Introduction

The origins of aggregate fluctuations are of essential interest to modern macroeconomics, as reaffirmed by the recent financial crisis and ensuing recession. A large literature has sought to ex lain the role of financial factors in the context of the financial accelerator mechanism, relying on re resentative agent assum tions in which a creditor lends to a borrower. This, however abstracts from the credit relationshi s amongst heterogeneous borrowers and lenders that characterizes most advanced economies. Yet the credit linkages between firms may ro agate firm-level shocks across the economy. The literature has therefore overlooked a otentially im ortant source of aggregate fluctuations, and is in need of a framework for evaluating whether the credit relationshi s between non-financial firms lay a role in the business cycle.

To this end, I build a tractable model of a credit network economy in which trade in intermediate goods is financed by su lier credit. I show analytically how the trade credit linkages between non-financial firms generate aggregate fluctuations from firm-level shocks, and show that the mechanism is quantitatively im ortant. I combine firm-level balance sheet data and industry-level in ut-out ut data to construct a roxy of su lier credit flows at the industry-level. I use this roxy to calibrate my model, and quantitatively analyze how the aggregate im act of idiosyncratic shocks de ends on the structure of the credit network. I then use a structural factor a roach to estimate the shocks which hit the US manufacturing and mining sectors over the eriod 1997-2013. Second, I use the model to shed light on the origins of aggregate fluctuations in the US by decom osing observed movements in industrial roduction (IP) into com onents arising from four ty es of shocks: aggregate roductivity, idiosyncratic roductivity, aggregate liquidity, and idiosyncratic liquidity shocks.

In so doing, I make two contributions to the literature. First, I show that the c(el)-280dss

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is the single most important source of short-term external finance for firms, accounting for more than half of firms' short-term liabilities and more than one-third of their total liabilities in most OECD countries.[2] In the US, accounts payable was three times as large as bank loans and fifteen times as large as commercial paper outstanding, on the aggregate balance sheet of non-financial corporations in 2012.[3] All of these facts point to the presence of strong credit linkages between non-financial firms.

An important feature of trade credit is that it leaves suppliers exposed to the liquidity problems of their customers. A notable example of this is the US automotive industry in 2008, when the Big Three automakers (Chrysler, Ford, and GM) faced a serious shortage of liquidity. While Ford did not require a bailout, it requested one from the US Congress on behalf of its competitors, fearing that a bankruptcy by Chrysler or GM would transfer the liqudity shortage to their common suppliers, as the money owed to them could not be paid until they exited bankruptcy. This episode suggests that when firms play a dual role of supplier and creditor, a shock may not only affect trade directly, but also the availability of liquidity to finance the trade.

There is growing evidence to suggest that this intuition is empirically relevant. A number of studies - including Boissay and Gropp (2012), Jacobson and von Schedvin (2015), and Raddatz (2010) - have found that firm- and industry-level trade credit linkages propagate liquidity shocks from firms to their suppliers. In spite of this evidence, the macroeconomic implications of trade credit have been largely overlooked in the literature. I therefore develop a framework for understanding how inter-firm trade and credit interact in response to credit conditions.

I consider an economy in which firms are organized in a production network and trade intermediate goods with one another. Each intermediate good is produced using labor and other intermediate goods. There is

A firm-level liquidity shock ro agates to other firms in the network via two channels. First is the standard in ut-out ut channel which has been the focus of studies such as Acemoglu et al. (2012) and Bigio and La'O (2013): the shocked firm cuts back on roduction, reducing the demand faced by its su liers and reducing the su ly of its good to its customers.

But the credit linkages between firms im lies that there is a new channel of ro agation - which I call the credit linkage channel - in which the shock directly affects the cash-in-advance ayment received by the firm's su liers. When the shocked firm cuts back on roduction, the rice of its good rises, which increases the collateral value of its receivables. Able to obtain a higher trade credit loan (er unit of out ut) from its su liers, the firm reduces the cash-in-advance ayments it makes u stream. With less cash, the su liers are more liquidity constrained, and they may themselves be forced to further cut back on their own roduction. If these su liers cut back on roduction, they reduce their demand for labor, am lifying the aggregate effect aggregate and idiosyncratic roductivity shocks. A variance decom osition of aggregate IP shows that the credit network of these industries accounts for one-fifth of aggregate IP volatility.

Much of the revious literature has relied on aggregate roductivity shocks to drive the business cycle. Yet by many accounts, this has been an unsatisfactory ex lanation due to the lack of direct evidence for shocks. This a er shows, however, that when one takes into account the credit linkages between non-financial firms in the economy, the role of aggregate roductivity shocks is minimal. On the contrary, aggregate liquidity shocks seem to lay a vital role the business cycle. Indeed, the im ortance of shocks emanating from the financial sector to real economy as a whole is well-documented. Thus, this a er suggests that a large fraction of aggregate fluctuations are erha s driven by shocks from the financial sector emanating to the real economy.

The rest of the a er is organized as follows. The next section reviews some of the literature to which this a er is related. Part I introduces the model. The first art of the model considers a sim le version in which the structure of the roduction network is a su ly chain. I derive analytical results using a stylized version of the full model. In the next art, I generalize the roduction network structure. Part II is a quantitative analysis. I describe the roxy of trade credit flow, the calibration, and quantiative results. In Part III, I erform my em irical analysis, and discuss the results.

Literature Review

(In rogress).

This a er relates to several strands of the literature. There is a large literature on the role of financial frictions in macroeconomics. Studies such as Bernanke and Gertler (1995), Bernanke et al. (1999), and Kiyotaki and Moore (1997b) evaluate the link between financial factors and the real economy. Most of this literature abstracts from heteregeneous agents models. Also, there has been little attention given to the credit relationshi s between non-financial firms. I consider a financial accelerator mechanism in the context of a network model and show that am lifies its effects.

A growing literature looks to network effects as a multi lier mechanism which can generate aggregate fluctuatinos from idiosyncratic shocks. Much of this literature builds on the multi-sector RBC model of Long and Plosser (1983). Most notably, these include Acemoglu et al. (2012), Shea (2002), Du or (1999), Horvath (1998), Horvath (2000), and Acemoglu et al. (2015). These studies all focus on the role of in ut-out ut linkages between firms. In ut-s ecificity in the roduction of intermediate goods revents firms from easily switching su liers or customers in res onse to roductivity shocks. Gerenally, these models rely on certain structural ro eorties of a network in which idiosyncratic shocks to firms in economy do not average out. Systemically im ortant firms, who take a central role inthe network, ro agate shocks across other firms in the network generating movements at the aggregate level of the economy. However, most of this literature do not model how trade in intermediate goods is financed. Indeed, most abstract away from financial frictions.

A notable work to which this a er is most closely related is that of Bigio and La'O (2013), who examine

Part I

Model

In Part I, I introduce and analyze the model. This section has two has two arts. For ease of ex osition, it is instructive to first consider the s ecial case of a vertical roduction network. I refer to this as the stylized model. The analytical tractability of this case ermits closed-form ex ressions for aggregate out ut. In the second art, I generalize the network structure.

1 Stylized Model: Vertical Production Structure

1.1 Economic Environment

There is one time eriod, consisting of two arts. At the beginning of the eriod, contracts are signed. At the end of the eriod, roduction takes lace and contracts are settled. There are three ty es of agents: a re resentative household, firms, and a bank. There are M goods, each roduced by a different firm. (Here the roductive unit could similarly be called an industry, which is com orised of a continuum of com etitive firms). Each good can be consumed by the household0o.Inoldusroddusro the roduction of other goods.

1.2 Representative Household0]TJ/F43 9.9626 Tf 0 -24.365 Td [(1.2.1)-1149(Preferences)]TJ/F15 9.

goods,h ro n427(TJ/F159.9 2 Tf150.41c)28(h)-N-28(o)-27(d)-1(s,)-32.411ch

$$C = wN + \sum_{i=1}^{M} {}_{i} \tag{1}$$

1.2.2 Optimality

The household's o timality condition is given by

$$\frac{V^0(N)}{U^0(C)} = w \tag{2}$$

This equates the com etitive wage with the marginal rate of substitution between labor and consum tion.

