Financial Linkages and the Global Business Cycle †

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Abstract

Business cycles are positively correlated across countries, yet standard quantitative models can account for a small fraction of this comovement. We examine the role of cross-border financial linkages between firms in driving the global business cycle. We model firms as buyers and suppliers of funding and incorporate their financial linkages into a standard production network model. We then use new data to focus on financial linkages between multinational subsidiaries and their parent companies. We exploit empirical variation in the availability of credit to U.S. multinationals during the 2008-09 crisis to identify the structural parameter in the model that governs international transmission of financial shocks. We find that financial linkages within multinationals account for about a fifth of global GDP comovement. We document substantial heterogeneity in the strength of this mechanism across countries. Our findings imply that countries with the largest foreign multinational presence experience more spillovers from foreign financial shocks, especially from shocks originating in the United States.

JEL Classification: E32; E44; F21; F23; F41; F42; F43; F44

Keywords: Financial linkages, Global business cycle, International comovement, Multinationals, Great Financial Crisis, Global Financial Cycle, Capital flows, Great Recession

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1. Introduction

The world's economies often move in lockstep. Economic growth tends to be positively correlated between countries, especially between economies that trade more and that have deeper financial ties (Frankel and Rose, 1998; Imbs, 2006). Understanding the sources of this comovement is important for assessing the spillover effects of macroeconomic policies. Yet standard quantitative models focusing on trade linkages account for a small fraction of GDP comovement in the data (e.g. Backus et al., 1993; Huo et al., 2019, 2020).

This paper examines the role of financial linkages between firms in driving business cycle comovement. Specifically, we focus on the transmission of financial shocks within multinationals as a new channel of international business cycle transmission. To overcome concerns that comovement of subsidiaries and parent companies is driven by common shocks, we use a natural experiment to estimate the strength of this channel. To this end, we build a new data set and exploit empirical variation in the availability of credit to U.S. multinationals during the 2008-09 crisis to identify the degree to which U.S. parent companies transmit financial shocks to their European subsidiaries. We estimate that the credit crunch at parent companies accounted for a quarter of the drop in output of European subsidiaries during the crisis. We then develop a dynamic multicountry model that we calibrate to these findings. We use the model to quantitatively examine the importance of financial linkages within multinationals for global business cycle comovement. We find that financial linkages within multinationals account for about a fifth of global GDP comovement between 2005 and 2016. We document substantial heterogeneity in the strength of this mechanism: countries with the largest foreign multinational presence experience more spillovers from foreign financial shocks, especially from shocks originating in the United States.

Before focusing on multinationals, we highlight the general importance of cross-border financial linkages for the international transmission of financial shocks. We start off by considering a small open economy framework with both trade and financial linkages in the spirit of Baqaee and Farhi (2019b,a). We introduce a limited enforcement constraint so that firms must seek funding in order to finance their working capital. Both foreign and domestic financial intermediaries can supply these funds. A financial shock that raises financial intermediaries' internal cost of funds thus affects output in another country by raising the cost of working capital for firms with cross-border financial linkages.

We show that, to a first order, the aggregate impact of foreign financial shocks on output in the domestic economy can be captured by the share of funding expenses that the domestic economy spends on funding from abroad.[1] We use data on cross-border financial positions to show that the typical first-order impact of a foreign financial shock on domestic GDP is at least as large through financial linkages as through trade linkages.

Our first-order result is exact only in the special case in which foreign and domestic funding are neither substitutes nor complements. We capture nonlinearities in the pass-through of financial shocks by providing a general second-order approximation. This approximation has a closed form if firms combine different funding sources with a constant elasticity of substitution. However, estimating this elasticity of substitution that governs the strength of transmission requires detailed firm-level microdata. In the rest of the paper, we therefore focus on financial linkages within multinational corporations. Cross-border financial positions within multinationals are sizable, having increased to about one third of global foreign financial liabilities in 2017 (Nardo et al., 2017).

We use exogenous variation in the availability of credit to U.S. multinationals during the 2008-09 crisis to identify the elasticity of substitution between foreign and domestic funding that governs the pass-through of financial shocks from multinational parents to their foreign subsidiaries. We construct a new data set that merges the Dealscan loan database, which contains the borrowing history of firms that have accessed the global syndicated loan market, with output and balance sheet data on U.S. multinationals and their European subsidiaries from Compustat and Orbis. We then compare the change in output at subsidiaries of parent companies that had borrowed before the crisis from relatively healthy financial institutions with otherwise similar subsidiaries of parent companies that had borrowed from lenders more adversely affected by the credit crunch.

We find that the drop in output of subsidiaries of parent companies with a 1 percentage point larger contraction in credit supply was about 0.14 percentage points larger than the decline in sales of otherwise similar subsidiaries. This effect is sizable since it implies that about a quarter of the drop in output of foreign subsidiaries in Europe can be accounted for by the contraction in credit supply of multinational parents during the crisis.

We show that our reduced form results inform an estimate of the elasticity of substitution between a subsidiary's use of foreign and domestic funding. We do this by comparing

[1] This result resembles that of Hulten (1978), who shows that the first-order impact of microeconomic TFP shocks on aggregate TFP is equal to the shocked producer's sales as a share of GDP.

the value of our reduced form estimate with the implied impact if the funding streams are neither substitutes nor complements. In the latter case, a first-order approximation would be exact and the subsidiary's share of funding from its parent would be a sufficient statistic for the impact of a financial shock. Intuitively, we are using the difference between the first-order approximation and our reduced form estimate to infer an estimate of the elasticity of substitution.

We use our findings from the microdata to assess the quantitative importance of financial linkages within multinationals for global shock transmission and output comovement. Our quantitative framework is a rich, dynamic multicountry model with multinational production, international trade, capital accumulation, endogenous labor supply and financial linkages within multinational firms. It nests the production network model that we used to derive first- and second-order output effects of foreign financial shocks. In the model, each country produces a final good by sourcing output from subsidiaries producing intermediate goods. Subsidiaries are subject to a working capital constraint and combine funding from local intermediaries with funding from their parent companies.

In the quantitative model, the local macroeconomic impact of a foreign financial shock is driven by three factors. First, the domestic impact is larger if the financial shock originates in a country that has a strong multinational presence in the domestic economy. We take the corresponding multinational production shares that measure this factor from OECD's Analytical AMNE database (Cadestin et al., 2018). Second, the impact is decreasing in the degree of substitution between domestic and foreign funds, a parameter that we calibrate using our micro-evidence. The third and remaining impact of the shock depends on general equilibrium parameters that we discipline using external micro estimates.

Finally, we highlight the importance of financial linkages within multinationals by using the calibrated model to conduct two quantitative experiments. First, we simulate each economy's response to a set of financial shocks that raise intermediaries' cost of funds in each country, and track the propagation of these shocks abroad. On average, a 1% financial shock in the rest of the world increases the local cost of funding by 0.07%. A financial shock that depresses output in the rest of the world by 1% decreases local GDP by an average of 0.35%. This impact is largest in countries with a large multinational presence. The United States is the most important driver of spillovers through financial linkages. A 1% financial shock in the United States increases the local cost of funding in the rest of the world by 0.03%, while a shock that depresses U.S. output by 1% lowers GDP in the average country by 0.06%. This U.S. effect is more than six times larger than the impact of a financial shock originating in the median country.

Second, we assess the overall impact of financial linkages on business cycle comovement. We compute the counterfactual business cycle correlation between each country-pair assuming that foreign subsidiaries are not financed by their parents. We apply our dynamic framework to data for 25 countries over the period from 2005 to 2016. We extract financial shocks that rationalize data on changes in investment spending. Our implied financial shocks for the United States closely match observed changes in credit spreads, even though we do not target these moments. We also introduce shocks to total factor productivity and costs of international trade and opening a foreign subsidiary, so that our calibrated model matches changes in GDP, trade flows and multinational sales shares. We then solve for a counterfactual in which multinational parents cannot finance their subsidiaries. Without financial linkages, the average pairwise correlation of GDP growth declines by 15 to 20 percent. This effect is particularly large for bilateral correlations of GDP growth with countries that have a large multinational presence, such as the United States. Moreover, financial linkages within multinationals are particularly important in accounting for business cycle correlations of countries in which foreign firms make up a large share of sales, such as the United Kingdom, the Netherlands, and Ireland. For some of these countries, the average growth correlation with other economies decreases by almost 40 % in our counterfactual.

Altogether our findings show that the impact of financial linkages within multinationals on the global business cycle is substantial, accounting for roughly one eighth of observed financial shocks and about a fifth of global output comovement in recent decades. We emphasize the cross-country heterogeneity driving these results. Specifically, the impact of foreign financial shocks is particularly large in countries where foreign subsidiaries account for a large share of economic activity. In addition, financial shocks originating from countries that have a large multinational presence abroad, such as the United States, have a larger impact on foreign output.

Contributions and Related Literature. This paper makes several contributions. First, we advance a new channel of international shock transmission, direct financial linkages between firms, and quantify its importance in multinationals for comovement at the macro level. In contrast to the existing literature (e.g. Kalemli-Ozcan et al., 2013; Cravino and

Levchenko, 2017; Huo et al., 2020), we use empirical variation from a natural experiment to estimate the strength of transmission, thereby overcoming concerns that comovement of connected firms or countries is driven by common shocks.[2] Our reduced form results imply that the higher cost of funding of U.S. multinationals accounted for a substantial fraction of the drop in output of foreign subsidiaries during the 2008-09 financial crisis. We estimate that this transmission channel is responsible for a substantial fraction of output comovement between the world's major economies in the last two decades.

