes	Yes	Yes	Yes
Δ Employment	No	No	No	Yes	Yes	Yes
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
State *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
Firm Characteristics	No	No	Yes	No	No	Yes
Stock Price Characteristics	No	No	Yes	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: asset soundness, Lehman lead share, deposits over assets, leverage, ABS exposure, bad loan provisions. 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.

A potential violation of the exclusion restriction is countered by adding capital investment intensity (Compustat item *capx* in 2009 and 2010 over physical capital *ppent* in 2007) and the change in employment (Compustat item *emp* in 2009 and 2010 over *emp* in 2007) as control variables to the estimations from Section 4.3. Table A10 in Appendix B, which repeats the first-stage univariate regressions from Table 3, confirms that these variables are significantly affected by exposure to the financial crisis. Because investments and employment are endogenous to potential output growth, both are instrumented by the set of bank health and debt structure variables that are also used to instrument productivity-enhancing investments. This is feasible, as long as the first-stage coefficients for each variable are sufficiently different. ABS exposure and Bad Loan Provisions, which significantly affect capital investments, are added as additional instruments to facilitate this.

Results are presented in Tables 7 and 8. Columns 1 to 3 control for intensity of capital investment, while Columns 4 to 6 also control for changes in employment.[33] Results in Table 7 are

[33] The sample in Columns 4 to 6 contains 12 fewer firms as data on employment is not available for all firms.

Table 8: Exclusion Restriction: Capital and Employment as Controls, Incl. Share Due

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014						
Panel A						
R&D Investments	1.928**	2.467**	2.293**	3.160***	2.602**	1.629
	(0.856)	(1.092)	(0.917)	(1.131)	(1.126)	(1.020)
First-Stage Angrist-Pischke F						
Prod. Enhancing Inv.	7.66	8.57	5.19	3.76	4.15	3.66
Capital Investments	4.49	8.47	2.27	11.33	9.51	3.40
Δ Employment	-	-	-	5.29	3.32	5.93
Observations	459	458	439	448	447	432
Panel B						
Investment in Intangibles	1.539***	2.944**	2.963**	4.080*	6.388*	3.145**
	(0.524)	(1.273)	(1.308)	(2.343)	(3.453)	(1.599)
First-Stage Angrist-Pischke F						
Prod. Enhancing Inv.	8.76	10.30	8.99	5.07	2.81	5.20
Capital Investments	5.06	11.14	3.59	10.03	11.15	3.66
Δ Employment	-	-	-	2.56	2.08	3.53
Observations	459	458	439	448	447	432
Endogenous Controls						
Capital Investments	Yes	Yes	Yes	Yes	Yes	Yes
Δ Employment	No	No	No	Yes	Yes	Yes
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
State *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
Firm Characteristics	No	No	Yes	No	No	Yes
Stock Price Characteristics	No	No	Yes	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: asset soundness, Lehman lead share, deposits over assets, leverage, ABS exposure, bad loan provisions, share of long term debt due in 2009. 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, resp.

similar to results in Table 5 in both size and significance. Controlling for capital investments has a modestly positive effect on the size of the coefficients in most specifications. Controlling for changes in employment makes the estimates either similar or substantially larger. Column 5 for instance suggests that a percentage point reduction in intangible capital investment intensity reduces medium-term output growth by 4.5 percentage points, compared to 1.5 percentage points in Table 5. Results in Table 8 are similar. The instability of these estimates might be driven by multicollinearity: reductions in productivity-enhancing investments involve reducing staff numbers in the associated divisions, causing a correlation between productivity-enhancing investments and employment growth. The estimated effect of investments on output ranges from 1.63 to 6.39 percentage points for each percentage point increase in productivity-enhancing investments. While adding capital investments and changes in employment as endogenous controls makes the estimates more volatile, the size of the estimates remains substantial throughout specifications.

An additional way of addressing concerns about the exclusion restriction involves running the second-stage regression in reduced form. By estimating the effect of exposure to credit tightening on medium-term output growth directly, the reduced form answers whether credit tightening affects growth irrespective of the channel through this runs. The estimation equation reads:

$$\Delta y_j = \alpha + \lambda' Exposure_j + \mu' X_j + \phi_k + \psi_s + \eta_j \tag{10}$$

where $Exposure_j$ is a vector of exposure-measures containing either bank-health variables or bank-health variables and the share of debt due in 2009. Results are presented in Table 9. Because these measures are correlated, most elements of λ are insignificant. Results from Wald tests of joint-significance are therefore presented instead. Control variables are added in the same sequence as in Table 5. Jointly, the effect of $Exposure$ on Δy is significant in all but one specification. This suggests that the fall in output compared to trend observed in recent years is at least in some part due to exposure to the crisis.

Table 9: Reduced Form: Effect of Crisis Exposure on Medium Term Growth

	(1)	(2)	(3)	(4)	(5)
Output Growth 2010-2014					
Panel A					
Exposure Partial F-Stat.	2.49*	2.88**	7.19***	6.09***	2.75**
F-Stat.'s P-value	0.05	0.03	0.00	0.00	0.03
R-squared	0.026	0.113	0.198	0.250	0.349
Observations	522	522	522	519	497
Panel B					
Exposure Partial F-Stat.	2.11*	2.72**	2.85**	1.35	2.45**
F-Stat.'s P-value	0.08	0.03	0.03	0.27	0.05
R-squared	0.044	0.136	0.236	0.292	0.366
Observations	458	458	458	457	439
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Exposure variables in Panel A: Lehman lead share, deposits over assets, asset soundness, leverage. Panel B adds the share of debt due in 2009. 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.

4.5. Time-Varying Effects

I next assess how the effect of productivity-enhancing investments on output develops over time. Because it takes a number of years for investments to affect a firm's potential output, the immediate effect of investments during the crisis on output should be limited, and increase over time. To test this, a two-step estimation is deployed. First, the fitted values of changes in investments during the crisis are obtained from the first-stage regression. These fitted values are constants, as the variables for exposure to the Global Financial Crisis do not change over time. The fitted values are then used to explain output growth in a panel-adaption of the second stage regression. The estimation equation reads:

$$\log y_{j,t} = \phi_j + \psi_t + \gamma' \widehat{rd_j/a_j} \psi_t + \varepsilon_{j,t} \tag{11}$$

where ϕ and ψ respectively denote firm and year fixed effects. γ is a vector of coefficients where each element denotes the effect of productivity-enhancing investments during the crisis on output in a subsequent year.

The results are plotted with red-circled lines in Figure 7. Each sub-figure shows results from a separate regression. Figures (a) and (b) respectively show the effect of R&D and intangible investments on output if instrumented by the bank health variables. Figures (c) and (d) add an additional instrument for the share of long-term debt due. Estimates are standardized to reflect a one standard deviation decline in investments. The figure shows that investments during the crisis have an immediate effect on output. Figures (b), (c) and (d) suggest that productivity-enhancing investments already affect output in 2008. This is implausible, as past work suggests that productivity-enhancing investments affect output with at least a 2 to 3 year lag (e.g. Mansfield et al. 1971, Ravenscraft and Scherer 1982, Cohen 2010).