1.3 Firms

There are M firms who each roduce a different good. Su ose for now that firms are arranged in a su ly chain, where each firm roduces an intermediate good for one other firm. The last firm in the chain roduces the consum tion good, which it sells to the household. Firms are indexed by their order in the su ly chain, with $i = M$ denoting the roducer of the final good.

Firms are rice-takers.[4] The roduction technology of firm i Cobb-Douglas over labor and intermediate goods.

$$x_i = \begin{cases} z_i^{\ i} n_i^{\ i} & \text{for } i = 1 \\ z_i^{\ i} n_i^{\ i} x_{i\ 1}^{(1\ \ i)!_{i;i\ \ 1}} & \text{for } i > 1 \end{cases}$$

Here, x_i denotes firm i's out ut, n_i its labor use, and $x_{i\ \ 1}$ its use of good $i \ \ 1$. Parameter z_i denotes firm i's total factor roductivity, ${}_i$ the share of labor in its roduction, and $!_{i;i\ \ 1}$ the use of good $i \ \ 1$ in firm i's roduction. Let p_s denote the rice of good s. The value of the sales from firm s to firm c is then $p_s x_{cs}$.

The in ut-out ut structure of the economy can be summarized by a matrix of inof

$$
\begin{bmatrix}
\omega_{11} & \omega_{12} & \omega_{13} & & \omega_{1M} \\
\omega_{21} & \omega_{22} & \omega_{23} & & \\
\omega_{31} & \omega_{32} & \omega_{33} & & \\
\vdots & & & \ddots & \\
\omega_{M1} & & & & \omega_{MM}
\end{bmatrix}
=
\begin{bmatrix}
0 & 0 & 0 & & 0 \\
\omega_{21} & 0 & 0 & & \\
0 & \omega_{32} & 0 & & \\
\vdots & & & \ddots & \\
0 & & & \omega_{M,M-1} & 0
\end{bmatrix}
$$

Bank lending: Each firm chooses how much to borrow from the bank, subject to a limited enforcement roblem. Firm i can obtain the loan b_i from the bank at the beginning of the eriod by ledging a fraction B_i of its total end-of-the- eriod revenue $p_i x_i$, and a fraction 1 of its accounts receivable $_{i+1}$, where 1. Thus, firm i faces a bank borrowing constraint of the form

$$b_i \quad B_i p_i x_i + (1 \quad) \; _i$$

Parameters B_i and rovide an exogenous source of liquidity to each firm, and re resent the severity of the agency roblem between firm i and the bank. I will later show that arameterizes the degree of substitutability between bank credit and cash-in-advance ayments from customers. Since b_i is chosen by firm i these bank borrowing constraint will bind in equilibrium as each firm obtains the maximum bank loan ossible.

Trade credit : Each firm i chooses the size of the trade credit loan $_{i \; 1}$ it obtains from its su lier. But a limited enforcement roblem between firms laces a limit on the size of this loan. In articular, firm i can ledge a fraction $_i$ of its end-of-the- eriod out ut to re ay its su lier. Then the trade credit loan is bounded by the collateral value of firm i's out ut

$$_{i \; 1} \quad _{i;i \; 1} p_i x_i$$

The recise limited enforcement roblem which roduces this borrowing constraint is described in detail in the A endix. In equilibrium, the firm takes the maximum loan that the su lier will allow, and so the borrowing constraint binds. This ins down the trade credit loan from su lier $i \quad 1$ at $_{i \; 1} = \; _{i;i \; 1} p_i x_i$. Note that the size of the loan to firm i de ends on the rice p_i of its good. (Hence, changes in the collateral value of good x_i will change the amount of cash-in-advance that su lier $i \quad 1$ can collect.)

The structure of the credit network between firms can be summarized by the matrix of $_{ij}$'s.

$$\begin{bmatrix} _{11} & _{12} & _{13} & & _{1M} \\ _{21} & _{22} & _{23} & & \\ _{31} & _{32} & _{33} & & \\ \vdots & & & \ddots & \\ _{M1} & & & & _{MM} \end{bmatrix}$$

g.d [(ca494 Tdw0.38 495 Td22)]J/F7 6.178 T96.9738 Tf 2.81J/F15 9.9

where

$$ _i \qquad \frac{b_i}{p_i x_i} + \frac{_i \quad _1}{p_i x_i} + 1 \qquad \frac{_i}{p_i x_i} $$

The variable $_i$ denotes the tightness of firm i's liquidity constraint. Notice that $_i$ is decreasing in $\frac{_i}{p_i x_i}$, the amount of i's out ut sold on credit: the more credit that i gives its customer, the less cash it collects at the beginning of the eriod. We can re lace $_i$ using $i+1$'s binding su lier borrowing constraint, to re-write $_i$.

$$ _i = B_i + \quad _{i;i} \quad _1 + 1 \qquad _{i+1\,;i} \frac{p_{i+1} x_{i+1}}{p_i x_i} \tag{4} $$

Equation (4) shows that $_i$ is an equilibrium object; it is an endogenous variable which de ends on the revenue of firm i and firm $i+1$. Hence, changes in the rice of its customer's good affect the tightness of firm i's liquidity constraint. Note also that the de endence of $_i$ on rices p_i and p_{i+1} means that changes a shock will have general equilibrium e ects on each $_i$.

in uts, it does not distort the firm's o timal choice of ex enditure on labor versus the intermediate good. However, the constraint will limit the firm's **total** ex enditure on both in uts.

If firm i's liquidity constraint is not binding in equilibrium, then it sim ly maximizes its rofit function. Its o timal level of ex enditure on each in ut is determined by a condition which equates the marginal cost of the in ut with its marginal revenue roduct. The firm's ex enditure on labor is therefore given by

$$wn_i = \ _i p_i x_i \ ; \qquad p_{i\ \ 1} = !_{i;i\ \ 1}(1 \quad _i)\frac{p_i x_i}{x_{i\ \ 1}}$$

If, on the other hand, the constraint is binding in equilibrium, then the amount of liquidity $\ _i p_i x_i$ that firm i has limits how much the firm can s end on **both** in uts. In articular, firm i's ex enditure on labor and good $i \quad 1$ is given by

$$wn_i = \frac{\ _i}{r_i} \ _i p_i x_i \ ; \qquad p_{i\ \ 1} = \frac{\ _i}{r_i} !_{i;i\ \ 1}(1 \quad _i)\frac{p_i x_i}{x_{i\ \ 1}}$$

I show in the A endix that firm i

Re-arranging this and re lacing $\frac{p_{i+1} \; x_{i+1}}{p_i \, x_i}$ in ( ) yields $_i$

$$\prod_{i=1}^{M} \quad P_{i} \quad {}_{j=1}^{i} \; \tilde{\jmath}$$

Thus, equilibrium aggregate out ut is log-linear in each firm's labor wedge, and equals Y if and only if $_i = 1$ for all i - i.e. if no firm's liquidity constraint is binding in equilibrium.[5] ca tures the aggregate liquidity available to all firms in the economy for trade in in uts. Therefore, (7) says that equilibrium aggregate out ut is constrained by the aggregate liquidity in the economy at the beginning of the eriod. Notice that through $\tilde{\jmath}$, firms who are further downstream have a higher share of total em loyment through the use of intermediate goods, and therefore have a higher im act on aggregate liquidity.

1.4.1 Equilibrium Characterization

To summarize the equilibrium, the cash-in-advance constraints faced by firms induces a wedge on their roduction, which de ends on the tightness of their constraints. But in a setting where firms share liqudiity via trade credit, these wedges de end endogenously on the rices of downstream goods and the structure of the credit network. In the next section, I ex lore the im lications of this endogenous relationshi between wedges and rices for how aggregate out ut res onds to firm-level shocks.