Our findings complement the recent empirical literature on the Global Financial Cycle that documents that a tightening of global financial conditions tends to precede a fall in cross-border capital flows and a decline in foreign economic activity.[3] Our model and empirical results imply that these patterns are partially driven by financial linkages within multinationals. Our findings are also consistent with the fact that global GDP comovement tends to spike shortly after periods of financial distress (IMF, 2013).[4]

Second, we contribute to the literature that uses microdata to study the role of firms in propagating aggregate and idiosyncratic shocks (e.g. Barrot and Sauvagnat, 2016; Huber, 2018; Benmelech et al., 2019). A key innovation of this paper is to build a unique data set that links information on foreign subsidiaries and their U.S. parent companies. We use this data set to provide the first evidence of how U.S. multinationals served as a conduit for transmitting the 2008-09 financial shock to their foreign subsidiaries. In contrast to studies that focus on firm-to-firm linkages in goods markets (e.g. Boehm et al., 2019), we examine a financial shock that indirectly affects the performance of foreign firms through ownership linkages.

Finally, we add to a literature on the role of economic networks in propagating shocks (Gabaix, 2011; Acemoglu et al., 2012; Bigio and La'O, 2016; Liu, 2019; Baqaee and Farhi, 2019a,b, among others). While this literature focuses on the role of *trade* linkages in production networks, we study the role of *financial* linkages in transmitting shocks across

[2]Existing papers study the role of international trade (e.g. Backus et al., 1993; Huo et al., 2020), technology transfer within multinationals (e.g. Cravino and Levchenko, 2017) and integration of financial markets (e.g. Kalemli-Ozcan et al., 2013; Perri and Quadrini, 2018; Devereux and Yu, 2020) in accounting for comovement and spillovers.

[3]Miranda-Agrippino and Rey (2020) provide a summary of these patterns. Other papers that study the Global Financial Cycle include Passari and Rey (2015), Rey (2015), Dedola et al. (2017), Erik et al. (2019), and Amiti et al. (2019).

[4]In particular, global output comovement spiked after the Latin American debt crisis in the mid-1980s, the 1987 stock market crash, the early 1990s recession, the Exchange Rate Mechanism crisis in 1992, the emerging market crises of the 1990s, the dot-com bust in 2000, the 2008-09 Global Financial Crisis, and the European debt crisis in 2012.

countries. Our theoretical results highlight the importance of considering nonlinearities in the pass-through of financial shocks and emphasize the importance of microeconomic elasticities of substitution for the exact impact of foreign financial shocks on domestic output.

The rest of this paper is organized as follows. Section 2 incorporates between-firm financial linkages into a standard production network model and derives first- and second-order effects of foreign financial shocks on domestic output. Section 3 describes the microdata and documents transmission of financial shocks within U.S. multinationals during the 2008-09 Great Financial Crisis. Section 4 develops a quantitative framework to study the macro implications of financial linkages within multinationals for global business cycle comovement. Section 5 provides conclusions, policy implications and suggestions for future research. We cover additional literature, data and model details, as well as replication exercises in the Online Appendix, available on marijnbolhuis.info.

2. A Macro Framework with Between-Firm Financial Linkages

In this section, we introduce our concept of between-firm financial linkages. We incorporate these linkages into a standard small open economy framework with international trade, and derive sufficient statistics that capture the impact of external financial shocks on domestic GDP.

2.1 Framework

Environment. We consider a small open economy n with a representative household that exogenously supplies a composite production factor $\bar{L}$ and consumes a numeraire final good. A representative domestic firm produces a final good which also serves as an intermediate input.[5] The firm can import foreign intermediate goods from countries $i \in \{n+1, .., N\}$ at exogenous prices $\bar{P}_i$.

Production. The representative firm produces gross output Y^G:

[5] In the Appendix, we generalize the framework to include inter-sectoral input-output linkages.

$$Y^G = zF(L; x_n, ..., x_N) \tag{1}$$

where x_n and $\{x_i\}_{i=n+1}^N$ denote quantities of domestic and foreign intermediate goods ('imports'). We assume $F(\cdot)$ is continuously differentiable, increasing and concave in all arguments, and exhibits constant returns to scale with respect to the factor and the domestic intermediate good. z is a Hicks-neutral productivity shifter.

The producer faces a working capital constraint. It must pay its input costs upfront.[6] Since sales are realized at the end of the period, the firm must finance working capital using external funding. In doing so, it faces an effective cost of working capital $u \geq 1$. The cost-minimization problem of the representative firm is:

$$P \equiv \min_{L;x_n,..,x_N} u(wL + Px_n + \sum_{i=n+1}^{N} \bar{P}_i x^i) \quad s.t. \quad zF(L; x_n, .., x_N) = 1 \tag{2}$$

where P is the market price of the domestic good, which will we use as the numeraire. w is the price of the composite factor.

Financing. We allow for financial linkages between firms, but assume financial autarky on part of the household.[7] Financial intermediaries supply working capital funding. Let $r_{n'}$ denote the (gross) rate at which an intermediary in country i can supply funding. Crucially, we allow for the possibility that the domestic representative firm can be financed by a foreign intermediary.[8]

As is standard in the corporate finance literature (e.g. Shapiro, 1978; Auerbach, 1979), the firm faces a two-step financing problem. First, it chooses the amount of funding from each intermediary $\{b_{n'}\}$ that minimizes the weighted average cost of capital (WACC), which we denoted above by u. Second, they maximize profits by choosing the optimal level of working capital. As a first step, the firm solves

[6]This friction naturally arises from a hold-up problem if the firm cannot commit to paying its input costs after sales have been generated (e.g. Neumeyer and Perri, 2005; Liu, 2019; Chodorow-Reich, 2014).

[7]Other papers that adopt the financial autarky assumption include Corsetti et al. (2008), Ruhl et al. (2008), and Huo et al. (2020), among others. We know from the international business cycle literature that models with financial autarky outperform (in)complete markets models in accounting for comovement of output, consumption, and factor demand (Heathcote and Perri, 2002; Imbs, 2006). Moreover, models with complete markets imply the qualitatively counterfactual result that a high trade intensity is associated with a lower business cycle correlation (e.g. Kose and Yi, 2001).

[8]We can extend this to the case of intra-sector financing, to which all the results developed in this section apply.

$$u \equiv \min_{b_n,..,b_N} \sum_{n'=n}^{N} r_{n'} b_{n'} \quad s.t. \quad 1 = G(b_n, .., b_N) \tag{3}$$

$G(\cdot)$ is a function that determines the amount of funding that can be used for working capital given the funding structure. For now, we assume that $G(\cdot)$ is continuously differentiable, increasing and concave in all arguments, and exhibits constant returns to scale. We thus allow for the possibility that different funding suppliers are imperfect substitutes, generating a deadweight loss relative to perfect capital markets that is borne by the buyer of funding. Like Kaplan & Zingales (1997), we are agnostic on whether the wedge between u and the WACC that would arise under perfect capital markets is caused by information asymmetries, as in (e.g. Myers and Majluf, 1984; Greenwald et al., 1984), agency problems (e.g. Jensen and Meckling, 1976; Grossman and Hart, 1982), or risk aversion (e.g. Hellwig, 2000).[9] Instead, we represent this additional cost of external funds in a reduced form using $G(\cdot)$.

The Production of Funds. Lenders receive interest payments and are not constrained by an aggregate supply of funds. However, they incur an exogenous cost $\bar{r}_n$ for each unit of funds created, making zero profits:

$$r_n = 1 + \bar{r}_n \tag{4}$$

Interest rates $r_{n'}$ are thus exogenously determined. We interpret these as corporate credit spreads (or external finance premia) that reflect changes in the health of financial intermediaries that are determined outside the corporate sector. For accounting purposes, we assume that these costs are in the form of disutility of the final good (Liu, 2019). We define the domestic deadweight loss:

$$\Pi \equiv \bar{r}_n b_n \tag{5}$$

Measurement of GDP. By definition, GDP Y in this economy equals gross output net of the deadweight loss from funding and expenses on the domestic intermediate good, represented by the accounting identity:

[9]In all cases, we can think of each lender demanding the firm not to invest all of its funding stream in working capital and this requirement becoming stricter as the relative size of the individual funding stream increases.

$$Y \equiv Y^G - \Pi - x_n \tag{6}$$

Household. The representative household spends factor income on consumption C:

$$C = w\bar{L} \tag{7}$$

Current Account. The domestic economy exports its final good to pay for the imported intermediate goods and for funding services from foreign financial intermediaries. In steady state, the current account is in balance, implying:

$$Y = C + \sum_{i=n+1}^{N} r_i b_i + \sum_{i=n+1}^{N} \bar{P}_i x_i \tag{8}$$

where the left-hand side represents income of the domestic economy, and the right-hand side covers expenditures on consumption, foreign financial services, and imports.

Equilibrium. Given fundamentals $\{\bar{P}_i\}_{i=n+1}^N, \bar{L}, z, \{\bar{r}_{n'}\}_{n'=n}^N$, an equilibrium is a collection of prices $P, w, \{r_{n'}\}_{n'=n}^N$, allocations $L, \{x_{n'}, b_{n'}\}_{n'=n}^N, Y, C, Y^G$, and quasi-rents Π such that (i) the representative firm picks $L, \{x_{n'}, b_{n'}\}_{n'=n}^N$ to solve cost-minimization problems in (2) and (3); (ii) intermediaries maximize profits such that the zero-profit condition (4) holds; (iii) C satisfies the consumer budget constraint (7), (iii) the accounting identity (6) holds; (iv) the current account is balanced (8) and (v) the factor market clears such that $L = \bar{L}$.