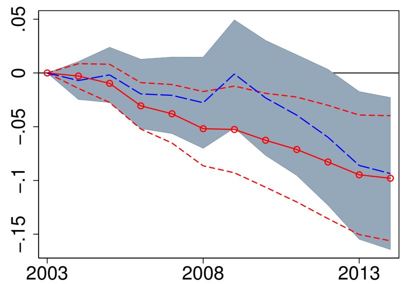
The immediate effect of investments might be due to a decline in capital and labor at firms with high exposure to the crisis. These factors have a direct effect on a firm's ability to produce. To control for the effect of capital investments and changes to employment, I also include the fitted values from separate first stage regressions for changes in both variables. The new estimation equation reads:

$$\log y_{j,t} = \phi_j + \psi_t + \gamma'_R \widehat{rd_j/a_j} \psi_t + \gamma'_K \widehat{\Delta k_j} \psi_t + \gamma'_L \widehat{\Delta l_j} \psi_t + \varepsilon_{j,t} \tag{12}$$

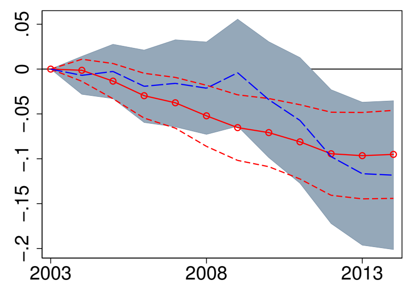
where $\widehat{\Delta k_j}$ and $\widehat{\Delta l_j}$ are the fitted values for capital investments and changes in employment during the crisis as defined in Section 4.4.

The estimates are plotted in blue-dashed lines on Figure 7. Results show that after controlling for firm effects, capital investments and employment, productivity-enhancing investments during the crisis have no significant effect before 2010. After 2010, investments have an increasingly positive effect on output. By 2013, the effect is significantly negative in all specifications. For each standard deviation decline in investments, medium-term output growth declines by 10 percent-

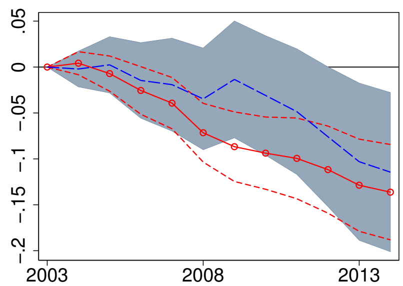
Figure 7. Time-varying Effect of Productivity-Enhancing Investments 2009-2010 on Output



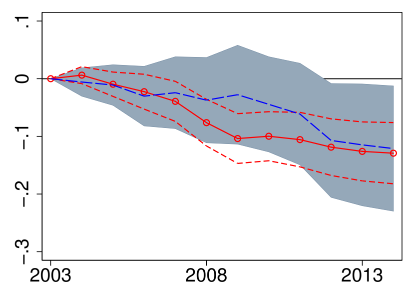
(a) R&D Investments, Bank Health



(b) Intangible Investments, Bank Health



(c) R&D Investments, Incl. Share Due



(d) Intangible Invest., Incl. Share Due

Note: Red (circled) lines are estimated without controls for labor and capital. Blue (dashed) lines control for changes in both. Vertical axis denote the percentage increase in output after a one-standard-deviation increase in the fitted value of investments. Bounds present 90% confidence intervals based on bootstrapped standard errors. Bank health instruments: asset soundness, change in asset soundness, percentage Lehman lead, ABS exposure, deposit-to-assets ratio, bad loan provisions, leverage ratio. Estimates present elements of vector γ in Equation 11.

age points. The effect starts growing less strongly in 2014, which could indicate that the effect of a one-time shortfall in investments affects the growth rate of output for a plausible 4 to 5 years. Figure A4 in Appendix B also present the time-varying output effects of physical investments and changes to employment during the crisis (coefficients γ_K and γ_L in eq. 12).[34] Consistent with theory, the graphs show that both variables do not affect medium-term output after controlling for productivity-enhancing investments.

4.6. Placebo Regressions

An alternative test of whether productivity-enhancing investments during the crisis affect output outside the crisis' aftermath involves running placebo regressions on growth after the recession of 2001. If results in Section 4.3 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

[34] Estimates in Figure A4 use research and development to measure rd_j. Results that use intangible investments are similar and available upon request.

Table 10: Placebo Effect of R&D Investment during Crisis on Growth

	(1)	(2)	(3)	(4)	(5)
Output Growth 2002-2004					
Panel A					
R&D Investments	0.551	0.365	0.341	0.0189	-0.251
	(0.988)	(1.095)	(0)	(1.497)	(1.551)
First Stage Partial R^2	0.0260	0.0341	0.0492	0.0412	0.0402
First Stage F-Statistic	4.235	5.910	11.01	11.83	14.79
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.55	0.75	0.87	0.86	0.52
Observations	521	521	521	518	496
Panel B					
Investment in Intangibles	1.061	0.744	0.820	0.341	-0.370
	(1.085)	(1.256)	(1.306)	(1.632)	(1.682)
First Stage Partial R^2	0.0252	0.0297	0.0367	0.0323	0.0373
First Stage F-Statistic	4.936	7.794	13.26	23.49	28.65
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.53	0.74	0.83	0.83	0.56
Observations	521	521	521	518	496
Control Variables					
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, share of long term debt due in 2009. 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.

yield insignificant coefficients. Results are presented in Tables 10 and 11, which replicate Tables 5 and 6, 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. All coefficients are insignificant in both tables and even some even turn negative in Table 10's specifications.

5. Aggregate Effects

The previous section has established a significant firm-level effect of productivity-enhancing investments on medium-term output. This section will assess to what extend these estimates explain the gap between post-crisis trend and actual GDP in the aftermath of the Global Financial Crisis.