At this stage, it is worth discussing how this economy com ares to that of Bigio and La'O (2013). The novelty of Bigio and La'O (2013) is to show how wedges aggregate in an in ut-out ut network. However, in Bigio and La'O (2013), all ayments between firms are settled at the end of the eriod after roduction takes lace. As a result, there is no role for trade credit; and $_i$ and $_i$ are fixed exogenously. As I show in the next section, the endogeneity of the wedges means that the economy behaves qualitatively very differently in res onse to local shocks.

1.5 Aggregate Impact of Firm-Level Shocks

In this section, I examine the res onse of aggregate out ut to firm-level liquidity and roductivity shocks.

1.5.1 Liquidity Shocks

I model a liquidity shock to firm i by a change in B_i, the fraction of firm i's revenue that the bank will acce t as collateral for the bank loan. Consider a marginal fall in B_i given by $d\,B_i$. This is a reduced-form way to ca ture an adverse shock to firm i's bank which affects the ability of firm i to obtain credit for urchasing in uts.[6]

[5] Note that although Y is log-linear in each $_i$, it is not globally log-linear in $_i$. (This is re ected in the kink in $_i$ at $_i = r_i$.) Why is Y not globally log-linear in $_i$? The liquidity constraint creates a kink in the policy function for employment n_i at the point at which the liquidity constraint is no longer binding, i.e. at $_i = r_i$. This kink carries over to Y in aggregation. The kink implies: i) Y is not di erentiable with respect to $_i$ at $_i = 1$ $_i = r$

Y globally log-linea

The fall in B_i directly affects the amount of cash firm i can raise at the beginning of the eriod. The closed-form ex ression for $_i$ (4) shows that the fall in B_i causes firm i's liquidity constraint to tighten.

$$\frac{d \quad _i}{d B_i} = 1 > 0$$

If firm i's liquidity constraint is binding in equilibrium, then the tighter liquidity constraint forces the firm

+

2) # i 1=) drop in demand for all j < i 1; drop in supply for all j > i 1 =) Y falls

d li

+

3) # i 2=) drop in demand for all j < i 2; drop in supply for all j > i 2 =) Y falls

⋮

In this manner, the credit linkages between firms trigger the standard in ut-out ut channel at every level of roduction, increasing the total demand/su ly effects faced by each firm. Thus, a firm-level liquidity shock to in my model is isomor hic to an aggregateliquidity shock to all firms in a model with fixed wedges, e.g. Bigio and La'O (2013). I ex lore this oint in further detail in the quantitative analysis.

1.5.2 Impact of Firm-Level Shock on Aggregate Output

I now formalize the network effects of the shock on aggregate out ut. Recall from (7) that equilibrium aggregate out ut is log-linear in each firm's wedge

$$\log Y = \log Y + \log$$

Then the elasticity of aggregate out ut with res ect to firm i's bank borrowing B_i is given by

$$d \log Y$$

1.5.3 Productivity Shocks

Now consider a roductivity shock to firm i, re resented by a fall in i's total factor roductivity (TFP) z_i. What is the effect on aggregate out ut? Recall the closed-form ex ression (7) for aggregate out ut

$$Y = Y$$

where

$$Y \quad \prod_{j=1}^{M} \tilde{}_j^{\,\neg_j} z_j^{!\neg_j} \qquad \prod_{j=1}^{M} {}_j^{\,P_{k=1}^{j} \neg_k}$$

I claim that is inde endent of z_i. To see this, first recall that $_M = \min f\,1; \frac{_M}{r_M} g$, where $_M = \quad _{M;M} \quad 1j$

of the economy which can be taken to the data. To this end, I return to the general network framework in the next section.

2 General Model

I now return to the general roduction network structure summarized by

$$\begin{bmatrix} \omega_{11} & \omega_{12} & \omega_{13} & & \omega_{1M} \\ \omega_{21} & \omega_{22} & \omega_{23} & & \\ \omega & & & & \end{bmatrix}$$

$$\frac{p_i c_i}{p_j c_j} = \frac{\ _i}{\ _j} ; \qquad N^{1+} = C$$

2.2 Firm Liquidity

Each firm's liquidity constraint takes the same form as in the stylized model, with the exce tion that each firm has M su liers and M customers instead of just one of each. Firm i is required to ay its wage bill wn_i and its intermediate good urchases $p_s x_{is}$ from each su lier s in advance. It receives a loan b_i from the bank and a trade credit loan $\ _{is}$ from each su lier.

$$wn_i + \underbrace{\sum_{s=1}^{M} (p_s x_{is} \quad _{is})}_{\text{net CIA payment to suppliers}} \qquad b_i + \underbrace{p_i x_i \sum_{c=1}^{M} \ _{ci}}$$

the quantitative redictions of the model, which I discuss later on.

Each firm chooses the size of the loan to obtain from each creditor, so that the borrowing constraints bind in equilibrium. Plugging the binding borrowing constraints into firm i's liquidity constraint yields a constraint on i's total in ut urchases

$$wn_i + \sum_{s=1}^{M} p_s x_{is} \qquad {}_i\, p_i x_i$$

where ${}_i$ denotes the tightness of i's liquidity constraint.

$${}_i = B_i + \sum_{s=1}^{M} {}_{is} + 1 \qquad \sum_{c=1}^{M} {}_{ci} \frac{p_c x_c}{p_i x_i}$$

Note that ${}_i$ is again an equilibrium object, de ending on the rices customers' goods p_c and forward credit linkages ${}_{ci}$ for all c.

TABLE SUMMARIZING DEFINITIONS OF PARAMETERS AND EQ. VARIABLES

2.3 Firm Optimality Conditions and Market Clearing

Firms choose labor and intermediate goods to maximize rofits subject to their liquidity constraint. This yields o timality conditions of the same form, equating the ratio of ex enditure on each good with the ratio of their marginal revenue roducts.

$$\frac{wn_i}{p_j x_{ij}} = \frac{{}_i}{(1 \quad {}_i)\,!\,{}_{ij}}$$

Again, the liquidity constraint of firm i inserts a wedge ${}_i$ between the marginal cost and marginal revenue roduct of each in ut

$$n_i = \quad {}_i \; {}_i \frac{p_i}{w} x_i \qquad\qquad x_{ij} = \quad {}_i \,(1 \quad {}_i)\,!\,{}_{ij} \frac{p_i}{p_j} x_i \tag{10}$$

where the wedge de ends on the tightness of i's consraint and its returns-to-scale.

$${}_i = \min \quad 1;\ \frac{{}_i}{r_i} \quad ; \qquad r_i \quad {}_i + (1 \quad {}_i) \sum_{j=1}^{M} \; !\,{}_{ij} \tag{11}$$

Note that the wedge is still an equilibrium object, de ending on collateral value of each customer's out ut and forward credit linkages. Endogenous wedges im ly equilbrium will take same form, and will res ond in qualitatively same way as reviously.

Market clearing conditions for labor and each intermediate good are given by

$$N = \sum_{i=1}^{M} n_i \qquad x_i = c_i + \sum_{c=1}^{M} x_{ci}$$

nn o o

$z_i ; B_i ; \quad_i ; \quad_i ; f \quad_{ij} ; ! \,_{ij} \; g_{j\,l} \quad_{i\,l} \; ; \; ; \; ;$

there is a unique solution to the system. Since the model is one eriod, the behavior of the system in res onse to shocks can be modeled by com arative statics. In articular, I am interested in the

i 6.9738 Tf 4.981 -3.3482 T2.988017l56T 491522 g 9.9626 Tf -321.649Td [( )]TJn pquaested e-131J/analysis blib(e)e-131J/F3one

3.1 Data

To build my roxy, I use two sources of data: in ut-out ut tables from the Bureau of Economic Analysis (BEA) and Com ustat North America over the sam le eriod 1997-2013. The BEA ublishes annual data on commodity use by industry (Uses by Commodity Table) at the three-digit level of the North American Industry Classification System (NAICS). At this level, there are 58 industries, exlcuding the financial sector. From this data, I observe annual trade flows between each industry- air, which corres onds to $p_j x_{ij}$ in my model for every industry air $\{i; j\}$. The BEA also ublishes an annual Direct Requirements tables at the same level of detail, which indicate for each industry the amount of a commodity that is required to roduce one dollar of that industry's out ut. These values are quite stable over my sam le eriod. In constructing my roxy, and also in calibrating the model later, I use the in ut-out ut tables of the median year in my sam le, 2005.