Summary. This model is a constant-returns-to-scale, non-parametric general equilibrium production network perturbed by fundamentals in the forms of productivity shifters and financial frictions. In the absence of financial linkages, the model is a version of the multi-country general equilibrium model in Baqaee and Farhi (2019b). It can also be seen as a generalization of the parametric input-output model in Jones (2011). Without trade and financial linkages, the model collapses to that of Liu (2019), which itself can be seen as a special version of the general model presented in Baqaee and Farhi (2019b). The network model in Acemoglu et al. (2012) is a parametric version of the latter. With endogenous labor supply, Cobb-Douglas production and no trade, our framework is similar to that of Bigio and La'O (2016).[10]

This is a stylized model that generates the linkages of interest in this paper. We can

[10]A key difference is the treatment of the financial frictions. This paper and Liu (2019) assume frictions create a deadweight loss that leaves the economy through the consumption good, whereas Bigio and La'O (2016) assume that producers incur these costs and rebate them to the household.

enrich the framework in several ways, and will do so when we bring the model to the data in the quantitative section.

2.2 First-Order Effects

The goal of the theory is to derive a set of empirical objects that capture how foreign financial shocks affect output of the domestic economy. For proofs, see Appendix section A.2.1.

Notation and Definitions. We start this section with some notation and definitions that will be useful when presenting the results. Let σ_x be the equilibrium production elasticity of the domestic intermediate input

$$\sigma_x \equiv \frac{\partial \ln F(\cdot)}{\partial \ln x_n} \tag{9}$$

Similarly, let σ_i be the equilibrium production elasticity of the foreign intermediate input

$$\sigma_i \equiv \frac{\partial \ln F(\cdot)}{\partial \ln x_i} \tag{10}$$

We define the input-output multiplier of the domestic economy ι as

$$\iota \equiv \frac{1}{1-\sigma_x}$$

Let $\lambda \equiv [\lambda_i]$ be the $N \times 1$ vector with shares of funding expenses on funding from country i:

$$\lambda_i \equiv \frac{r_i b_i}{\sum\limits_{n'=1}^{N} r_{n'} b_{n'}}$$

In the rest of the paper, we will refer to λ as the vector of *funding shares*.

We are now ready to derive our first-order effects. First, we show that financial frictions manifest themselves as output wedges for the domestic producer by raising input costs.

Lemma 1 *(Output wedge)*

The financing constraint acts as an output wedge, i.e. for any equilibrium allocation, *there exists a function τ such that*

$$(1-\tau) = \frac{1}{u}$$

and the representative firm effectively produces

$$Y^G = z(1-\tau)F(\cdot)$$

The lemma follows naturally from the assumption that all inputs face the same working capital constraint, and a shock to the cost of working capital thus acts as an input-augmenting productivity shock. The lemma is useful to the extent that, in the rest of this section, external financial shocks manifest themselves as TFP shocks to the domestic producer. At the aggregate level, the effect of TFP shocks on output depends on the input-output multiplier.

Lemma 2 *The first-order impact of a domestic productivity shock on output of the domestic economy is given by:*
$\frac{d\ln Y}{dlnz} = \iota$

The input-output multiplier is thus a sufficient statistic for how output responds to TFP shocks. Loosely speaking, it captures a notion of returns-to-scale at the aggregate level. As production elasticities determine how changes in one price affect another, ι captures the direct effect of a TFP shock through consumption and the general equilibrium effects on factor income through the domestic intermediate good. We are now ready to discuss an extension of this lemma, capturing the first-order impact of an external financial shock on output.

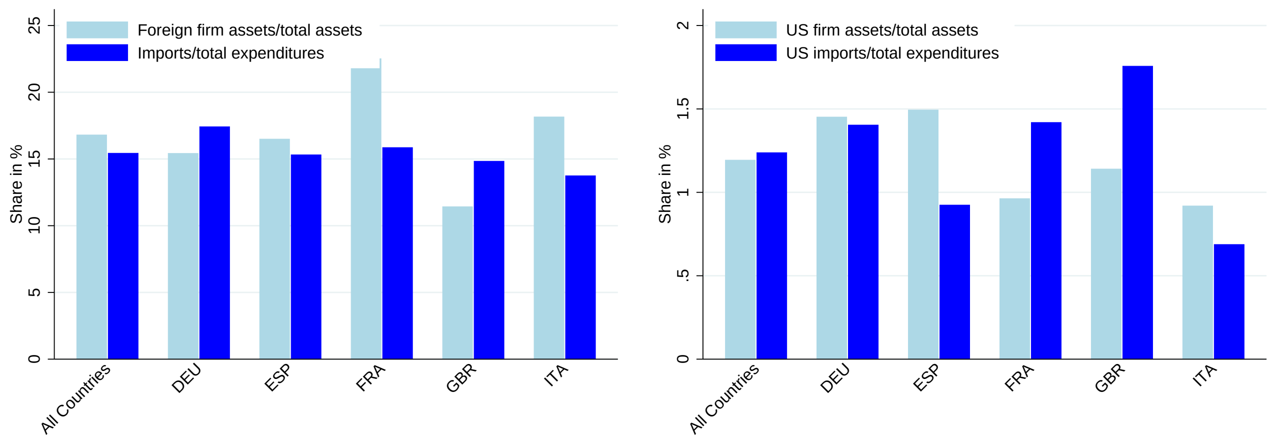
Proposition 1 *(Financial Hulten)*

The first-order impact on real GDP of the domestic economy resulting from a financial shock to country i is given by:

$$\frac{d\ln Y}{d\ln r_i} = -\iota[\lambda_i + \sigma_i]$$

This result highlights the two channels through which an external financial shock affects domestic output. The impact of financial linkages is increasing in the share of funding financed by the country impacted by the shock (λ_i) and in the elasticity of domestic

Figure 1 Funding Shares and Import Shares for Selected European Countries



Notes: The left figure plots foreign funding shares and import shares for the 5 largest European economies in 2015. Light blue bar plots the share of total firm assets owned by foreign entities in Orbis. Dark blue bar plots the share of foreign bank liabilities as a share of total bank liabilities in the BIS Locational Statistics. The dark bar plots imports as a share of total sales in Activities of Multinational Enterprises (AMNE). The right figure plots these same shares but for the US only.

output with respect to imports from that same country. Proposition 1 shows that, up to a first-order, knowledge of cross-border financial flows and production elasticities are sufficient to capture the impact of an external financial shock on domestic output. These sufficient statistics are nonparametric in the sense that, in order to construct the output impact of an external financial shock, one does not need to specify structural properties of $F(\cdot)$, $F_j(\cdot)$ or $G(\cdot)$. All that's necessary is knowledge of ι, λ_i, and σ_i which are all reduced-form objects in the local equilibrium that are, in principle, observable.

The proposition provides three takeaways. First, the impact of an external financial shock is larger when the domestic economy is more dependent on financing or imports from country i. Second, this impact is magnified by the input-output multiplier. Finally, to empirically examine the impact of an external financial shock, it is necessary to have data on bilateral cross-border financial flows that can construct λ_i, as well as input-output and trade data that can be used to construct ι and σ_i.

2.2.1 Quantitative Example

How large are these first-order effects in practice? We now develop an illustrative quantitative application of our results to gauge the first-order importance of financial linkages relative to trade linkages. We can construct the first-order impact of foreign financial shocks using data on the foreign financial positions of non-financial firms, as well as international input-output data. We plot the corresponding shares for the largest five European economies in Figure 1. Across the board, our proxy for financial linkages (the share of firm assets owned by foreign companies) is at least as large as our proxy for trade linkages (imports as a share of total expenses).

2.3 Higher-Order Effects

Proposition 1 shows how to construct perturbations to aggregate GDP growth from financial shocks. It also provides a benchmark answer for counterfactual questions in structural models with international financial and trade linkages. This result is surprisingly general. After all, if ι, λ_i and σ_i can be constructed using directly observable data, then we need not concern ourselves with the details of the underlying microeconomic system that gave rise to these data.

It is key to recognize that Proposition 1 only provides a first-order approximation. It is well-known that nonlinearities can significantly degrade the quality of a first-order approximation for large enough shocks (Baqaee and Farhi, 2019b). To capture these nonlinearities, we provide a general second-order approximation by characterizing the derivatives of the funding shares λ_i with respect to external financial shocks. In principle, the higher-order terms are shaped by the microeconomic details of firms' production and financing structure. To highlight our result, we restrict ourselves to an environment in which the production function $F(\cdot)$ is Cobb-Douglas. This assumption ensures that the higher-order effects capture financial linkages only.[11]

Proposition 2 *The second-order impact on real GDP of the domestic economy resulting from a financial shock in country i is given by:*

$$\frac{d^2 \ln Y}{d \ln(r_i)^2} = \iota \frac{d\lambda_i}{d \ln r_i} = \iota \lambda_i \sum_{n' \neq i}^{N} \lambda_{n'} \frac{d \ln \lambda_{n'}/\lambda_i}{d \ln r_i}$$

The second-order impact of a financial shock in country i is equal to the change in the funding share of country i scaled by the input-output multiplier. This change depends on how relative funding shares respond to the financial shock, which depends on the reduced-form elasticities of substitution $\frac{d \ln \lambda_{n'}/\lambda_i}{d \ln r_i}$ between different sources of funding. The fund-

[11] In the Online Appendix, we provide a general derivation of the second-order effects.

ing shares λ_i, the input-output multiplier ι and these elasticities form sufficient statistics for the second-order response of domestic output to a foreign financial shock. This result implies that the first-order approximation in Proposition 1 is globally accurate if the reduced-form elasticities are unitary ($\frac{d \ln \lambda_{n'}/\lambda_i}{d \ln r_i} = 1$ for every $n' \neq i$), which is the case if $G(\cdot)$ is Cobb-Douglas.