Table 11: Placebo Effect of R&D Investment during Crisis on Growth, Incl. Share Due

	(1)	(2)	(3)	(4)	(5)
Output Growth 2002-2004					
Panel A					
R&D Investments	0.544	0.518	0.865	1.246	1.023
	(1.035)	(1.166)	(0.911)	(1.198)	(1.420)
First Stage Partial R^2	0.037	0.040	0.048	0.041	0.035
First Stage F-Statistic	6.020	6.185	11.01	19.72	14.03
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.96	0.64	0.94	0.93	1.00
Observations	458	458	458	457	439
Panel B					
Investment in Intangibles	1.181	1.184	1.307	1.665	1.375
	(1.172)	(1.256)	(0)	(1.306)	(1.343)
First Stage Partial R^2	0.037	0.040	0.0384	0.031	0.033
First Stage F-Statistic	11.30	19.96	23.02	12.94	9.992
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.98	0.73	0.96	0.90	1.00
Observations	458	458	458	457	439
Control Variables					
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

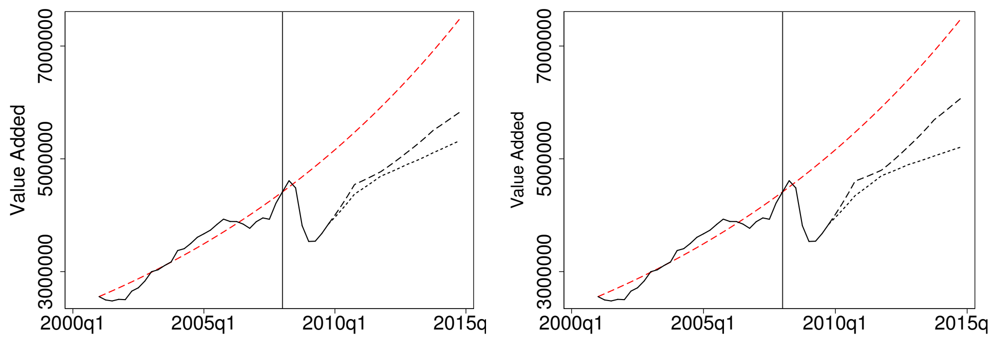
Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, leverage, share of long term debt due in 2009. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, respectively. Firm characteristics: log firm age and firm asset size in 2007.

5.1. Partial Equilibrium Aggregation

The fraction of the gap explained by the shortfall in productivity-enhancing investments can be calculated under two assumptions. First, it is assumed that in the absence of the Global Financial Crisis, investment intensity in 2009 and 2010 would have equalled average intensity in 2006 and 2007. Second, it is assumed that the aggregate effect of productivity-enhancing investments on growth equals the sum of the firm-level effects estimated in Section 4. This assumption means that the general equilibrium effect of productivity-enhancing investments is the same as the partial equilibrium effect, which is further discussed in Section 5.2.

The aggregation exercise is conducted in three steps. First, average intensity of productivity-enhancing investments in 2006 and 2007, defined as average investments in those years to the stock in 2004 (analogous to the definition of rd_j/a_j for 2009 and 2010), is obtained by firm. Second, the effect of productivity-enhancing investments on output is estimated using seperate regressions for each year after 2010. The specification of Column 1 in Table 5 is used, as it is available for the full sample of firms and yields conservative estimates on the effect of investments on growth. The firm-

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



(a) R&D Investments (b) Intangible Investments

Note: Dotted line presents fitted path of aggregate value added in the re-weighted sample under actual investments. Dashed line presents fitted investment growth in the counterfactual scenario of constant investments. Left figure uses R&D investments to measure rd_j/a_j, right figure uses intangible investment.

level counterfactual growth rate of output is then calculated by inserting the 2006-2007 investment intensity into the estimated equation, taking into account the firm's covariates:

$$\Delta y_{2010+h}^{CF} = \widehat{\gamma}'_h \left(\frac{rd_j}{a_j}\right)^{CF} + \widehat{\delta}'_h \chi_j \tag{13}$$

where variables with superscripts *CF* contain counterfactual values while $h \in \{1,..,4\}$. Third, the firm-level estimates from (13) are transformed in two ways. First, firm output is multiplied the average percentage value added in sales for each firm's 6-digit industry, to account for the use of intermediate goods in production.[35] Second, firms are reweighed 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. This is to correct for the fact that firms in the merged Compustat-Dealscan sample consist of publicly listed firms, which are much larger than the average U.S. firm.[36] As sampled firms are responsible for 58% of aggregate R&D expenditures, developments in value added for the reweighted sample are then divided by 58% to approximate the out-of-sample effect of investments on GDP. The aggregate value added V_t under the counterfactual scenario of constant productivity-enhancing investment intensity follows from adding output of the reweighted firms:

$$V_{2010+h} = \sum_{j\in J} \Omega_j \left(y_{j,2010}\right) \Pi_{z=1}^{h} \Delta y_{2010+z}^{CF} \tag{14}$$

[35] 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. Value added is instead derived 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).

[36] Details are provided in Table A5 of Appendix B.

Table 12: Aggregate Effect of Productivity-Enhancing Investments

Investment Variable	Aggregate Value Added (fitted, mil.) Actual rd_j/a_j	Pre-crisis rd_j/a_j	Implications Percent Change	Percent Change 2014 GDP
R&D Estimates	5,312,089	5,816,226	9.49	**3.15**
Intangible Inv. Estimates	5,200,933	6,063,892	16.58	**5.39**

where Ω_j is the reweighing term.

Results are plotted in Figure 8. The solid line plots aggregate value added of the reweighed sample prior to 2010. The dotted line then plots fitted investments based on actual investment intensity of each firm, while the dotted line plots development in output in the counterfactual scenario of constant investments. The vertical axis presents value added of the reweighed sample, expressed in 2009 U.S. Dollars. In line with time-varying estimates in Section 4.5, the effect of productivity-enhancing investment increases over time. By 2014, aggregate value of the sample added would have been 9.5% to 16.6% higher if investment intensity had remained constant (Table 12). This implies that GDP would have been 3.2 to 5.4% higher in 2014, which is between a third and half of the deviation of GDP from its pre-crisis trend. The aggregation exercise thus suggests that productivity-enhancing investments explain a significant share of the shortfall in output.

5.2. Limitations

The aggregate effects summarized in Table 12 should be interpreted with caution as they draw on a strong assumption: the aggregate effect of productivity-enhancing investments must equal the sum of firm-level effects. There are three reasons why this assumption may be violated. Equation (5) of the analytical framework provides the first two: marginal costs and aggregate demand. If all firms increased productivity-enhancing investments, demand for capital and labor increases, raising the associated factor prices and reducing the increase in output produced by individual firms. Alternatively, an increase in productivity across firms raises aggregate output, which raises demand for all goods at given relative prices. Under symmetry, the effects of both channels cancel out. The relative importance of the first channel outside the symmetric case depends primarily on the extent to which firms compete (measured through elasticity of substitution ε), and the extent to which factor prices respond to demand (measured through labor supply elasticity $1/\psi$). The well-documented lack of disinflation in the aftermath of the crisis (e.g. Gilchrist et al., 2015) suggests that it is unlikely that wage costs would have increased substantially if productivity-enhancing investments had remained at pre-crisis intensity. The demand channel is therefore relatively important, which makes it likely that the results in Table 12 underestimate the aggregate effects.

The third channel through which aggregate and firm effects may differ is technological spillovers. Productivity-enhancing investments in one firm may generate knowledge, skills or ideas that benefit the process of productivity-enhancement at other firms. Using patent data from 1976 to 2006, Lucking et al. (2017) find that the social rate of return to R&D exceeds the private rate of return by a factor 4, while estimates in Bloom et al. (2013) suggest that the social rate of return is 3.5 times larger. Both are in line with high spillovers identified in industry-level and case-study evidence, summarized by Hall et al. (2010). If these estimates apply to the firms in this paper, the underestimation of aggregate effects in Table 12 is substantial.