Com ustat collects balance-sheet information annually from all ublicly-listed firms in the US. The available data includes each firm's total accounts ayable, accounts receivable, cost of goods sold, and sales in each year of the sam le. Therefore, while I cannot identify from whom each firm receives trade credit or to

$$PayFin_{f;t} = \frac{.5\,(AP_{f;t-1} + AP_{f;t})}{COGS_{f;t}}$$

I do this only for years in which there is data for both AP and COGS for each firm. I obtain a firm-level measure of ayables financing by taking the median of $PayFin_{f;t}$ across time, to minimize effect of outliers and get a re resentative firm-level estimate of the average COGS financed with trade credit. Then to get an industry-level measure of ayables financing, I take the median of $PayFin_f$ across all firms f in each three-digit level NAICS industry. In this way, I obtain a measure of ayables financing for each of my industries.

Raddatz (2010) uses this industry-level measure of PayFin to construct q_{ij}. However, since he only uses AP data, he must im ose that $q_{ij} = q_{ik}$ for all $j; k$. In other words, he assumes that each industry finances the same fraction of urchases with trade credit, across all of its su liers. This is a fairly strong assum tion

3.3 Choosing a Proxy

In this section, I consider an alternative weighting scheme for building the roxy $\hat{q}_{ij}$ and com are it with my baseline weighting scheme. Let $F_B(PayFin_i; RecLend_j)$ denote the baseline weighting function for building $\hat{q}_{ij}$, in which weights are assigned each argument according to the size of each industry.

$$F_B(PayFin_i; RecLend_j) = \frac{p_i x_i}{p_i x_i + p_j x_j} PayFin_i + \frac{p_j x_j}{p_i x_i + p_j x_j} RecLend_j$$

The alternative I consider is F_A, in which I assign equal weights to the arguments.

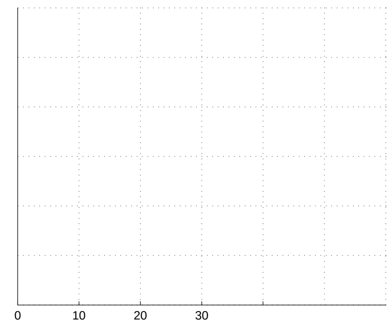
$$F_A(PayFin_i; RecLend_j) = \frac{1}{2} PayFin_i + \frac{1}{2} RecLend_j$$

F_B and F_A are equivalent when all industries have the same revenue. To the extent that there is greater variation in the size of industries, the two weighting schemes will roduce different roxies for q_{ij}. Since the variation in the observed size distribution of industries is non-negligable, I need a metric by which to choose between F_B and F_A.

Recall that the measures $PayFin_i$ and

$jRecLend_i \quad F_P(PayFin_c; RecLend_i$

Figure 1:



These two measures res ectively measure how much trade credit an industry rovides the rest of the economy,

Figure 2:

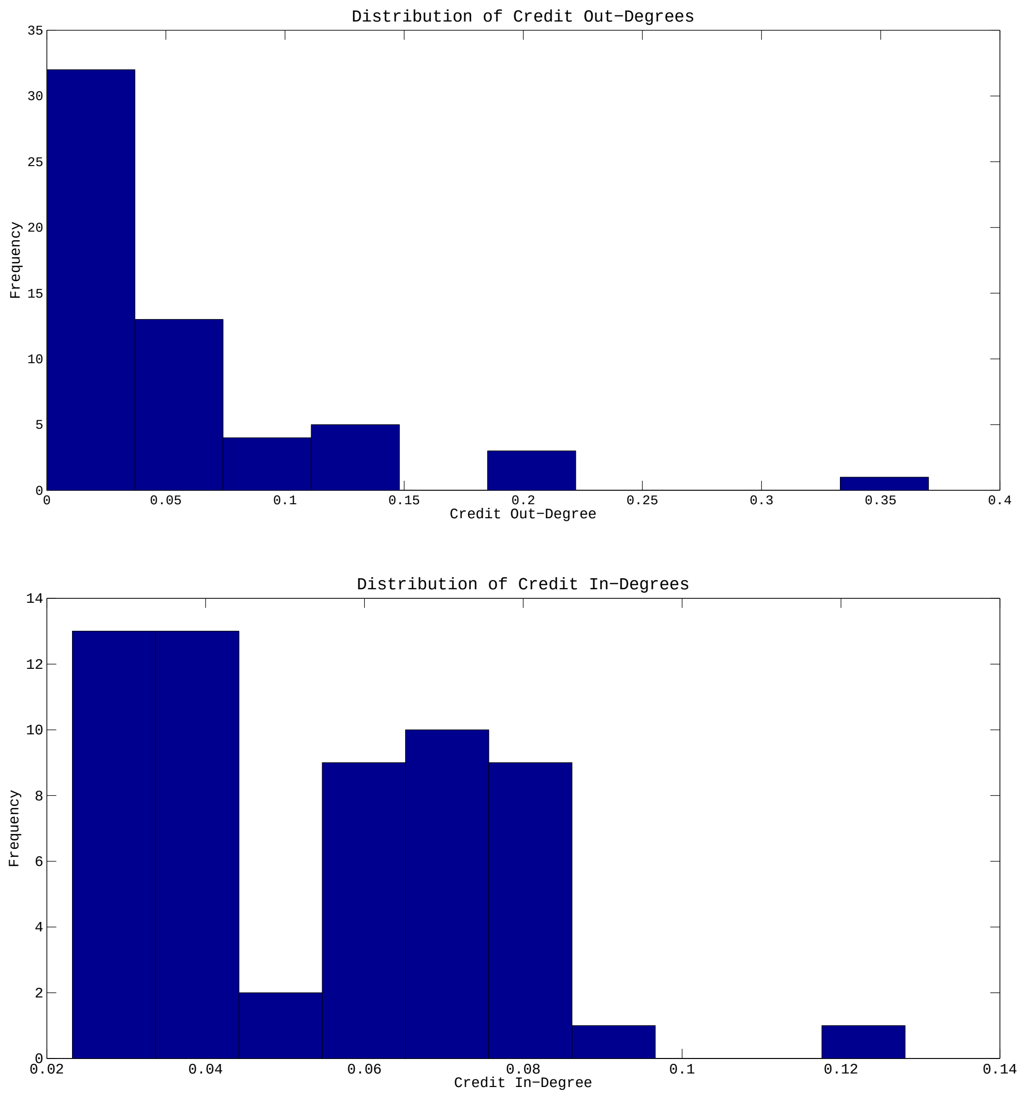
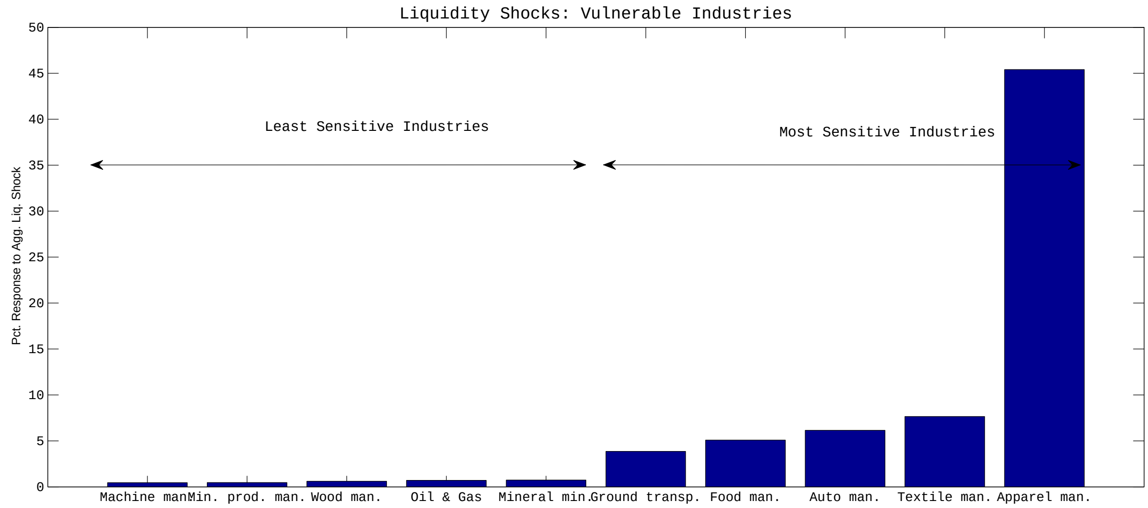