Outside of the special Cobb-Douglas case, there are nonlinearities in pass-through, and the quality of the first-order approximation deteriorates as the size of the financial shock increases. We can illustrate this using a tractable and natural form of $G(\cdot)$, the standard constant elasticity of substitution function (CES). In this case the WACC becomes:[12]

$$u^{CES} = [\sum_{n'=n}^{N} \zeta_{n'} (r_{n'})^{1-\phi}]^{1/(1-\phi)}$$

where $\{\zeta_{n'}\}$ are parameters that reflect access and effectiveness of funding sources from different countries. $\phi \geq 0$ is the elasticity of substitution between sources of funding. This form nests two extreme cases that are common in the literature that models financial frictions. First, if the sources of funding are perfect substitutes, the model converges to one with perfect capital markets. In this case, the WACC becomes:

$$\lim_{\phi \to \infty} u = \min_{n'} \{r_{n'}\}$$

Second, if the sources of funding are perfect complements, the WACC reads:

$$\lim_{\phi \to 0} u = \sum_{n'=n}^{N} \zeta_{n'} \cdot r_{n'}$$

In this instance, the model converges to a case in which firms always use the same mix of funding, regardless of the cost of individual funding streams.[13] With $G(\cdot)$ CES, we can work out the closed form of the second order approximation:

Corollary 1 *If $G(\cdot)$ is CES with elasticity of substitution ϕ, the second-order approximation of the impact on real GDP of the domestic economy resulting from a financial shock to coun-*

[12]See Appendix section A.2.2 for the derivation.

[13]This case delivers a cost of funding similar to that in models with a collateral constraint (e.g. Banerjee and Newman, 2003; Buera and Shin, 2013; Moll, 2014). To see this, consider the case of a firm subsidiary that has access to an exogenous amount of collateral E at shadow price r^E, which it can lever up using external debt D financed at price r^D. The collateral constraint is $D/(E + D) \leq \ell$. If the constraint binds, the effective cost of funding is $\ell r^D + (1 - \ell) r^E$.

try i is given by:

$$\frac{d\ln Y}{d\ln r_i} + \frac{d^2 \ln Y}{d\ln(r_i)^2} = -\iota[\lambda_i - \lambda_i(1-\lambda_i)(\phi - 1) + \sigma_i]$$

Corollary 1 shows that when funding streams are complements ($\phi < 1$), the second-order terms amplify the negative output effect of financial shocks relative to the first-order approximation. Instead, when funding streams are substitutes, the second-order approximation attenuates the effect of financial shocks as the representative firm substitutes away from the affected intermediary.

Constructing higher-order effects requires detailed microdata. In the rest of the paper, we therefore focus on financial linkages within multinational corporations. In the next section, we first use exogenous variation in the availability of credit to US multinationals during the 2008-09 crisis to identify ϕ, which governs the pass-through of financial shocks from multinational parents to their foreign subsidiaries.

3. Using Microdata to Estimate International Transmission of Financial Shocks

In this section, we provide micro-evidence of the transmission of financial shocks through financial linkages of US multinationals during the 2008-09 crisis. We show that our reduced form results inform an estimate of the degree to which subsidiaries can substitute funding from their parent with local funds.

3.1 Data and Descriptive Evidence

Data. One of the innovations of this article is to link data sets on US multinationals, their foreign subsidiaries, and their borrowing activity to observe the transmission of financial shocks from parent to subsidiary. We briefly summarize how we connect these data sets here, and refer the reader to the Online Appendix for extensive details on data selection, cleaning, and variable definitions.

Our data on subsidiaries come from Orbis, a large cross-country database maintained by Bureau van Dijk. This data set contains information on listed and unlisted firms, mainly collected from national registries and annual reports. What sets Orbis apart for our analysis is that it contains information on the 'global ultimate owner' of a large number of firms. We specify that the 'parent' of a firm should own at least 50% of the affiliate. Our main variable of interest from Orbis is the total sales (turnover) of each subsidiary.

We merge the data on subsidiaries with balance sheet data of US multinationals in Compustat. As there is no formal identifier to link firms in the two data sets, we use a fuzzy matching algorithm instead.

As a last step in our data merging process, we match the multinationals in Compustat with information from Dealscan on their participation in the global syndicated loan market. Dealscan collects loan-level information on syndicated loans from Securities and Exchange Commission (SEC) filings, company statements, and media reports, and the purpose of the data set is to represent the universe of such loans (Chodorow-Reich, 2014). Each loan contains information on the identities of the borrower and lenders, the terms, and the purpose of the loan.

Descriptive Evidence. Our final sample contains about 300 US multinationals that account for roughly 15 % of employment and sales in Compustat in 2008. Panel A of Table

1 presents the corresponding summary statistics. On average, multinationals in Orbis are substantially larger, in terms of sales and employment, than other public firms in Compustat, which is in line with evidence on the pecking order of productivity among firms (Helpman et al., 2004; Yeaple, 2009). Of those, multinationals that are also in Dealscan are even larger, which is in line with empirical evidence that larger firms are more likely to issue debt in the public market, including the syndicated loan market (Denis and Mihov, 2003; Altunbaş et al., 2010).

Foreign subsidiaries, and especially those with owners residing in the US, account for a large share of economic activity among European firms in Orbis. Panel B of Table 1 summarizes the economic activity of registered firms in the European countries in Orbis. Foreign subsidiaries form 45 % of sales, and 38 % of employment. Among firms with at least 5 employees, US subsidiaries form less than 1 %, but they account for 5 % of sales, and 4 % of employment, respectively.

3.2 Identification

3.2.1 Strategy

Ideally, we would like to study how an observed change in the cost of capital of a multinational parent ω affects economic activity of its subsidiary abroad. We index the country of origin of the owner by o, and the country of production of the subsidiary by x. Formally, write (log) sales s as a function of the cost of capital u, a vector of observable characteristics $X^{ob.}$, unobservable characteristics $X^{un.}$ and an unobserved idiosyncratic component uncorrelated with the other variables:

$$\ln s^{\omega}_{ox} = f(u^{\omega}_{ox}, X^{ob.\omega}_{ox}, X^{un.\omega}_{ox}, \epsilon^{\omega}_{ox}) \tag{11}$$

We assume the subsidiary uses only funds provided by the local intermediary in country x and its parent in country o. Let $r_{\omega,o}$ denote the cost of funding of the parent. We incorporate the local cost of funding in $X^{un.\omega}_{ox}$

$$u^{\omega}_{ox} = g(r^{\omega}_{o}, X^{ob.\omega}_{ox}, X^{un.\omega}_{ox}, \eta^{\omega}_{ox}) \tag{12}$$

where η^{ω}_{ox} is an unobserved idiosyncratic component uncorrelated with the other variables. Under the assumptions of (i) statistical independence between $X^{un.\omega}_{ox}$ and r^{ω}_{o}, (ii) separability of $f(\cdot)$ between its first two and second two arguments, equations (11) and (12) can be estimated using the generalized method of moments, with the moment condition

$$E[(\ln s_{ox}^{\omega} - f(u_{ox}^{\omega}, X_{ox}^{ob.\omega}, 0, 0)) \cdot r_o^{\omega}] = 0$$

Unfortunately, we cannot follow this approach, because we do not directly observe r_o^{ω}. Instead, we need an observable shifter M_o^{ω} that satisfies $Corr(r_o^{\omega}, M_o^{\omega}) \neq 0$ and statistical independence with respect to $X_{ox}^{un.\omega}$. With such a shifter in hand, we can consistently estimate:

$$\gamma = \frac{df(\cdot)}{du_{ox}^{\omega}} \frac{du_{ox}^{\omega}}{dr_o^{\omega}} \frac{dr_o^{\omega}}{d\ln M_o^{\omega}}$$

Our setup thus requires (a) a large exogenous shock to r_o^{ω}, indirectly observed using a shifter M_o^{ω}), with (b) exogenous differential treatment across firms. We will now outline the quasi-natural experiment that we use for identification.

3.2.2 The Experiment

The 2008-09 global financial crisis had its origins outside the corporate sector. The collapse of the U.S. housing market led to large writedowns on bank's mortgage portfolios, culminating in an extended period of stress in short-term funding markets. This stress increased banks' cost of funding, especially for those more reliant on these markets. As a result, banks cut down on lending, including to their corporate clients. We summarize the origins of the crisis in more detail below.[14]

The crisis is particularly useful to study financial linkages within multinationals, for several reasons. First, the crisis led to a large aggregate shock to firm's cost of capital. In the US, the average credit spread on senior unsecured bonds issued by nonfinancial firms increased to almost 8 percentage point at the height of the crisis (Gilchrist and Zakrajšek, 2012). In contrast, during the unwinding of the dot-com bubble, this credit spread peaked at 4 percentage points. Second, during the 2008-09 crisis there was ample cross-sectional variation across firms, making a between-firm comparison possible. Bank-firm relationships tend to be sticky in the short-run and firms connected to banks more reliant

[14]For a full overview of the global financial crisis, see the review articles by Brunnermeier (2009), Mishkin (2011), and Gertler and Gilchrist (2018).

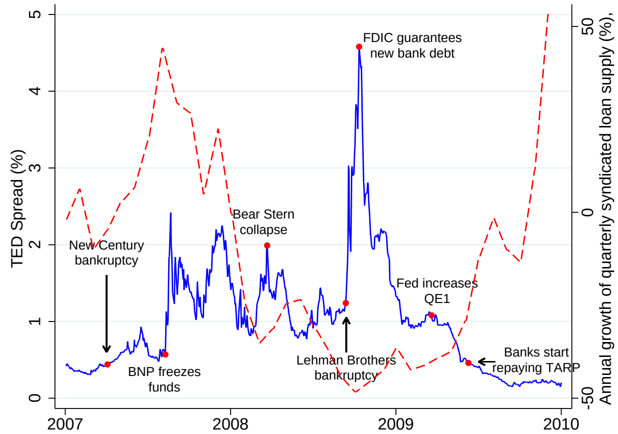
on short-term funding thus experienced a larger credit supply shock. Third, the crisis had its origins in the U.S., directly affecting the cost of capital of U.S. parent companies but leaving European firms initially unexposed. The combination of exogenous intertemporal and cross-sectional variation in financing conditions allows us to study the pass-through of a financial shock from parents to subsidiaries while keeping constant both time-varying and firm-specific factors.