6. Conclusion

This paper has shown that the Global Financial Crisis affected productivity-enhancing investments and subsequent output growth. Exogenous variation in firm-level exposure to the crisis is used to isolate exogenous variation in investment intensity. Firms that prior to the crisis relied on loans from banks that with low asset soundness, deposit-to-asset ratios, high leverage or high exposure to Lehman Brothers invested significantly less in research & development and intangible capital during the crisis. The main results show that investments have meaningful effects on output: annual growth between 2010 and 2014 is 0.3 percentage points lower for each percentage point decline in the intensity of productivity-enhancing investments. Controlling for capital and labor, the effect of productivity-enhancing investments appears with a plausible 2-3 year lag from the start of the crisis. A conservative partial-equilibrium aggregation exercise suggests that output by 2014 would be 3.2 to 5.4% higher if productivity-enhancing investments had remained at pre-crisis intensity.

The results are relevant for the debate on the post-crisis slowdown of productivity growth. Recent authors have argued that the slowdown commenced prior to the crisis (e.g. Fernald 2014, Reifschneider et al. 2015, Fernald et al. 2017), and can therefore not be a consequence of the crisis. My results suggest that a substantial fraction of the productivity slowdown is explained by the temporary reduction in productivity-enhancing investments during the crisis. This may have worsened a pre-existing secular decline in productivity growth. The mechanism identified in this paper also implies that the effect of a one-time reduction in productivity-enhancing investments on growth will wear off over time. Productivity should therefore regain some of its original growth rate over the coming years.

For policy makers, the results show that there are substantial gains to stimulating productivity-enhancing investments during financial crises. Given the effect of restricted credit on investments, fiscal and monetary policies that facilitate the provision of credit by the banking sector, such as refinancing operations, are likely to have prevented a larger permanent decline in output. In future crises, such policies could be supplemented by the direct provision of credit or by subsidizing credit for productivity-enhancing investments. Fiscal policy could also replace some private sector's investments, in particular human capital investments. Analyzing the effects of policies that were implemented during the crisis on productivity-enhancing investments is a promising avenue for future research.

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Appendix A: RBC Model with Endogenous Growth

This appendix presents the real business cycle (RBC) model of which the firm side was discussed in Section 2. The model contains three sectors: a household that saves, consumes the final good, and supplies labor; intermediate good producers that compete monopolistically; and a parsimonious financial sector that channels deposits from the household to firms to finance physical capital and productivity-enhancing investments. The model shows that, when productivity growth is endogenous, a textbook model replicates the non-transitory effect of financial shocks on output. A simulation is used to illustrate this result.

A1. Structure

There is a continuum of households with measure unity. The representative household consumes C units of the final good, supplies labor L, and holds savings in the form of deposits at financial intermediaries. The household maximizes the expected value of lifetime utility:

$$\max E_t \sum_{i=0}^{\infty} \beta^i \left[\log C_{t+i} - \chi \frac{L_{t+i}^{1+\psi}}{1+\psi} \right]$$

where discount factor $\beta \in (0,1)$, while the disutility of labor has relative weight $\chi > 0$ and the inverse of the Frisch elasticity of labor supply $\psi > 0$. Utility is optimized subject to the intratemporal budget constraint:

$$D_{t+1} = D_t(1+r_t) + (W_t/P_t)L_t + \Pi_t - C_t.$$

where D are one-period deposits held at financial intermediaries, L denotes labor supply, W/P denotes the real wage and Π denotes lump-sum transfers from firms.

The first order condition for consumption yields the standard Euler equation:

$$\mathcal{M}_{t,t+1}(1+r_{t+1}) = 1 \tag{1}$$

where $\mathscr{M}_{t,t+1} = \beta C_t / E_t(C_{t+1})$ is the stochastic discount factor. The first order condition for labor reads:

$$\chi C_t = \frac{W_t}{P_t}(L_t)^{-\psi} \tag{2}$$

The economy is inhibited by a continuum of intermediate good producers that monopolistically produce varieties. Production occurs along a Cobb-Douglas production function with labor-augmenting productivity and firm-specific total factor productivity $a_{j,t}$:

$$y_{j,t} = k_{j,t}^{\alpha}(a_{j,t} l_{j,t})^{1-\alpha} \tag{3}$$

Labor $l_{j,t}$ is rented from households, while capital $k_{j,t}$ is rented from a competitive sector of capital producers. Varieties are used as inputs of the final good by a competitive sector of wholesale firms that combine the intermediate goods using a constant elasticity of substitution (CES) technology. The aggregation function reads:

$$Y_t = \left[\int_0^1 y_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where Y_t is aggregate output, $y_{j,t}$ is the output by intermediate firm j and ε is the elasticity of substitution. Cost-minimization by the wholesale sector yields the demand function for output from firm j:

$$y_{j,t} = \left[\frac{p_{j,t}}{P_t}\right]^{-\varepsilon} Y_t \tag{4}$$

where p_j is the price set by firm j while P is the CES-aggregated price index:

$$P_t = \left[\int_0^1 p_{j,t}^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

Firms can increase total factor productivity by engaging in innovative projects $rd_{j,t}$. By investing in projects at time t, firms increase the level of productivity for all periods from $t+1$ onwards. The growth rate of firm-specific productivity $g_{j,t+1}$ is a function of expenditure on productivity-enhancing projects along:

$$g_{j,t+1} = \zeta\left(\frac{rd_{j,t}}{a_{j,t}}\right)^{\phi} \tag{5}$$

where the time-specific effectiveness of research is captured by $\zeta > 0$, while returns to scale are captured by $\phi \in (0,1)$. The latter assures that there is a profit maximizing investment intensity rd_j / a_j for a given marginal cost of investments. The presence of a_j reflects that productivity-enhancement becomes increasingly costly as a firm's production technologies become more advanced.[37] It assures that firms with different levels of productivity have the same investment-intensity rd_j / a_j and growth rate of output along the balanced growth path.

[37] This is a standard assumption that is widely confirmed in the empirical finance literature. See Cohen and Klepper (1996) or Cohen (2010) for a review.

Firms finance productivity-enhancing investments and the rents on physical capital with loans from financial intermediaries. The timing in each period is as follows. After production has occurred, firms repay financial intermediaries the principal and interest payments on the sum of loans for physical and productivity-enhancing investments in the previous periods. Remaining profits are transferred to the household in lump sum. Firms then decide how much to invest in next period's productivity-enhancement and secure the necessary loans, after which next period's production occurs. This precludes firms from self-financing investments through retained earnings, as in Moll (2014).[38] The costs of obtaining credit from intermediaries is a stochastic percentage $\mu^C_{j,t}$ of total investments. Shocks to $\mu^C_{j,t}$ capture interest rate costs as well as other costs of obtaining credit, such as collateral costs. In the model, shocks change the external finance premium, which follows an AR(1) process:

$$\mu^C_{j,t} = r_t + \mu_{ss} + \rho(\mu^C_{j,t-1} - \mu_{ss}) + \nu_{j,t}$$

where ρ determines the persistence of credit shocks.