Distribution of Credit Out−Degrees
Frequency
Credit Out−Degree
35
30
25
20
15
10
5
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Distribution of Credit In−Degrees
Frequency
Credit In−Degree
14
12
10
8
6
4
2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14

Figure 3:



	Total	With credit linkage channel Shut-Off
Pct. Fall in Y	3.15	2. 1

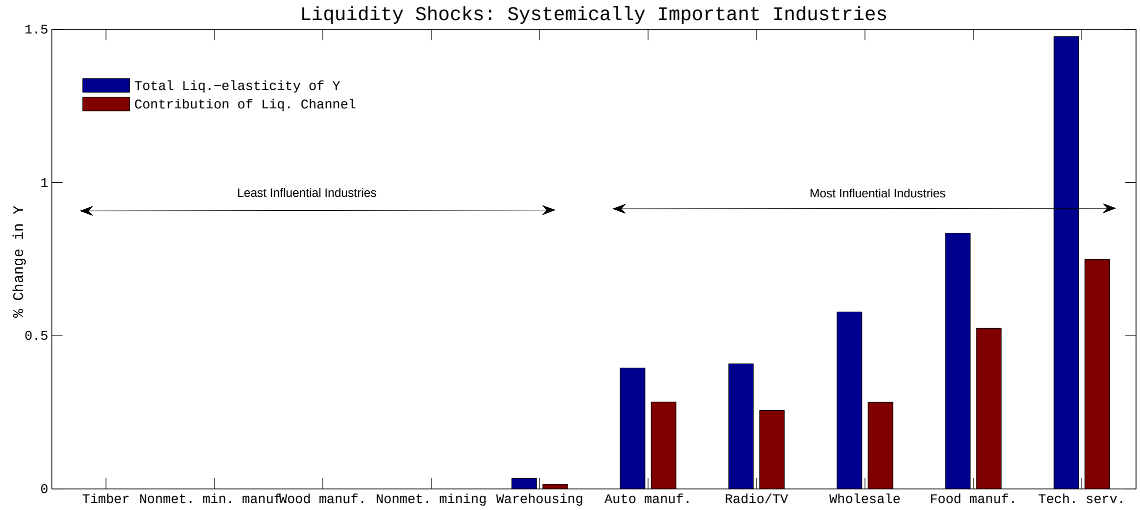
is one of the most vulnerable industries. (Will ex and on this).

5.1.2 Results for for = :8

Next, I erform the same exercise for with = :8, allowing for substitutability between bank credit and cash-in-advance ayments. Table 2 re orts the results.

Even in this more conservative case, the aggregate im act of the shock is quite large: Y falls by 3.15 ercent. Although the am lification generated by the credit network falls substantially, it is still quantitatively relevant. The credit linkages between industries roduce a larger dro in Y by .54 ercentage oints. Put differently, the credit network of the US accounts for 17.1 ercent of the dro in GDP in res onse to the aggregate liquidity shock. Therefore, even allowing for firms to substitute lost ayments with increased bank borrowing does not substantially diminish the effect of credit linkages in generating aggregate fluctuations. The remainder of the a er uses = :8.

Figure 4:



5.2 Industry-Level Liquidity Shocks

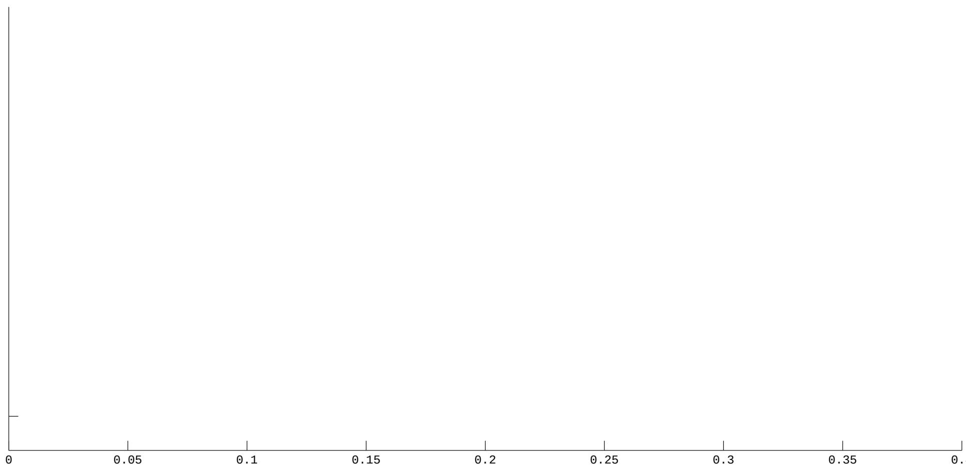
Next, I ask which industries are most systemically im ortant in the economy, and how this relates to their osition in the credit network. I measure the systemic im ortance of industry i by the elasticity of aggregate out ut with res ect to its liquidity B_i.[9] A higher elasticity im lies that an industry-level liquidity shock to i has a larger im act on aggregate out ut.

Figure 4 shows a bar gra h of the five most and five least systemically im ortant industries in the US. The blue bars show the elasiticity of aggregate out ut with res ect to each industry's liquidity, or the ercentage dro in Y following a 1 ercent dro in B_i.

The red bars show the contribution of the full credit network to each elasticity, which is com uted by subtracting the dro in Y that occurs with credit linkage channel shut off, from the total dro in Y. To shut off the credit linkage channel, I im ose that each industry's wedge ${}_i$ changes only in res onse to a direct liquidity shock to that industry, and not endogenously through credit linkages with other industries.

.0 9 ercent of US GDP, a one ercent liquidity shock this industry causes a fall in GDP of .19 ercent, due to its in ut-out ut and credit linkages with other industries. This is an enormous res onse in aggregate out ut. In the absence of any linkages, the elasticity of GDP to this industry's liquidity would be equal to its share of GDP; i.e. GDP would fall by only .0 9 ercent in res onse to this shock. Therefore, the

Figure 5:



industries. On average, increasing the credit out-degree of i's most im ortant su lier increases i's systemic influence by ___ ercentage oints. This is a quantitatively significant effect, indicating that the aggregate im act of an industry-level shock to industry i de ends strongly on how much liquidity i's main su liers rovide to the rest of the economy.

The reason for this was elucidated by the analytical results of the stylized model, and can be understood in two ste s. Su ose industry i ex eriences a liqudity shock to B_i, and su ose that its most im ortant su lier is industry j. First, the liquidity shock to i acts as a su ly shock to each of its M customers, which increases the rice of these customers' goods. This increase in rice increases the collateral value of each customer's out ut. Second, since industry j also su lies goods to these M industries, the increase in collateral value means that j collects cash-in-advance becomes more constrained. Industry j then asses this shock to to the rest of the economy, and so on. The stronger that industry j's downstream credit linkages are with other industries, i.e. the higher its credit out-degree, the stronger this effect is, and the greater the aggregate im act of the shock to B_i. The mechanics of this is ex lained in detail in the A endix using the log-linearized equations.

5.4 Summary of Quantitative Analysis

The quantitative analysis showed that i) the credit linkages between US industries lay a quantitatively how im ortant for the economy its su liers are in roviding credit.

Therfore an understanding of the role that credit linkages lay in ro agating idiosyncratic shocks introduces a new notion of the systemic im ortance of firms or industries based on their lace in the credit network. The effects of these linkages are quantitatively im ortant. Therefore, by overlooking the im ortance of credit linkages between nonfinancial firms, the literature has missed an im ortant determinant of what makes an industry or firm systemically im ortant.