Time line. The countrywide fall in US housing prices led to first signs of distress in financial markets in the summer of 2007, snowballing into a panic after the bankruptcy of Lehman Brothers in the fall of 2008. In April 2007, New Century, a real estate investment trust specializing in subprime lending and securitization, filed for bankruptcy. Two months later, financial markets started to show the first strains when Bear Stearns was forced to bail out two of its hedge funds with exposure to subprime mortages through investments in collateralized debt obligations. In early August, BNP Paribas blocked withdrawals from three of its hedge funds, sparking the first substantial rise in interbank borrowing costs (Figure 2). After months of writedowns on subprime portfolios, the unwillingness of short-term funding markets to provide funds to Bear Stearns forced its sale to J.P. Morgan in March 2008. Financial conditions stabilized over the summer, but worsened sharply in September 2008 after Lehman Brothers was unable to obtain short-term financing. Its bankruptcy led to a widening of credit spreads and a cascade of events, including the bailout of AIG, freezing of short-term lending markets, and the bankruptcy of Washington Mutual. It was only when congress had passed TARP and the FDIC had guaranteed newly issued senior debt of all FDIC-insured institutions did the stress in the interbank lending market begin to ameliorate.

The major corporate failures during the crisis were a direct consequence of exposure to the mortgage and short-term funding markets. On the asset side of their balance sheet, Bear Stearns, BNP Paribas, Lehman Brothers, Washington Mutual and AIG - all had aggressively gained exposure to mortgage securities, leading to large losses in the run-up to the crisis. On the liability side, many institutions, including Lehman, relied heavily on short-term financing, leaving the firms vulnerable to a freeze in short-term funding markets (Gorton and Metrick, 2012). Between late 2007 and 2009, banks' outstanding liabilities in short-term funding markets declined by 25 % (Figure 3(a)).

The mortgage-related asset writedowns and associated reduction in short-term funding availability led to an increase in the internal cost of funds and a large fall in banks'

Figure 2 Credit Spread and Crisis Time line



Notes: On left axis, blue line plots the TED spread (3-month LIBOR minus 3-month US Treasury bill) over time. Data from FRED. On right axis, dashed red line plots the annual growth of quarterly new loans in the syndicated loan market. Data from Dealscan. For a detailed time line of the crisis, see Lybeck (2011).

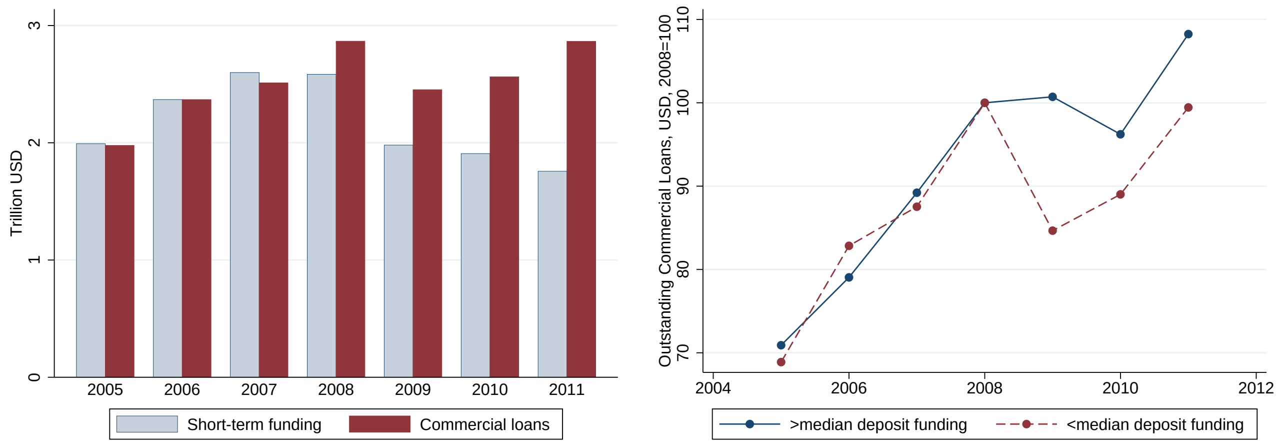
supply of loans. The freeze of short-term funding markets tightened banks' funding constraints, thereby increasing the internal cost of funds. Both the fall in equity from write-downs and the lack of access to short-term funding naturally decreased banks' loan supply. It is therefore not surprising that the 15 % fall in outstanding corporate loans between 2008 and 2009 (Figure 3(a)) was mainly driven by banks more reliant on funding in short-term markets (Figure 3(b)).

As bank-firm relationships tend to be sticky in the short-run, reductions in bank-specific credit availability gave rise to an increase in the cost of capital of US firms. It is well-known that firms tend to stick to their bank, even during a crisis, leading to differential performance depending on the health of the bank (e.g. Khwaja and Mian, 2008; Amiti and Weinstein, 2011)).[15] Indeed, Chodorow-Reich (2014) estimates that the withdrawal of corporate credit in the U.S. syndicated loan market accounts for a substantial share of the U.S. employment decline during the crisis.[16]

[15]Other papers that use bank-firm relationships to estimate the effect of credit shocks include, among others, Chodorow-Reich and Falato (2017), Ridder (2017), Popov and Rocholl (2018), Manaresi and Pierri (2019), and Alfaro et al. (2019).

[16]Moreover, Campello et al. (2010) use survey data to show that financially constrained firms planned to cut more investment and production inputs at the height of the crisis. Duchin et al. (2010), Almeida et al. (2012) and Siemer (2019) use firm-level data to show that financially constrained firms reduced investment and employment more during the crisis.

Figure 3 Short-Term Funding Markets and Corporate Loan Supply



Notes: The left figure plots total short-term funding and commercial loans on balance sheets of US banks between 2005 and 2011. Right figure plots outstanding commercial loans over time for banks with more or less than the median share of funding from customer desposits. Data from FitchConnect.

3.2.3 Measuring Loan Supply

We use data on the U.S. syndicated loan market for our measure of firm-specific credit supply, which we use as a shifter of the cost of funding of US multinational parents.[17] Figure 2 shows that over time, the growth of newly supplied loans in the syndicated loan market was negatively correlated with the US credit spread. At the time of the Lehman Brothers bankruptcy, supply was down by 50% compared to a year earlier. Figure A.1 in the Appendix documents that syndicated loan supply closely tracked foreign direct investment by US multinationals.

We construct our measure of credit supply to each parent firm as the weighted average of loan supply of all lenders of the last pre-crisis loan syndicate. First, we construct the change in loan supply for each lender. Let M_{b,t_1-t_2} denote the total value of loans supplied by lender b between periods t_1 and t_2. We define the change in loan supply ΔM_b as

$$\Delta M_b = \frac{M_{b,Q4/08-Q2/09}}{0.5(M_{b,Q4/05-Q2/06} + M_{b,Q4/06-Q2/07})}$$

which is the proportional change in loan supply from October 2008 to June 2009, the height of the crisis, and average loan supply during the same quarters in 2005-06 and 2006-

[17] Chodorow-Reich (2014) uses a similar strategy to identify the effect of the 2008-09 credit crunch on employment in the US. He shows that for firms that borrowed in the syndicated loan market during the crisis, interest rates spiked significantly less for firms connected to stronger banks.

07. We are now ready to construct the firm-specific change in loan supply as the logarithm of the weighted average over all key members of the last precrisis loan syndicate Ω_{ω}^{pre}:

$$\Delta \ln M_{\omega} = \ln \sum_{b \in \Omega_{\omega}^{pre}} \alpha_{b,\omega}^{pre} \Delta M_b$$

where $\alpha_{b,\omega}^{pre}$ is a weight that reflects the importance of lender b in the last syndicate. Our main measure of $\ln M_{\omega}$ uses equal weights over lead arrangers, but our results are robust to other specifications.

The measured variation in the credit supply shock at the lender level is correlated with exposure to the mortgage market, money markets, and Lehman Brothers more specifically. Using data from Chodorow-Reich (2014), in the Online Appendix we show that lenders that participated in a higher fraction of syndicates where Lehman Brothers had a lead lending role cut down on new lending by more. We also present evidence that banks more reliant on short-term funding decreased lending by more. Furthermore, we show that banks with stock returns that load strongly on an index of subprime residential mortgage-backed securities tended to reduce lending by more.[18]

3.2.4 Characteristics of Borrowers

Our measure of credit supply provides a simple and transparent proxy for the exogenous shock to firms' cost of capital resulting from the mortgage crisis. However, it relies on the assumption that the cross-sectional variation in bank credit supply is uncorrelated with unobserved characteristics of the borrowing firms. We believe this is a plausible assumption, given the origins of the 2008-09 crisis, the extensive literature that has showed how these exogenous origins led to cross-sectional variation in bank health, and other work that has used bank-firm relationships to study the effect of credit shocks (e.g. Chodorow-Reich, 2014; Bentolila et al., 2018; Alfaro et al., 2019).