A2. Firm Optimization Derivations

The firm's static optimization problem is standard, and involves choosing p_j and factors k_j and l_j to maximize gross profits. The optimal price is a constant markup over the marginal costs:

$$\frac{p_{i,t}}{P_t} = \left(\frac{\varepsilon}{\varepsilon - 1}\right) mc_{j,t} \tag{6}$$

where $mc_{j,t}$ is the marginal cost under optimal factors:

$$mc_{i,t} = \frac{1}{a^{1-\alpha}_{i,t}} E_t \left(r^K_{j,t} \left[\frac{k_{j,t}}{l_{j,t}}\right]^{1-\alpha} + \frac{W_t}{P_t} \left[\frac{k_{j,t}}{l_{j,t}}\right]^{-\alpha} \right)$$

in which the cost-minimizing capital-labor ratio is given by:

$$\frac{k_{j,t}}{l_{j,t}} = \frac{\alpha}{1-\alpha} \left(\frac{W_t/P_t}{r^K_{j,t}}\right) \tag{7}$$

where r^K denotes the rental rate of capital.

As productivity-enhancing investments raise a_j in all subsequent periods, the optimal investment decision is dynamic:

$$V(a_{j,t}, Y_t) = \max_{rd_{j,t}} \left\{\pi(a_{j,t}, Y_t) + \mathcal{M}_t V(a_{j,t+1}, Y_{t+1})\right\} \text{ such that} \tag{8}$$

$$a_{j,t+1} = a_{j,t} \left(1 + \zeta \left[\frac{rd_{j,t}}{a_{j,t}}\right]^{\phi}\right) \tag{9}$$

[38] Similar simplifying assumptions are found in related work such as Gertler and Karadi (2011a) and Chodorow-Reich (2014). An extended model would allow firms to retain earnings and gradually become less dependent on external credit.

$$\pi(a_{j,t}, Y_{j,t}) = \frac{1}{\varepsilon - 1}\left(\frac{\varepsilon}{\varepsilon - 1}\right)^{\varepsilon} Y_t \left(A_t^{\alpha-1}\right)^{1-\varepsilon} (\widetilde{mc}_{j,t})^{1-\varepsilon} \tag{10}$$

where optimal profit function $\pi(a_{j,t}, Y_{j,t})$ follows from inserting the demand constraint and optimal prices into the accounting equation for profits. The firm's first order condition involves choosing the level of investments that maximizes (8) subject to (9) and (10). It requires that the increase in firm value equals the costs of investments, which is given by the discounted sum of direct costs (1) and financing costs (μ^C):

$$V_h'(a_{j,t}, Y_t) = \frac{\partial \pi(a_{j,t}, Y_t)}{\partial rd_{j,t}} + E_t\left[\mathcal{M}_t V_a'(a_{t+1}, Y_{t+1})\left(\frac{\partial a_{t+1}}{\partial rd_{j,t}}\right)\right] = E_t \mathcal{M}_t (1 + r_{j,t+1}^c)$$

where the first derivative is zero as investments yield costs and an increase in profits only from the second period onwards due to the lag with which they generate higher productivity. The derivative of the value function is given by:

$$V_a'(a_{j,t}, Y_t) = (1-\alpha)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} Y\,[\widetilde{mc}_t]^{1-\varepsilon}\left(a_{j,t}^{-\alpha\varepsilon+\alpha+\varepsilon-2}\right) + \mathcal{M}_t V_a'(a_{j,t}, A_t)\frac{\partial a_{j,t+1}}{\partial a_{j,t}}$$

Inserting this result into the first order condition and isolating investment intensity on the right hand side yields the equation for the firm's optimal investment decision:

$$\frac{rd_{j,t}}{a_{j,t}} = E_t\left[\left(\frac{\zeta\phi}{1+\mu_{j,t+1}^C}\right)^{\frac{1}{1-\phi}}\left(\frac{(1-\alpha)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{-\varepsilon} Y_{t+1}\,[\widetilde{mc}_{t+1}]^{1-\varepsilon}\left(a_{j,t+1}^{-\alpha\varepsilon+\alpha+\varepsilon-2}\right)}{1-\mathcal{M}_{t+1}\left(1+\phi g_{j,t+2}\right)}\right)^{\frac{1}{1-\phi}}\right] \tag{11}$$

which yields that investments increase in the effectiveness of research and development, fall with the costs of obtaining funds and rise with the discount factor and expected future profitability. In the symmetric case, equation (11) simplifies to:

$$\frac{rd_{j,t}}{a_{j,t}} = E_t\left[\left(\frac{\zeta\phi}{1+\mu_{j,t+1}^C}\right)^{\frac{1}{1-\phi}}\left(\frac{(1-\alpha)\left(\frac{\varepsilon}{\varepsilon-1}\right)^{\frac{\varepsilon\alpha-\alpha-\varepsilon}{1-\alpha}} L_{t+1}\left(\frac{\alpha}{r_{j,t+1}^K}\right)^{\frac{1}{1-\alpha}}}{1-\mathcal{M}_{t+1}\left(1+\phi g_{j,t+2}\right)}\right)^{\frac{1}{1-\phi}}\right] \tag{12}$$

The right hand side of (12) does not contain current productivity $a_{j,t}$. A firm that seeks to maintain constant growth must increase productivity-enhancing investments at the same rate as productivity, yielding a constant investment intensity $rd_{j,t}/a_{j,t}$ in the steady state. As a consequence, there is no mean-reversion in the level of productivity-enhancing investments $rd_{j,t}$. Transitory shocks to variable on the right hand side of (12) lead to transitory changes in investment intensity, but permanently affect the path of both $rd_{j,t}$ and $a_{j,t}$

A3. Equilibrium

The equilibrium is a path for quantities $\{C_t, y_{j,t}, a_{j,t}, h_{j,t}, k_{j,t}/l_{j,t}\}$, prices $\{r_{j,t}, p_{j,t}/P_t, W_t/P_t\}$ and growth rate g, subject to first order conditions (1), (2), (6), (7) and (12), growth equation (5), production function (3) and resource constraint $y_{j,t} = C_t + k_{j,t+1} - (1-\delta)k_{j,t} + RD_{j,t} \forall j$, where δ is the depreciation rate.[39] The equilibrium is characterized by a balanced growth path where quantities $\{C_t, y_{j,t}, a_{j,t}, h_{j,t}, k_{j,t}/l_{j,t}\}$ and real wage W_t/P_t grow at a constant rate, while prices $\{r_{j,t}, p_{j,t}/P_t\}$ are constant.