5.5 Aggregate Productivity Shock

Part III

Empirical Analysis

Now that I have established the role that the credit network lays in ro agating shocks, and shown that it can lay a quantitatively significant role in generating fluctuations in aggregate out ut by am lifying

6.1 Data

From the Federal Reserve Board's Industrial Production Indexes, I observe the growth rate in out ut of all affect wedges, but directly affect the the amount of labor em loyed per unit of out ut roduced. The model uses these differential effects to identify the source of fluctuations in observed out ut and em loyment.

To see this, recall the roduction functions, o timality conditions for labor use, and definition of the wedges. First, the em loyment and out ut of an industry are linked by the industry roduction function $x_{it} = z_{it} n_{it}^{\ i} \prod_{s=1}^{M} x_{ist}^{!\ is}$ $^{1\ \ i}$. Therefore, a change in the TFP of industry i is given by

$$\tilde{z}_{it} = \tilde{x}_{it} \quad {}_i\,\tilde{n}_{it} \quad (1 \quad {}_i) \sum_{s=1}^{M} !\,{}_{it}\,\tilde{x}_{ist}$$

The constant returns-to-scale of industry i's roduction function i[illegible] that if an observed change in industry i's out ut $\tilde{x}_{it}$ from eriod $t \quad 1$ to t exceeds that of $n_{it}^{\ i} \prod_{s=1}^{M} x_{ist}^{!\ is}$ [illegible], then there must have been an increase increase in i's TFP such that $\tilde{z}_{it} > 0$.

Industry i's o timality condition for labor equates the ratio of its wage bill to revenue with labor's marginal roduct, times the wedge, i.e. $\frac{wn_{\ i}}{p_i\,x_{\ i}}$ it

6.3 Using the Model to Back Out Shocks from the Data

Recall that equations ()-() are a system of log-linear equations describing the (first-order a roximated) elasiticity of each equilibrium variable to the liquidity B_i and roductivity z_i of each industry i. Su ose that the static model is extended to be a re eated cross-section. Then equations ()-() describe the evolution of the equilibrium variables that occurs each eriod in res onse to liquidity and roductivity shocks, to a first-order a roximation. I obtain a closed-form solution for this evolution, which is derived in the A endix.

Let X_t and N_t denote the M-by-1 dimensional vectors of industry out ut and em loyment growth at time t, $\tilde{x}_{it}$ and $\tilde{n}_{it}$, res ectively. And let B_t and z_t similarly denote the M-by-1 dimensional vectors of industry liquidity and roductivity growth (i.e. shocks) at time t, $\tilde{B}_{it}$ and $\tilde{z}_{it}$, res ectively. The closed-form solutions for X_t and N_t yield

$$X_t = G_X B_t + H_X z_t$$

$$N_t = G_N B_t + H_N z_t$$

These res ectively describe how each industry's out ut and em loyment changes each eriod in res onse to the liquidity and roductivity shocks to every industry. Here, the M-by-M matrices $G_X; G_N; H_X$ and H_N are functions of the economy's in ut-out ut and credit networks and , and ca ture the effects of the in ut-out ut and credit linkages in ro agating either ty e of shock across industries, as was described in the theoretical analysis. The elements of these matrices de end only on the model arameters, and therefore take their values from my calibration.

I construct X_t and N_t for US industrial roduction industries (at the three-digit NAICS level) from the out ut and em loyment data described above. Let $\hat{X}_t$ and $\hat{N}_t$ denote these observed fluctuations. I then have a system of $2M$ equations in as many unknowns for each quarter, and can invert the system to back-out shocks B_t and z_t each quarter from 1997 Q1 to 2013 Q4.

$$B_t = G_N^{1} \quad \hat{N}_t \quad H_N z_t$$

$$z_t = Q \quad ^{1}\hat{X}_t \quad Q \quad ^{1}G_X G_N^{1} G$$

Figure :

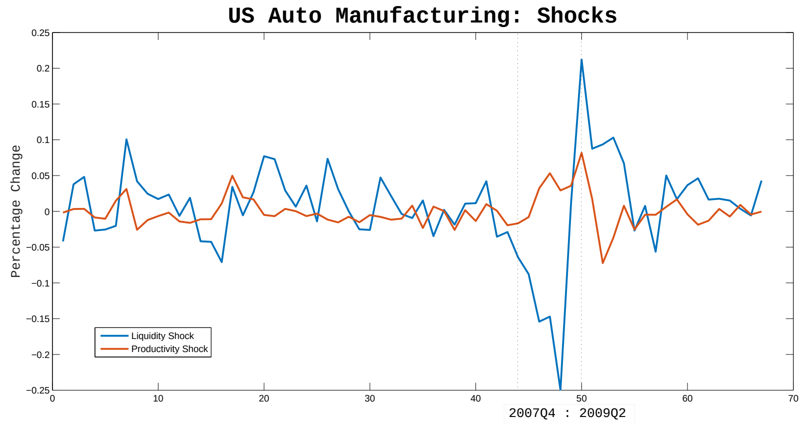


Figure shows the time series of the estimated liquidity and roductivity shocks which hit the US auto manufacturing industry each quarter over the sam le eriod.

From the figure, we can see that the changes in auto manufacturing's liquidity and roductivity both fluctuate moderately around zero for most of the sam le eriod. Between 2007 and 2009, the liquidity available to this industry took a shar dro for a number of consecutive quarters, reaching u to a 25 ercent decline. Over this eriod, the industry's out ut and em loyment ex erienced a large dro attributable to changes in the labor wedge of the industry. Given the credit linkages, the model is able to trace how much of the dro in th ewedge is due to a direct liquidity shock to auto manufacturing versus shocks to other industries being transmitted to it. The blue line lotted in the figure reflect the direct liquidity shocks ex erienced each quarter by the industry.

In addition, the TFP of the industry seems to have not fluctuated greatly over this recessionary eriod; in fact, it increased slightly. These features broadly hold across most industries in industrial roduction. The aggregate effects of these features and their inter retation will be discussed in subsequent sections.

6.4 Dynamic Factor Analysis

Next, I decom ose the changes in industry liquidity and roductivity, B_t and z_t, into an aggregate and industry-level shock. I assume that each may be described by a common com onent and a residual idiosyncratic com onent.

$$B_t = \quad {}_B F_t^B + u_t$$

$$z_t = \quad {}_z F^z_t + v_t$$

Here, F^B_t and F^z_t are scalars denoting the common factors affecting the out ut and em loyment growth of each industry, res ectively, at quarter t. I inter ret these factors as aggregate liquidty and roductivity shocks, res ectively. The M-by-1 vectors ${}_B$ and ${}_z$ denote the factor loadings, and ma the aggregate shocks into each industry's liquidity and roductivity shocks. Together, ${}_B F^B_t$ and ${}_z F^z_t$ com rise the aggregate com onents of B_t and z_t.

The residual com onents, u_t and v_t, unex lained by the common factors, are the idiosyncratic or industry-level shocks affecting each industry's liquidity and roductivity growth. I assume that $F^B_t; u_t$ and $F^B_t; u_t$ are each serially uncorrelated, $F^B_t; u_t; F^z_t;$ and v_t are mutually uncorrelated, and the variance-covariance matrices of u_t and v_t, ${}_{uu}$ and ${}_{vv}$, are diagonal.

I su ose further that the factors follow an AR(1) rocess such that

$$F^B_t = \quad {}_B F^B_{t \quad 1} + \quad {}^B_t$$

$$F^z_t = \quad {}_z F^z_{t \quad 1} + \quad {}^z_t$$

Here, ${}^B_t$ and ${}^z_t$ are inde endently and identically distributed. Hence, I have two dynamic factor models; one for the liquidity shocks B_t and one for the roductivity shocks z_t.