Nevertheless, we deal with this concern in two ways. First, we compare observable characteristics, used as control variables in the regressions below, of parents and subsidiaries along the distribution of changes in credit supply. Table A.1 in the Appendix presents summary statistics for the control variables after splitting borrowers into five quantiles of the treatment measure $\Delta \ln M_{\omega}$. Before the crisis, lenders that performed bet-

[18]These results are in line with the empirical evidence presented by Ivashina and Scharfstein (2010) and Cornett et al. (2011), among others.

ter during the crisis did not lend to multinationals with subsidiaries in counties or industries that had systematically better crisis sales outcomes. As a result, bank specialization by industry or geography is unlikely to drive outcomes in our setup, reflecting strong balancing of our sample along these observable characteristics. Table We document a similar pattern for the remaining covariates.

As a second check, we report estimates with and without the inclusion of control variables, and use coefficient stability to infer the potential extent of omitted variable bias. Under the assumption that the relationship between the treatment and controls is informative about the relationship between the treatment and unobservable characteristics (Altonji et al., 2005), we also examine how robust our estimates are to omitted variable bias using the method developed by Oster (2019).

3.3 Findings

We are now ready to show our main empirical findings. Foreign subsidiaries of US multinationals connected to weaker banks experienced a significantly larger drop in sales during the crisis than comparable subsidiaries operating in the same country and sector. Our difference-in-differences estimating equation reads:

$$\ln s_{x,t}^{\omega,j} = \gamma \times \Delta \ln M^{\omega,j} \times 1_{t\in\{09,10\}} + \delta_x^{\omega,j} + \delta_{x,t} + \delta_t^j + \beta' \times X_x^{\omega,j} \times 1_{t\in\{09,10\}} + \nu_{x,t}^{\omega,j} \qquad (13)$$

where subscript ω indexes the parent, x indexes the country where the subsidiary is located, and t indexes the year. Superscript j indexes the sector in which the parent is active. We use a balanced sample that contains only subsidiaries of US multinationals from 2005 to 2010.[19] The dependent variable $\ln s_{\omega,n,t}^j$ is log sales of the subsidiary. The treatment variable of interest is $\Delta \ln M_\omega^j$ and we consider the years 2009 and 2010 as the treatment period. $\delta_{\omega,n}^j$, $\delta_{n,t}$ and δ_t^j are subsidiary, country-year and sector-year-specific fixed effects, respectively. Subsidiary-specific fixed effects account for time-invariant differences across subsidiaries. Country-year and sector-year fixed effects control for country-specific (e.g. currency fluctuations) and sector-specific (e.g. investment cycles) macroeconomic shocks

[19]We emphasize that we only examine the effect of a credit supply shock on economic activity along the intensive margin. Our analysis abstracts from the extensive margin adjustment of subsidiaries. We cannot discipline this adjustment with our data as Orbis does not distinguish between firms entering/exiting production or the data set. Given that firms facing larger credit shocks are more prone to exit (Leibovici et al., 2019), our estimates are likely a lower bound compared to an analysis that also includes the extensive margin.

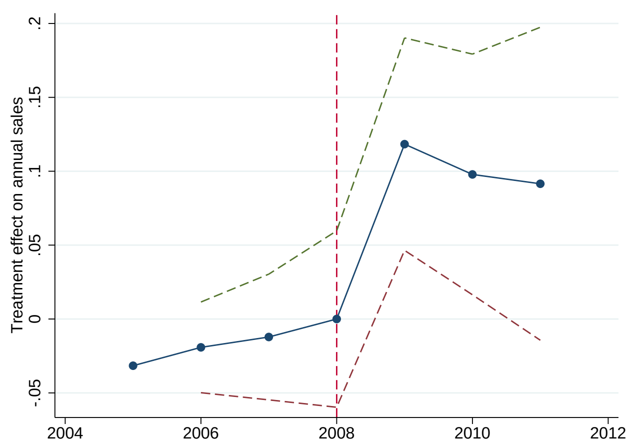
that affect all subsidiaries in a given year. $X_x^{\omega,j}$ is a vector of subsidiary-specific controls interacted with the treatment period. By including the control variables, we ensure that any spurious correlations between the loan supply shock and these factors do not bias our estimates. $\nu_{x,t}^{\omega,j}$ is an error term. The coefficient of interest, γ, thus measures the average log difference in sales after 2008 for subsidiaries with parents connected to stronger banks relative to subsidiaries in the same country and sector with parents connected to weaker banks. We use two-way robust clustering at the parent and year level, adjusting standard errors for unobserved correlated shocks within the same parent and year.

We find that on average, sales of subsidiaries of parents with a 1 percentage point larger contraction in loan supply dropped by 0.11 percentage points more between the crisis and the pre-crisis period. Column 1 of Table 2 summarizes this result. Inserting controls and accounting for sector-time and sector-country-time fixed effects does not substantially change this estimate. In our full specification (column 3), we estimate that this difference is about 0.14 percentage points.

Our result is not driven by diverging trends before the crisis. We show this by estimating equation 13, but now with year-specific treatment. Figure 4 plots the coefficients and associated confidence intervals. While subsidiaries connected to stronger banks did not grow significantly faster between 2005 and 2008, they started to significantly outperform comparable subsidiaries with parents connected to weaker banks in 2009. This treatment effect subsided somewhat over time but remained elevated in 2011, which is consistent with other empirical evidence that documents a long-lasting effect of credit shocks on firm activity (e.g. Huber, 2018).

We perform several additional robustness checks that suggest that it is unlikely that intra-firm trade, financial firms, or selection on unobservables drive our findings. Even though sales of firms in Orbis exclude intra-firm revenue, one might still be concerned that our results are driven by reduced output in the subsidiary as a result of intra-firm supply chains, rather than an increase in the cost of capital of the subsidiary. If this would be the case, then we should expect the relationship we document to be weaker for subsidiaries of multinationals that are active in the services sector, where intra-firm trade is less common. However, when we interact our treatment with a dummy for whether the multinational is primarily classified as a services firm (column 1 in Table A.4), the estimated effect *increases.* Moreover, we repeat our estimates without subsidiaries of multinationals classified as active in finance, insurance, or real estate. Table A.2 shows that despite losing 1/6 of our observations, this leaves our estimates unchanged. We also establish that it is improbable that selection on observables could have affected the qualitative results presented in Tables 2 and A.2. In particular, Oster's β^* in Columns 3 of these tables suggests that if unobservables were as correlated with the treatment as the observables, then the estimated treatment effect would be unchanged. Moreover, Osters δ suggests that in order to generate a null effect, selection on unobservables would have to be implausibly large (Oster, 2019). Finally, our results are not purely cross-sectional, and are not driven by outliers. In Table A.3, we regress the change in subsidiary sales between 2008 and 2009 on the change in credit supply. We find a similar elasticity when exploiting the temporal variation only. Moreover, the binned scatterplot in Figure A.2 shows that the strong positive relationship between changes in sales and the treatment variable is not driven by outliers.[20]

Figure 4 Treatment Effect Over Time



Notes: Figure plots the treatment effect over time, i.e. we estimate $\ln s^j_{\omega,n,t} = \sum_t \gamma_t \times \Delta \ln M^j_\omega + \delta^j_{\omega,n} + \delta_{n,t} + \delta^j_t + \beta' \times X_{\omega,n} \times 1_{t\in\{09,10\}} + \nu^j_{\omega,n,t}$ and plot the γ_t coefficients and their 90 % confidence interval. See Table 2 for other details on the sample and standard errors.

3.4 Interpretation

[20] We perform additional robustness checks in Table A.4, which indicate that our results are not driven by subsidiaries from specific countries, and hold both for subsidiaries of parents with US-based lenders and non-US-based lenders.

3.4.1 Reduced Form

With some additional assumptions, we can use the findings from the previous section to infer the aggregate reduced form effects of the financial shock in the U.S. on the sales of foreign subsidiaries. We assume:

A1 *The aggregate effect equals the sum of direct sales effects measured at each subsidiary.*

A2 *The least affected firms did not experience a shift to their loan supply during the crisis.*

Under these assumptions, we show that the aggregate change in sales ΔS is given by[21]

$$\Delta S = \int s^{ob.\omega}(1 - \exp\{-\gamma(\Delta \ln M^{\omega} - \Delta \ln M^{1})\})d\omega$$

where $s^{ob.\omega}$ is the observed level of sales during the crisis in 2009, and $\Delta \ln M^1$ is the measured loan supply shifter for the least affected banks.

We estimate that about a quarter of the drop in sales of foreign subsidiaries in Europe can be accounted for by the shift in loan supply at multinational parents during the crisis. Table 3 reports results using the 95th percentile treatment as the least affected firms. Total sales at foreign subsidiaries declined by 18 % between 2008 and 2009. Our back-of-the-envelope calculation suggests that the reduced form effect of the shift in loan supply can account for about a 5 % drop.

[21] See Appendix section A.2.2 for a derivation.

Table 3 Total Effect of Credit Shock on Sales of US Subsidiaries

		2008-2009 (%)
Data	Sales decline, Europe, domestic firms	-11.1
	Sales decline, Europe, foreign firms	-18.0
	Sales decline, Europe, US owned firms	-19.2
Reduced form estimate	Sales decline, Europe, US subsidiaries, All	-4.7
	Sales decline, Europe, US subsidiaries, Non-FIRE	-4.9

Notes: Sales data from OECD's Activities of Multinational Enterprises (AMNE). Reduced form estimate uses the estimate in Table 2.

3.4.2 Implied Model Elasticity

We are now ready to identify the structural parameter that governs the pass-through of financial shocks from multinational parents to their foreign subsidiaries. If $G(\cdot)$ takes the CES form, then the degree of transmission of a shock to the cost of capital of the parent firm r_o^ω to the cost of capital of the subsidiary u_x^ω is decreasing in the elasticity of substitution ϕ:

$$\frac{d\ln u_x^\omega}{d\ln r_o^\omega} = [(1-\lambda_{ox}^\omega) + \lambda_{ox}^\omega(1+dr_o^\omega/r_o^\omega)^{1-\phi}]^{1/(1-\phi)} - 1$$

where λ_{ox}^ω is the share of owner capital in total assets of the subsidiary, which can be measured using microdata from Orbis.