A4. Calibration and Simulation

To illustrate the permanent effect of financial shocks in this parsimonious model, I simulate the effects of financial shocks of magnitudes similar to the Global Financial Crisis. The calibration is summarized in Table A1. Parameters for the depreciation rate δ and discount rate β are set to 0.10 and 0.98 respectively for an annual calibration. Labor share $1-\alpha$ is calibrated to 0.56 in line with aggregate U.S. data for 2007. The weight of labor in utility χ, Frish elasticity ψ, and elasticity of substitution ε are taken from Gertler and Karadi (2011b). The steady-state markup of interest rates is 2 percentage points, in line with the maturity-adjusted average spread of BBB-rated corporate bond rates over treasury notes. The financial crisis is calibrated to cause a 6 percentage points shock to μ^C, in line with the peak increase in the spread on BBB-rated corporate bonds.

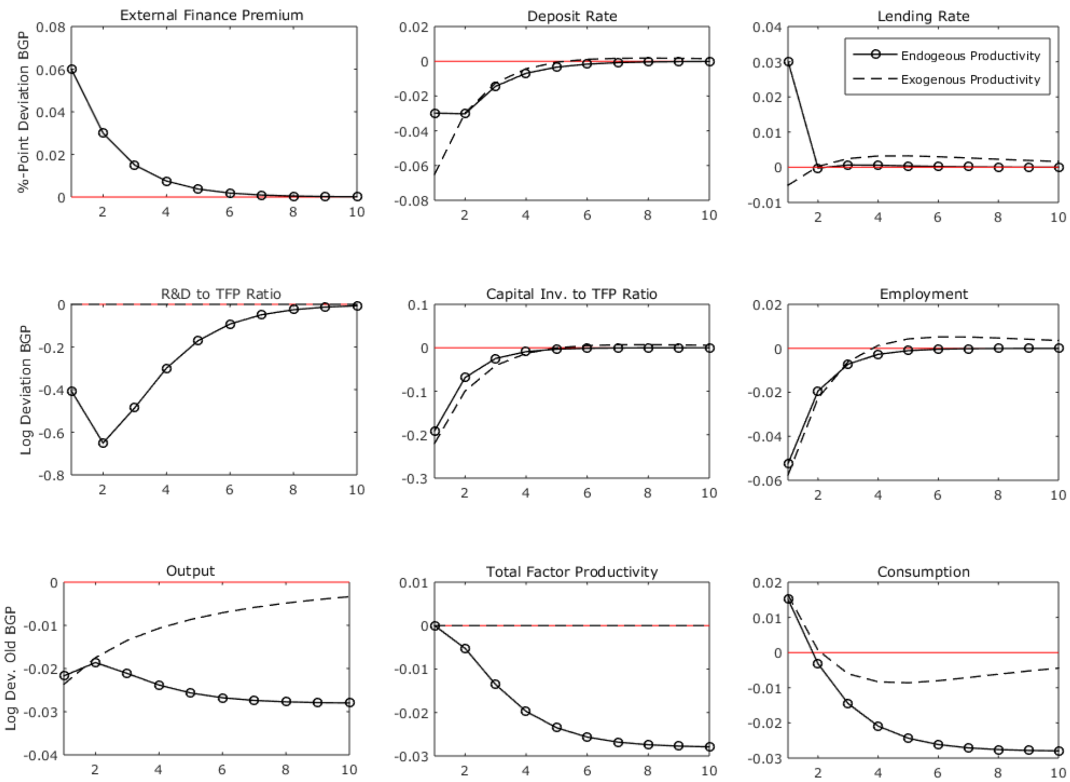
Impulse response functions are plotted in Figure A3. The upper figures present responses for interest rates while the middle figures present responses for investment-intensity variables and employment. The bottom panel presents responses of output, productivity and consumption, in log deviation from the original balanced growth path. Solid-circled lines present responses for the

Table A1: Parameter Calibration

Households		
β	0.98	Discount rate
χ	3.41	Relative utility weight of labor
ψ	0.27	Inverse of Frish elasticity
Intermediate Firms		
1-α	0.56	Labor share in production
ϵ	4.17	Elasticity of substitution
ζ	0.02	Research effectiveness
ϕ	0.70	Research returns to scale
Other		
δ	0.10	Depreciation rate capital
μ^C_{ss}	0.02	Steady state lending spread in p.p.
σ	0.06	Shock to spread in p.p.
ρ	0.50	Persistence of premium shock

[39] Productivity-enhancing investments do not depreciate. The permanent effect of financial crises on the level of output holds for any positive depreciation rate below 1.

Figure A3. Effect of Financial Shock on Selected Variables



Note: Horizontal axis denote years from shock.

endogenous growth model. For comparison, dashed lines present impulse responses in the model when endogenous growth is shut-off, and productivity grows exogenously at the steady-state rate. The increase in the external finance premium leads to a jump in the lending rate. This reduces optimal productivity-enhancing investments and capital. Because there is less demand for borrowed funds, this causes a drop in the interest rate on deposits. Within 6 years after the shock, the intensity of productivity-enhancing recovers to steady-state levels. Output, productivity and consumption therefore remain at a level that is permanently below the original trend. If productivity growth is exogenous, firms have an incentive to increase the capital stock as the marginal product of capital is high, causing output to recover and employment to temporarily exceed the steady state level. In the endogenous growth model, the temporary reduction of investment intensity leaves productivity and output close to 3% behind trend, which is similar to the empirical estimates in Section 5.

Appendix B: Additional Tables

Table A2: Distribution of Firms Across 2-digit SIC Industries

SIC 2-digit Code	Description	Count
01	Agricultural Production - Crops	1
10	Metal Mining	1
12	Coal Mining	1
13	Oil and Gas Extraction	6
14	Mining and Quarrying of Nonmetallic Minerals, Except Fuels	2
15	Construction - General Contractors & Operative Builders	1
16	Heamy Construction, Except Building Construction, Contractor	1
20	Food and Kindred Products	19
21	Tobacco Products	2
22	Textile Mill Products	4
23	Apparel, Finished Products from Fabrics & Similar Materials	1
24	Lumber and Wood Products, Except Furniture	3
25	Furniture and Fixtures	11
26	Paper and Allied Products	14
27	Printing, Publishing and Allied Industries	2
28	Chemicals and Allied Products	79
29	Petroleum Refining and Related Industries	3
30	Rubber and Miscellaneous Plastic Products	10
31	Leather and Leather Products	3
32	Stone, Clay, Glass, and Concrete Products	7
33	Primary Metal Industries	7
34	Fabricated Metal Products	20
35	Industrial and Commercial Machinery and Computer Equipment	73
36	Electronic & Other Electrical Equipment & Components	77
37	Transportation Equipment	41
38	Measuring, Photographic, Medical, & Optical Goods, & Clocks	50
39	Miscellaneous Manufacturing Industries	9
48	Communications	7
50	Wholesale Trade - Durable Goods	4
51	Wholesale Trade - Nondurable Goods	3
58	Eating and Drinking Places	3
73	Business Services	51
79	Amusement and Recreation Services	2
80	Health Services	1
87	Engineering, Accounting, Research, and Management Services	3