Use standard methods to estimate the model. To redict the factors, I use both a one-ste rediction method and Kalman smoother. The Kalman smoother yields factors which ex lain more of the data. Since it

Figure 7:

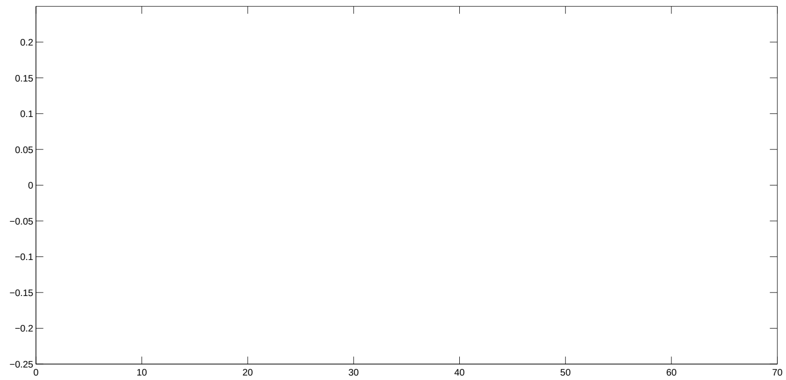
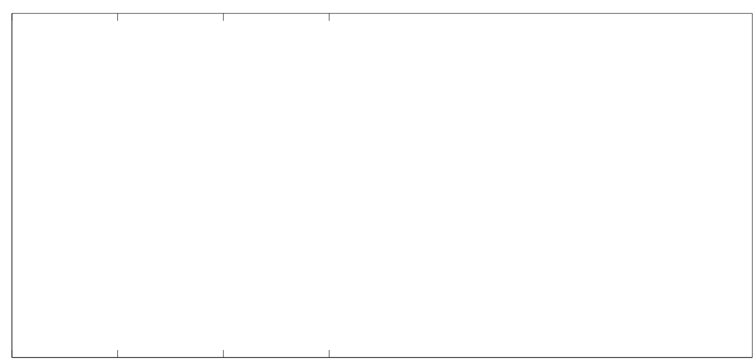


Figure 8:



7 Empirical Results

I now resent and discuss the em irical results using the shocks estimated in the revious sections.

7.1 Aggregate Volatility Over Full Sample Period

In this section, I use the shocks estimated in the revious section to estimate how much of observed volatility in aggregate industrial roduction from 1997Q1:2013Q4 can be ex lained by each ty e of shock. In addition, I estimate the contribution of the credit network of the US industrial roduction industries to aggregate volatility. What follows is a brief summary of the rocedure; a more detailed descri tion is given in the A endix.

7.1.1 Shocks and Aggregate Fluctuations

Let the variance-covariance matrix of industry out ut growth X_t be denoted by ${}_{XX}$. In addition, let s denote the M-by-1 vector of industry shares of aggregate out ut during the median year of my sam le, 2005. Since these shares are close to constant across the quarters in my sam le, the volatility of aggregate industrial out ut - henceforth aggregate volatility - can be a roximated by ^{2}, where

$$ {}^2 \quad s^0 \, {}_{XX} \, s $$

The factor model described above im lies the following identities for the variance-covariance matrices of out ut growth X_t and those of the shocks B_t and z_t.

$$ {}_{XX} = G_X \, {}_{BB} \, G_X^0 + H_X \, {}_{zz} H_X^0 $$

$$ {}_{BB} = {}_B \, {}^B_{FF} \, {}^0_B + {}_{uu} \qquad {}_{zz} = {}_z \, {}^z_{FF} \, {}^0_z + {}_{vv} $$

The fraction of observed aggregate volatility generated by aggregate liquidity shocks can be com uted as the ratio of volatility generated by the aggregate com onent of B_t to ^{2}.

$$ s^0 G_X \, {}_B \, {}^B_{FF} \, {}^0_B \, G_X^0 \, s \quad {}_B \quad {}_{XX} $$

Table 1: Com osition of Agg. Vol.: 1997Q1:2013Q4

	Fraction of Agg. Vol. Explained
Productivity Shocks	.210
Agg. Component	.066
Idios. Component	.144
Liquidity Shocks	.790
Agg. Component	.654
Idios. Component	.136

The results of this analysis are summarized in Table (). I find that, for the full sam le eriod 1997Q1:2013Q4, aggregate volatility in industrial roduction is about 0.19%[12], and is driven rimarily by idiosyncratic ro-

Table 2: Contribution of Credit Network

	Contribution of Credit Network
E ect of Prod. Shocks On Agg. Vol.	.019
E ect of Liq. Shocks On Agg. Vol.	.211
Total Agg. Volatility	.171

the theoretical analysis, the credit network rimarily ro agates liquidity shocks. Indeed, most of the effect of the credit network is in am lifying the aggregate liquidity shock.

7.1.3 Discussion

In summary, the main results of this analysis are that, when taking into account the credit linkages between industries,

1. Aggregate roductivity shocks do not lay an im ortant role in aggregate fluctuations in industrial roduction
2. Aggregate volatility is driven rimarily by idiosyncratic productivity shocks and aggregate liquidity shocks
3. The credit network of the economy lays an im ortant role in am lifying fluctuations in aggregate out ut

How does this com are to the findings of studies? Foerster et al. (2011) show that, when accounting for the effects of in ut-out ut linkages in ro agating shocks across industries, the role of aggregate roductivity shocks in driving the business cycle is diminished; more of aggregate volatility in IP can be ex lained by industry-level roductivity shocks. Nevertheless, they still find a quantitatively large role for aggregate roductivity shocks. On the other hand, my analysis shows that when one takes into account the credit linkages between non-financial firms in the economy, the role of aggregate roductivity shocks is minimal. On the contrary, aggregate liquidity shocks seem to lay a vital role the business cycle. Indeed, the im ortance of shocks emanating from the financial sector to real economy as a whole is well-documented.

7.2 Great Recession

A1. Agency Problem

—

A2. Simple Model Solution

Solved in closed-form recursively, starting with the final firm in the chain, firm M.

Firm M

Recall that firm M collects none of its sales from the household u front (does not give the household any trade credit, \tau_M=0). Then its roblem is to choose its in ut urchases, loan from the bank, and the trade credit loan from M-1, to maximize its rofits, subject to its cash-in-advance, su lier borrowing, and bank borrowing constraints.

$$\max_{n_M\,;x_{M\quad 1};b_M\,;\quad{}_{M\quad 1}} p_M\,x_M \quad wn_M \quad p_{M\quad 1}x_{M\quad 1}$$

$$s{:}t{:}\;\; wn_i + (1 \quad {}_{i\quad 1})p_{i\quad 1}x_{i\quad 1} \quad b_i + \quad {}_{i\quad 1} + p_M\,x_M \quad {}_M$$

$$b_M \quad (B_M + (1 \quad) \;{}_M\,)\,p_M\,x_M$$

$${}_{M\quad 1}p_{M\quad 1}x_{M\quad 1} \quad {}_{M;M\quad 1}p_M\,x_M$$

Recall that the firm does not collect any cash-in-advance from the household, so that its trade credit ${}_M = p_M\,x_M$. Also recall that its borrowing constraints () and () bind in equilibrium, so that the roblem can be rewritten

$$\max_{n_M\,;x_{M\quad 1};\;{}_M} p_M\,x_M \quad wn_M \quad p_{M\quad 1}x_{M\quad 1}$$

$$s{:}t{:}\;\; wn_M + p_{M\quad 1}x_{M\quad 1} \quad {}_M\,p_M\,x_M$$

where

$${}_M = \quad {}_{M;M\quad 1} + B_M$$

Notice that because ${}_M = p_M\,x_M$, ${}_M$ is given by exogenous arameters.

$$w = {}_{M} \quad {}^{M}$$

$$_{M \quad 1} = \; _{M;M \quad 1} + B_M \; + 1 \qquad \frac{_M \, p_M \, x_M}{p_{M \quad 1} x_{M \quad 1}}$$

And () and () im ly that $\frac{p_M \, x_M}{p_{M \quad 1} x_{M \quad 1}} = \frac{1}{_M \, ! \, _{M;M \quad 1}(1 \quad _M)}$. Therefore,

$$_{M \quad 1} = \; _{M;M \quad 1} + B_M \; + 1 \qquad \frac{_M}{}$$

$M;M \quad 1$

$$wn_{M \quad 1} = \quad _M \quad _M \quad _1 \quad _M \quad _1 ! _{M;M \quad 1}(1 \quad _M) p_M x_M$$

Continuing recursively, we can write n_i as a function of x_M, for each i (LEFT OFF HERE)

$$wn_i = p_M x_M @ \prod_{j=i}^{M} \quad _j A @ \prod_{j=i}^{M \quad 1} ! _{j+1;j} (1 \quad _j) A \quad _i$$

The household's references and o timality conditions im ly

$$w = \frac{V^0(N)}{U^0(x_M)} = x_M$$

Let good M be the numeraire. Combining () with () yields a closed-form ex ression for each firm's labor use.

$$n_i = \quad _i \prod_{j=i+}^{M} ! _{j;j \quad 1}(1 \quad _j) \quad _j$$

Recall that the roduction functions im ly that aggregate out ut can be written

Then () and () yield a closed-form ex ression for aggregate out ut.