How does this relate to the reduced form estimate in this section? Note that the estimate $\hat{\gamma}$ captures the empirical elasticity of sales with respect to parent credit supply:

$$\gamma = \frac{d\ln s_x^\omega}{d\ln u_x^\omega} \cdot \frac{d\ln u_x^\omega}{d\ln r_o^\omega} \cdot \frac{d\ln r_o^\omega}{d\ln M_o^\omega}$$

For non-multinational firms, transmission is perfect ($\frac{d\ln u_x^\omega}{d\ln r_o^\omega} = 1$), and we know from the literature that $\frac{d\ln s_x^\omega}{d\ln M_o^\omega} \sim 0.5$.[22] Combining gives

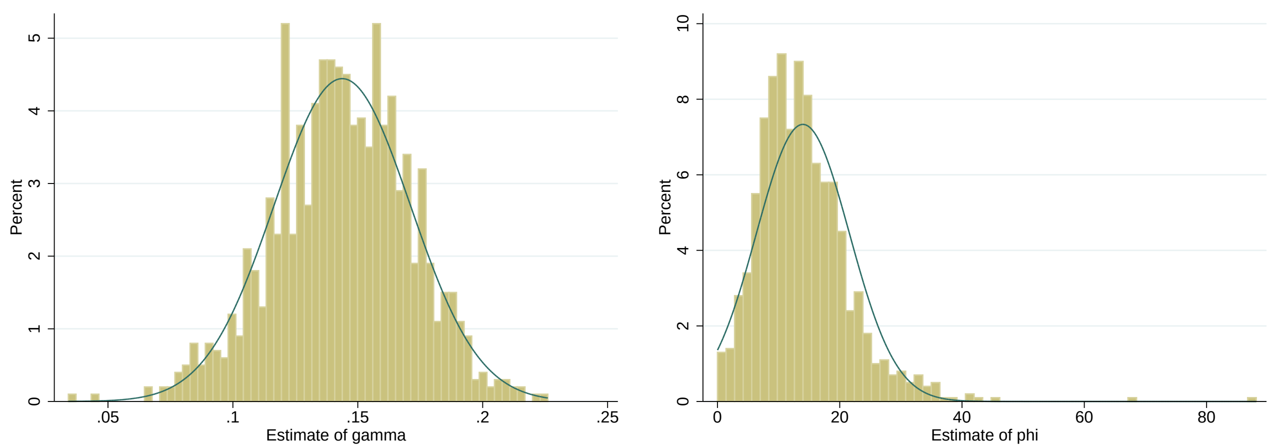
[22] To be more specific, Bentolila et al. (2018) estimate that the elasticity of firm employment with respect to a credit supply shock is about 0.5. This is similar to the estimate of Chodorow-Reich (2014) for large US firms. Given that sales to employment tends to be constant in heterogeneous firm models, we conclude that the literature suggests that $\frac{d\ln s_x^\omega}{d\ln M_o^\omega} \sim 0.5$.

$$\hat{\gamma} = 0.5[(1-\lambda^{\omega}_{ox}) + \lambda^{\omega}_{ox}(1+dr^{\omega}_{o}/r^{\omega}_{o})^{1-\phi}]^{1/(1-\phi)} - 0.5 \tag{14}$$

Armed with an estimate γ we can derive the level of ϕ that is consistent with the values of λ^{ω}_{ox} in the data. We bootstrap this procedure on the panel of subsidiaries used in section 3.3.

We present the distribution of estimates of γ and ϕ in Figure 5. The median estimate of γ is about 0.14, close to the point estimate in the previous section. The median value of ϕ consistent with this is about 13.[23]

Figure 5 Bootstrap estimates of γ and ϕ



Notes: Figures plot histograms of the bootstrap estimates of γ, the first-order effect of subsidiary sales with respect to parent credit supply, and ϕ, the elasticity of substitution between subsidiary's funding from its parent and local funding. We perform 1000 bootstraps on the panel 403 subsidiaries, first estimating γ using estimating equation 13, then computing the implied ϕ using equation (14) and a mean value of λ^{ω}_{ox} for the observations in the bootstrap sample.

[23]What are the implications of our results for pass-through of the shock? Our median estimates imply

$$\frac{d\ln u^{\omega}_{x}}{d\ln r^{\omega}_{o}} \equiv 0.28$$

In other words, we estimate that the first-order pass-through of the shock is about 28%. The magnitude of this estimate is similar to that of the reduced form elasticity of subsidiary sales with respect to parent sales, which Cravino and Levchenko (2017) estimate to be between 0.23 and 0.28.

Table 1 Summary statistics

Panel A: firms in Compustat in 2008		All	Matched w/ Orbis	Matched w/ Dealscan
# firms		4,579	1,141 (25 %)	298 (7 %)
Sales (bill. $)	Total	17,483	6,451 (37 %)	2,283 (13 %)
	Mean	3.8	5.7	7.7
	Median	0.3	0.7	2.0
Employment (thous.)	Total	42,274	16,067 (38 %)	6,032 (14 %)
	Mean	9.2	14.1	20.2
	Median	0.8	2.0	6.3
Industry (% sales)	Agr./Mining	5.3 %	7.0 %	7.9 %
	Manufacturing	54.7 %	51.1 %	55.9 %
	Services	40.0 %	41.9 %	36.2 %
Panel B: firms in Orbis in 2008		All	Foreign subsidiaries	US subsidiaries
# firms		1,326,608	83,695 (6.3 %)	11,075 (0.8 %)
Sales (bill. $)	Total	29,828	13,314 (45 %)	1,553 (5.2 %)
	Mean	0.02	0.2	0.15
	Median	0.001	0.02	0.02
Employment (thous.)	Total	89,372	27,726 (31 %)	3,241 (3.6 %)
	Mean	0.07	0.4	0.3
	Median	0.01	0.05	0.07
Industry (% sales)	Agr./Mining	13.0 %	13.3 %	6.6 %
	Manufacturing	26.0 %	30.5 %	36.3 %
	Services	61.1 %	56.1 %	57.2 %

Notes: Panel A reports summary statistics of subsidiaries in Orbis in 2008 that are located in Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Latvia, Netherlands, Norway, Poland, Portugal, Romania, Sweden, Slovenia, and Slovakia. We restrict the sample to firms with positive sales and at least 5 employees. Column (1) reports all firms. Column (2) reports subsidiaries of which the global ultimate owner does not reside in the same country. Column (3) reports subsidiaries of which the global ultimate owners resides in the United States.
Panel B reports summary statistics of firms in Compustat in 2008. Numbers cover consolidated balance sheet, so sales and employment include foreign subsidiaries. We restrict the sample to firms with positive sales and employment. Column (1) reports all firms. Column (2) reports firms linked to Orbis using the fuzzy matching algorithm outlined in the Online Appendix. Column (3) reports firms in column (2) linked to Dealscan using the identifiers from Chava and Roberts (2008).

Table 2 The Effect of a Financial Shock on Subsidiary Sales

	(1)	(2)	(3)	(4)
Dependent variable: (log) sales of subsidiary $\ln s^j_{\omega,n,t}$				
$\Delta \ln M^j_\omega \times 1_{t\in\{09,10\}}$	0.109**	0.125***	0.143***	0.130***
	(0.0308)	(0.0302)	(0.0295)	(0.0252)
Observations	2,418	2,418	2,412	2,304
R-squared	0.993	0.993	0.993	0.993
Controls	NO	YES	YES	YES
Subsidiary FE	YES	YES	YES	YES
Country-Year FE	YES	YES	YES	NO
Sector-Year FE	NO	NO	YES	NO
Country-Sector-Year FE	NO	NO	NO	YES
# of subsidiaries (ω, n)	403	403	403	384
# of countries (n)	22	22	22	
β_{Oster}			0.125	
δ_{Oster}			11.6	

Notes: Controls include (log) sales of the subsidiary and parent in 2006, the year of the last pre-crisis syndicate of the parent, and growth of sales of the subsidiary and parent between 2005 and 2007. We restrict the sample to a balanced panel of subsidiaries that have positive entries for sales, both for the parent and the subsidiary, in all years from 2005 to 2010. To avoid picking up mergers and acquisitions, we drop subsidiaries with absolute sales growth of more than 50 % in one of these years. We use two-way robust clustering by parent and year. To avoid overstating statistical significance, we drop singleton observations within the fixed effects and clusters (Correia, 2015).

4. Quantifying the Contribution of Financial Linkages to Global GDP Comovement

In this section, we incorporate the financial linkages from section 2 into a dynamic multi-country general equilibrium model with multinational production. In contrast to standard international business cycle models (e.g. Perri and Quadrini, 2018; Ayres, 2018; Drozd et al., 2020), it allows for an arbitrary number of countries. Two-country models tends to over-estimate the importance of transmission through trade linkages for driving bilateral business cycle comovement because there is no scope for trade diversion to other countries. Moreover, having multiple countries allows us to fit our counterfactual series to the actual macroeconomic data using hat algebra (Dekle et al., 2007), providing a better comparison between counterfactual series and the data.