Table A3: First Stage Results: Combined Instruments and Control Variables

	(1)	(2)	(3)	(4)	(5)
Productivity-enhancement					
R&D Investments					
Asset Soundness	0.007	0.007	0.009	0.011**	0.012**
	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)
Deposits-to-Assets	0.012	0.015*	0.019*	0.015	0.013
	(0.007)	(0.009)	(0.010)	(0.011)	(0.012)
Lehman Exposure	0.009	0.010*	0.011*	0.007	0.006
	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)
Leverage	-0.001	-0.001	-0.001	-0.002	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R-squared	0.127	0.233	0.342	0.404	0.425
F-statistic	11.69	16.42	16.47	11.08	10.24
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00
Observations	522	522	522	519	497
Intangible Capital					
Asset Soundness	0.011*	0.011*	0.014**	0.016***	0.015***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)
Deposits-to-Assets	0.007	0.008	0.010	0.008	0.007
	(0.005)	(0.007)	(0.008)	(0.009)	(0.010)
Lehman Exposure	0.015***	0.017***	0.015***	0.012***	0.010**
	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Leverage	-0.001	-0.002	-0.001	-0.002*	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R-squared	0.165	0.240	0.326	0.394	0.435
F-statistic	18.07	24.12	15.04	16.66	13.09
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
Observations	522	522	522	519	497
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is rd_j/a_j. Explanatory variables are standardized to have unit standard deviations. Control variable definitions: Firm characteristics include pre-crisis assets (log), age (log), cash-to-asset ratio, profitability,rofit margin, leverage and loss of cash flow in '08. Stock price characteristics: book-to-market and price-earnings ratio. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level.

Table A4: First Stage Results: Combined Instruments, Incl. Share Due, and Control Variables

	(1)	(2)	(3)	(4)	(5)
Productivity-enhancement					
R&D Investments					
Asset Soundness	0.005	0.003	0.004	0.006	0.008
	(0.007)	(0.008)	(0.008)	(0.007)	(0.008)
Deposits-to-Assets	0.012	0.015*	0.019*	0.013	0.012
	(0.007)	(0.009)	(0.011)	(0.011)	(0.012)
Lehman Exposure	0.005	0.007	0.006	0.004	0.003
	(0.007)	(0.007)	(0.008)	(0.009)	(0.009)
Leverage	-0.002	-0.002*	-0.002	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share Debt Due	-0.013**	-0.012**	-0.010**	-0.008*	-0.006*
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)
R-squared	0.127	0.233	0.342	0.404	0.425
F-statistic	11.69	16.42	16.47	11.08	10.24
F-Stat.'s P-value	0.00	0.00	0.00	0.00	0.00
Observations	522	522	522	519	497
Intangible Capital					
Asset Soundness	0.007	0.008	0.010	0.005	0.005
	(0.006)	(0.007)	(0.008)	(0.009)	(0.010)
Lehman Exposure	0.012**	0.014***	0.012***	0.010**	0.008
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Leverage	-0.002	-0.002**	-0.002*	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share Debt Due	-0.013***	-0.013***	-0.012**	-0.010*	-0.008
	(0.004)	(0.005)	(0.004)	(0.006)	(0.005)
R-squared	0.161	0.258	0.355	0.412	0.438
F-statistic	11.23	27.47	15.95	14.21	5.93
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
Observations	522	522	522	519	497
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is rd_j/a_j. Explanatory variables are standardized to have unit standard deviations. Control variable definitions: Firm characteristics include pre-crisis assets (log), age (log), cash-to-asset ratio, profitability,rofit margin, leverage and loss of cash flow in '08. Stock price characteristics: book-to-market and price-earnings ratio. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level.

Table A5: 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.

Table A6: Second Stage: Robustness to Years Included in Investment Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Output Growth 2010-2014	'09	'09	'09	'08/'09	'08/'09	'08/'09
Panel A						
R&D Investments	1.098*	1.510***	1.129***	1.424*	1.761***	1.216***
	(0.644)	(0.486)	(0.418)	(0.847)	(0.577)	(0.444)
First Stage Partial R^2	0.0456	0.0821	0.0683	0.0339	0.0675	0.0605
First Stage F-Statistic	12.64	14.04	15.02	11.28	18.50	10.86
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.48	0.46	0.40	0.52	0.47	0.37
Observations	522	522	497	522	522	497
Panel B						
Investment in Intangibles	1.461*	2.414***	1.676**	1.835*	3.017***	1.958**
	(0.761)	(0.817)	(0.693)	(0.999)	(1.055)	(0.802)
First Stage Partial R^2	0.0402	0.0514	0.0555	0.0304	0.0382	0.0484
First Stage F-Statistic	16.96	10.20	7.966	15.45	11.82	8.208
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.33	0.36	0.53	0.29	0.40	0.53
Observations	522	522	497	522	522	497
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
State *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
Firm Characteristics	No	No	Yes	No	No	Yes
Stock Price Characteristics	No	No	Yes	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, leverage, share of long term debt due in 2009. 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, resp.

Table A7: Second Stage: Robustness to Years Included, Incl. Share Debt Due

Output Growth 2010-2014	(1) '09	(2) '09	(3) '09	(4) '08/'09	(5) '08/'09	(6) '08/'09
Panel A						
R&D Investments	1.318*	1.552**	1.605***	1.744*	1.704**	1.717***
	(0.691)	(0.625)	(0.595)	(0.932)	(0.715)	(0.603)
First Stage Partial R^2	0.0456	0.0821	0.0683	0.0339	0.0675	0.0605
First Stage F-Statistic	12.64	14.04	15.02	11.28	18.50	10.86
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.53	0.59	0.56	0.63	0.60	0.54
Observations	458	458	439	458	458	439
Panel B						
Investment in Intangibles	1.659**	2.571**	2.513**	2.226**	3.163**	2.949**
	(0.728)	(1.031)	(1.054)	(1.043)	(1.391)	(1.215)
First Stage Partial R^2	0.0475	0.0509	0.0474	0.0334	0.0356	0.0397
First Stage F-Statistic	9.792	8.145	4.434	7.495	8.261	4.247
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.38	0.68	0.52	0.40	0.60	0.64
Observations	458	458	439	458	458	439
Control Variables						
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
State *Fixed Effects*	No	Yes	Yes	No	Yes	Yes
Firm Characteristics	No	No	Yes	No	No	Yes
Stock Price Characteristics	No	No	Yes	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, leverage, share of long term debt due in 2009. 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, resp.