—

A3. Production In uence Vector

$$v = \begin{bmatrix} v_1 & v_2 & v_3 & & v_M \\ 0 & v_1 & v_2 & & \\ 0 & 0 & v_1 & & \\ \vdots & & & \ddots & \\ 0 & 0 & 0 & & v_1 \end{bmatrix} 1_{M \times 1}$$

v_i=¬ ca tures downstream ro agation (su ly effects). But misses u stream demand effects. Total effect is sum $\sum_{j=1}^{i} v_i$

v07

v2

07

A4. Proof of Proposition 1

Proof: From () (chi de ntion) and () (phi interdependence),

$$_i = \min \quad 1; \ \frac{1}{r_i} \quad B_i + \quad {}_{i;i} \quad {}_1 \qquad {}_{i+1\,;i} \frac{1}{{}_{i+1}\,!\ {}_{i+1\,;i}\,(1 \qquad {}_{i+1})}$$

It follows that

$$\frac{d \quad {}_{i \quad 1}}{d B_i} = \begin{cases} \frac{1}{r_i} \frac{{}_{i;i \quad 1}}{{}_i\,!\ {}_{i;i} \quad {}_1(1 \quad {}_i)} > 0 & \text{if} \quad {}_{i \quad 1} < 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\frac{d \quad {}_j}{d B_i} = 0 \ \ 8 j > i \ \ \text{and} \quad \frac{d \quad {}_j}{d B_i} = \frac{1}{r_i} > 0 \text{ for } j \ = i$$

Putting these cases together, we can write $\frac{d \log \quad {}_j}{d B_i}$ for any j.

$$\frac{d \log \quad {}_j}{d B_i} = \begin{cases} \frac{1}{r_i} > 0 & \text{if } j \ = i \\ \frac{1}{{}_j} \frac{1}{r_j} \frac{{}_{kj}}{{}_k\,!\ {}_{kj}\ (1 \quad {}_k)} \frac{d \quad {}_k}{d B_i} \quad 0 \ 8 k & \text{if } j < i \\ 0 & \text{otherwise} \end{cases}$$

It follows that $\frac{d \log \quad {}_j}{d B_i} \quad 0$ and $\frac{d}{d \quad {}_{ij}} \quad \frac{d \log \quad {}_j}{d B_i} \qquad 0.$

—

A5. Solution Procedure in General Model

Claim: solution rocedure takes same form in general model as in stylized.

Firm i's roblem is to maximize rofits subject to its liquidity constraint.

$$\max_{n_i\,;f\,x_{is}\ g_{s\,I}} \quad p_i x_i \quad w n_i \quad \sum_{s=1}^{M} p_s x_{is}$$

$$w n_i + \sum_{s=1}^{M} p_s x_{is} \qquad {}_i\,p_i\,x_i$$

where $_i$ denotes the tightness of i's liquidity constraint.

—

Use of I-O tables and Com ustat data

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A6. Log-Linearized System

Stars are oint around which system is a roximated. Calibrated equilibrium values.

For all i and j

In order: firm i's o timality condition for in ut j, firm i's o timality condition for labor, definition of wedge hi_i, household o timality condition for consum tion of each good, market clearing for good i, roduction function for firm i, household budget constraint, labor market clearing condition, household o timality for labor versus aggregate consum tion.

$$p_j + x_{ij} = \tilde{}_i + p_i + x_i \qquad w + n_i = \tilde{}_i + p_i + x_i \qquad \tilde{}_i = \begin{cases} \tilde{}_i^{c} & \text{if } {}_i < 1 \\ 0 & \end{cases}$$

Log-linearizing $_i$ yields

$$\tilde{}_i = \begin{cases} \frac{B_i}{r_i \; _i} \tilde{B}_i + \frac{}{r_i \; _i} \sum_{c=1}^{M} \frac{_{ci}}{_c (1 \; _c)! \; _{ci}} \tilde{}_c & \text{if} \; _i < 1 \\ 0 & \text{otherwise} \end{cases}$$

Thus, in the full model wedges res ond endogenously to direct liquidity shocks B_i and to changes in its customers' wedges $_c$

$$\tilde{}_i = \begin{cases} \tilde{}_i^{\,c} & \text{if } \;_i < 1 \\ 0 & \text{otherwise} \end{cases}$$

where

$$\tilde{}_i^{\,c} = \frac{B_i}{r_i \;_i}\tilde{B}_i + \frac{}{r_i \;_i}\sum_{c=1}^{M} \frac{\;_{ci} \;_{ci}}{\;_c(1 \quad _c)! \;_{ci}}\tilde{}_c \quad \frac{}{r_i \;_i}\sum_{c=1}^{M} \frac{\;_{ci} \;_{ci}}{\;_c(1 \quad _c)! \;_{ci}}\tilde{}_{ci}$$

and

$$\tilde{}_{ci} = \tilde{x}_{ci} \quad \tilde{x}_i$$

This ex ression says that industry i's wedge can change either from direct liquidity shock to i (given by $\tilde{B}_i$), changes in the wedges of customers (given by $\tilde{}_i$) through credit linkages $_{ci}$, or changes in the com osition of industry i's sales (given by $\tilde{}_{ci}$ for all customers c), also through credit linkages.

Consider first a liquidity shock to industry j, given by $\tilde{B}_j < 0$. How does this affect $_i$, and how does this effect de end on i's credit linkages with j? From (), we can see that there are two effects. First, the shock reduces $_j$, so that $\tilde{}_j < 0$. This ushes $_i$ down. Second, because i has M customers, x_{ji} falls by more than x_i falls. Therefore, j's share of i's out ut $_{ji}$ falls, and $\tilde{}_{ji} < 0$. This ushes $_i$ u . The stronger is j

small, as discussed in the quantitative analysis.

–

A9. Aggregate Volatility

Recall that the growth in industry out ut can be written as a function of the industry liquidity and ro- ductivity shocks. Recall that X_t is a vector of the ercentage change x_{it} in each industry's out ut at time t.

$$X_t = G_X B_t + H_X z_t$$

And the shocks B_t and z_t, in turn, are com osed of an aggregate and idiosyncratic com onents.

$$B_t = {}_B F_t^B + u_t \qquad F_t^B = {}_B F_{t\ 1}^B + {}_t^B$$

$$z_t = {}_z F_t^z + v_t \qquad F_t^z = {}_z F_{t\ 1}^z + {}_t^z$$

Then letting $_{XX}$ denote the variance-covariance matrix of X_t (and similarly for the other variables), we have

$$_{XX} = G_X \ {}_{BB} G_X^0 + H_X \ {}_{zz} H_X^0$$

$$_{BB} = {}_B \ {}_{FF}^B \ {}_B^0 + {}_{uu}$$

$$_{zz} = {}_z \ {}_{FF}^z \ {}_z^0 + {}_{vv}$$

where $_{uu}$ and $_{vv}$ are diagonal matrices.

Aggregate manufacturing out ut at time t is defined as $_i x_{it}$. Let

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