Table A8: Second Stage: Productivity Stock based on 2005, 2006, 2007

	(1)	(2)	(3)	(4)	(5)
Output Growth 2010-2014					
Panel A					
R&D Investments	1.257**	1.691*	1.887***	1.440***	1.336**
	(0.557)	(0.893)	(0.525)	(0.459)	(0.530)
First Stage Partial R^2	0.026	0.023	0.034	0.026	0.030
First Stage F-Statistic	7.25	6.09	5.94	5.81	5.81
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.57	0.44	0.48	0.31	0.33
Observations	522	522	522	519	497
Panel B					
Investment in Intangibles	1.541**	1.800**	1.935***	1.572***	1.191***
	(0.631)	(0.795)	(0.466)	(0.402)	(0.366)
First Stage Partial R^2	0.015	0.015	0.027	0.026	0.041
First Stage F-Statistic	5.603	4.332	6.764	6.452	9.663
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.50	0.47	0.49	0.46	0.43
Observations	522	522	522	519	497
Control Variables					
Lagged Output Growth	Yes	Yes	Yes	Yes	Yes
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, leverage, share of long term debt due in 2009. 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, resp.

Table A9: Second Stage: Productivity Stock based on 2005, 2006, 2007, Incl. Share Due

	(1)	(2)	(3)	(4)	(5)
Output Growth 2010-2014					
Panel A					
R&D Investments	1.358**	1.579**	1.987***	1.893***	2.030**
	(0.547)	(0.722)	(0.702)	(0.596)	(0.797)
First Stage Partial R^2	0.039	0.032	0.034	0.029	0.028
First Stage F-Statistic	12.38	8.585	15.25	8.934	6.34
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.47	0.60	0.55	0.66	0.53
Observations	458	458	458	457	439
Panel B					
Investment in Intangibles	1.425***	1.471**	1.707***	1.753**	1.680**
	(0.531)	(0.596)	(0.633)	(0.780)	(0.830)
First Stage Partial R^2	0.025	0.023	0.030	0.032	0.039
First Stage F-Statistic	7.150	7.956	18.11	12.14	11.94
F-Stat's P-value	0.00	0.00	0.00	0.00	0.00
J-test Overid. P-value	0.43	0.53	0.49	0.59	0.41
Observations	458	458	458	457	439
Control Variables					
Sector *Fixed Effects*	No	Yes	Yes	Yes	Yes
State *Fixed Effects*	No	No	Yes	Yes	Yes
Firm Characteristics	No	No	No	Yes	Yes
Stock Price Characteristics	No	No	No	No	Yes

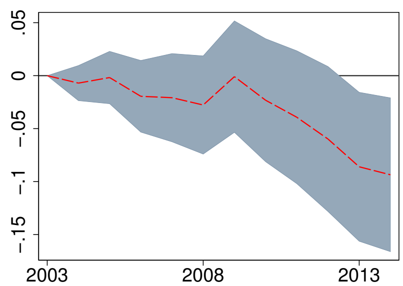
Note: Dependent variable is Δy between 2010 and 2014. Instruments: Lehman lead share, deposits over assets, asset soundness, leverage, share of long term debt due in 2009. Bank variables are weighted by firm's last pre-crisis loan syndicate. Standard errors, clustered by industry, in parentheses. *, **, and *** denote significance at the 10 and 5, and 1% level, resp.

Table A10: Effect of Crisis-Exposure on Capital Investments and Employment

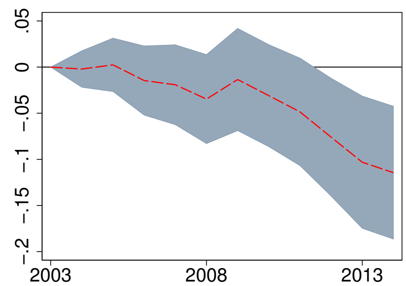
	Firm-Bank Relationship Measures						Debt Structure
	Asset Soundness	Deposits to Assets	Lehman Exposure	ABX Exposure	Leverage Assets	BLP to Assets	% Long-Term Debt Due
Capital Invest.							
Coefficient	-0.019	-0.032***	-0.015*	-0.025***	0.007	-0.011*	-0.015*
	(0.012)	(0.005)	(0.009)	(0.009)	(0.011)	(0.006)	(0.009)
Observations	522	522	522	522	522	522	458
F-statistic	2.76	41.91	3.02	7.71	0.44	3.33	2.90
Δ *Employment*							
Coefficient	-0.038***	-0.028**	0.002	-0.017	-0.011	-0.002	-0.048***
	(0.010)	(0.014)	(0.019)	(0.018)	(0.025)	(0.009)	(0.008)
Observations	522	522	522	522	522	522	458
F-statistic	15.76	4.23	0.017	0.94	0.20	0.06	32.39

Note: Dependent variable in upper and lower panel is physical capital investment intensity and change in employment in 2009-2010 to stock in 2007, resp. Estimates obtained from OLS. Controls for sector and state fixed effects, firm size, age, pre-crisis avg. growth. Standard errors clustered by industry and given in parentheses. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.

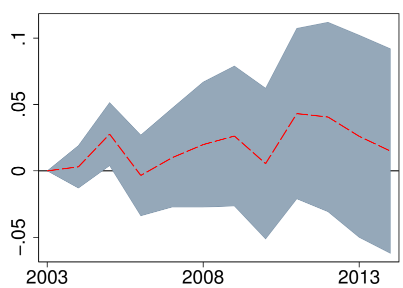
Figure A4. Time-varying Effect of Investments and Δ Employment during Crisis on Output



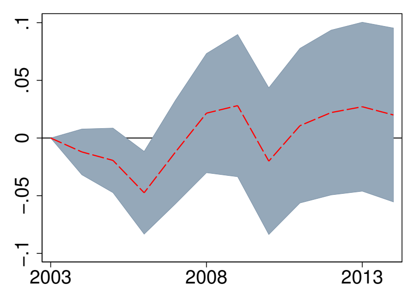
(a) Research & Development



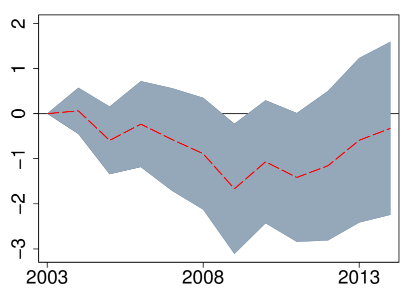
(b) Research & Dev. (Incl. Share Due)



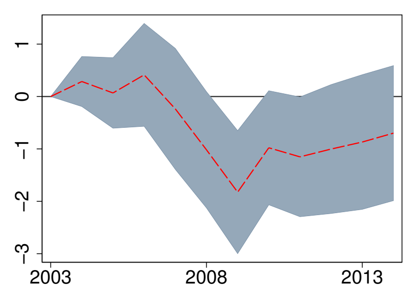
(c) Capital Investment



(d) Capital Inv. (Incl Share Due)



(e) Δ Employment



(f) Δ Emp. (Incl Share Due)

Note: Vertical axis denote the percentage increase in output after a one-standard-deviation increase in the fitted value of investments. Bounds present 90% confidence intervals based on bootstrapped standard errors. Instruments in the left-hand figures measure bank-health: asset soundness, change in asset soundness, percentage Lehman lead, ABS exposure, deposit-to-assets ratio, bad loan provisions, leverage ratio. Right-hand figures add share of debt due. Estimates present elements of vector γ_R, γ_K, and γ_L, in Equation 12.