As is standard in the literature on shock transmission in production networks, the core of the model is static, featuring predetermined factor supply. We allow for capital accumulation using the machinery of Eaton et al. (2016) so that the response of output in the static model coincides with the impact response of the fully dynamic model.[24]

4.1 A Dynamic Multicountry General Equilibrium Model with Financial Linkages

Environment. We consider a global economy like the one in section 2 with N countries indexed $o, x, i \in \mathbf{N} = \{1, ..., N\}$. Time is discrete, indexed t. In each country, there is a continuum of firms producing varieties indexed $\omega \in [0, 1]$. A final goods aggregator combines these varieties with a constant elasticity of substitution $\sigma > 1$. Firms use the same technology $F(\cdot)$ but differ in their Hicks-neutral productivity terms z^{ω} and in their access to funds. In a given period, each country x is endowed with a stock of capital $K_{x,t}$ and a stock of labor $\bar{L}_{x,t}$. Financial intermediaries provide households with funds for investment, and firms with funds to finance their working capital.

[24] However, we know from Huo et al. (2020) that delayed propagation would contribute relatively little to overall GDP comovement compared to the impact effects captured by the static model.

4.1.1 Static Core

Production. Country o ('owner') can open a subsidiary in country x ('exporter'). Each country has a technology to produce each variety, described by the Hicks-neutral productivity term $z^{\omega}_{o,t}$. If the firm owning that technology decides to produce in country x, it has an effective productivity of $z^{\omega}_{o,t}\delta_{ox,t}$, where $\delta_{ox,t} \geq 1$ represents the cost of technology transfer. $F(\cdot)$ takes the Cobb-Douglas form such that

$$Y^{\omega}_{ox,t} = z^{\omega}_{ox,t}(\frac{K^{\omega}_{ox,t}}{\alpha(1-\alpha^X)})^{\alpha(1-\alpha^X)}(\frac{L^{\omega}_{ox,t}}{(1-\alpha)(1-\alpha^X)})^{(1-\alpha)(1-\alpha^X)}(\frac{x^{\omega}_{ox,t}}{\alpha^X})^{\alpha^X} \quad ; \quad \alpha, \alpha^X \in [0,1]$$

International Trade. Only varieties can be traded between countries, and shipping goods internationally is costly. Trade costs take the iceberg form, defined in physical units of the same variety. Shipping one unit of a variety from country x to i requires producing $d_{xi,t} \geq 1$ units in x, with $d_{xi,t} = 1$ if $x = i$. Trade arbitrage ensures the triangle inequality holds such that $d_{xi,t}d_{in,t} \geq d_{nx,t} \forall t, x, i, n$.

Productivity distributions. Owners are endowed with source-country specific productivity levels, drawn from a Frechet distribution with location parameter $A_{o,t}$ and dispersion parameter $\theta > \max\{1, \sigma - 1\}$:

$$Pr(z_{o,t} \leq z) = \exp[-A_{o,t}z^{-\theta}]$$

Financial Intermediaries. For each unit of funding supplied, intermediaries from country x incur an exogenous cost $\bar{r}_{x,t}$.

Ownership. The subsidiary finances its working capital by combining funding from the parent at price $r_{o,t}$ and the local financial intermediary at price $r_{x,t}$. $G(\cdot)$ takes the CES form with elasticity of substituion ϕ.[25] The unit cost function of a subsidiary is given by:[26]

$$u_{ox,t} = [\zeta r^{1-\phi}_{o,t} + (1-\zeta)r^{1-\phi}_{x,t}]^{1/(1-\phi)}$$

[25] This means we impose homogeneity in terms of financing within an owner-exporter cell, thereby implicitly subsuming bank-related heterogeneity into the owner-specific productivity term.

[26] Under additional assumptions, this way of modeling unit costs actually generates an economy-wide unit cost function like the one used in section 2. See the Online Appendix for a derivation.

where ζ is a constant parameter that governs the share of funding by the parent.

Optimal sourcing by the final goods aggregator gives the share of expenditure of country i on goods produced in country x with owners from country o:

$$\pi_{oxi,t} = [\frac{A_{o,t}}{\delta_{ox,t}} \frac{P_{i,t}}{c_{ox,t} u_{ox,t} d_{xi,t}}]^{\theta} \tag{15}$$

where $c_{ox,t}$ is the unit cost of a variety producer in x with an owner from o. This expression shows that country i will spend more on goods produced by a given owner-exporter pair if owners tend to be more productive (higher $\frac{A_{o,t)}}{\delta_{ox,t}}$) or if the cost of delivering a good in country i is low relative to the overall price index (higher $\frac{P_{i,t}}{c_{ox,t} u_{ox,t} d_{xi,t}}$). In the calibration, we will use this expression to back out shocks to $A_{o,t}$, $\delta_{ox,t}$, and $d_{xi,t}$.

Endogenous labor supply. Labor supply is elastic, taking the form (Greenwood et al., 1988):

$$U(C_{x,t}, L_{x,t}) = C_{x,t} - \frac{L_{x,t}^{1+1/\psi}}{1 + 1/\psi} \qquad \psi \geq 0$$

The static core of the model nests several canonical models in the literature. In the absence of financial linkages and multinational production ($\delta_{ox} \to \infty$) the model collapses to the Ricardian input-output model of Caliendo and Parro (2015) (if $\psi = 0$) or those of Huo et al. (2020) and Esposito et al. (2017) (if $\psi > 0$). Without financial linkages ($\zeta_{ox} = 0$) and with exogenous factor supply ($\psi = 0$), the model becomes a special version of that in Ramondo and Rodríguez-Clare (2013). Without production linkages, the model is isomorphic to a setup in which comovement of output between countries arises from technology transfer, as in Cravino and Levchenko (2017) or Ayres (2018).

4.1.2 Dynamics

Capital Stock Dynamics. Capital in country x accumulates according to

$$K_{x,t+1} = (I_{x,t}^{\alpha^K} (K_{x,t})^{1-\alpha^K} + (1 - \delta) K_{x,t} \tag{16}$$

where $I_{x,t}$ is investment, $\alpha^K \in (0, 1]$ governs adjustment costs and δ is the depreciation rate.

Household. In each period, the household in country x consumes $C_{x,t}$, chooses labor supply $L_{x,t}$ and invests in its capital stock. It receives income from supplying capital and labor to local firms. For investment, it needs to take out a loan with the local financial intermediary, which provides funds at a cost $r_{x,t} \geq 1$. The lifetime utility of the household is given by

$$V_x = \sum_{t=1}^{\infty} \beta^{t-1} \nu_{x,t} U(C_{x,t}, L_{x,t})$$

where β is a constant discount factor and $\nu_{x,t}$ is an aggregate demand shock. The household maximizes this utility subject to the period-by-period budget constraint:

$$P_{x,t}C_{x,t} + P_{x,t}I_{x,t}r_{x,t} = w_{x,t}L_{n,t} + \rho_{n,t}K_{n,t} \tag{17}$$

4.1.3 Market Structure and Equilibrium

Markets are perfectly competitive and complete. Foresight is perfect. In the absence of market failures, we can solve for allocations using the planner's problem. Let η_x be the Pareto weight that the planner assigns to the household in country x. We normalize aggregate demand shocks such that $\sum_{n'=1}^{N} \eta_{n'} \nu_{n',t} = 1$, which implies that global consumption serves as the numeraire (Eaton et al., 2016):

$$\sum_{n=1}^{N} P_{n,t} C_{n,t} = 1 \quad \forall t$$

In section A.1.2 of the Appendix, we set up the planner's problem. The solution to this problem delivers allocations and shadow prices that correspond to the decentralized equilibrium, which we also summarize in the Appendix.

4.2 Calibration

Exogenous Variables. We consider two sets of exogenous variables. First, we have time-invariant preference and technology parameters that we summarize in the vector

$$\Theta = \{\beta, \psi, \theta, \alpha, \alpha^X, \delta, \phi, \zeta\}$$

Second, we have time-varying shocks that drive deviations from the stationary equilibrium, summarized in the vector

$$\Psi_t = \{\bar{r}_{x,t}, A_{x,t}, \nu_{x,t}, d_{xi,t}, \delta_{ox,t}\} \tag{18}$$

A common solution technique is to linearize the model around its stationary state and consider local deviations to assess the importance of different mechanisms in the model. Instead, inspired by Eaton et al. (2016) we solve the model using exact hat algebra (Dekle et al., 2007). We define a variable x in 'hats' or 'changes' as $\hat{x}_t = x_t/x_{t-1}$. With the model in changes, we circumvent the need to know any of our shocks which relaxes the data requirements.

Parameters. In implementing the model, we need to take a stand on the values of several parameters. Table 4 summarizes our assumptions in this respect. The values of α, α^X, β, ψ, α^K and δ are relatively uncontroversial. We set the trade elasticity θ equal to 2, in between smaller values used in the international macro literature and the larger values used in the trade literature. We set $\zeta = 0.4$, which corresponds to the median share of assets owned by multinational parents in Orbis. Finally, to be consistent with our identification results from section 3, we set $\phi = 13$.

Capital. We freeze the levels of all subsequent shocks at their values in the terminal period of our data, 2016, and assume that the global economy is in a stationary state after that period. That is, we assume $\hat{\Psi}_s = \{1, 1, .., D_{n,2016}\}$ and $\hat{K}_{n,s}$ for $s > 2016$.

With $\hat{K}_{n,t+2}$ in hand, we iterate backwards and extract $\hat{K}_{n,t+1}$ for the periods of our data. We can express the law of motion of capital in changes as:

$$\frac{\hat{K}_{n,t}}{\hat{K}_{n,t} - (1-\delta)} = \beta \frac{\alpha^K}{X^K_{n,t-1}} \rho_{n,t} K_{n,t} + \beta \hat{X}^K_{n,t} [(1-\alpha^K) + \frac{1-\delta}{\hat{K}_{n,t} - (1-\delta)}] \tag{19}$$

where $X^K_{n,t}$ is the change in investment spending. We can use this equation to extract the changes in capital stock $\hat{K}_{n,t}$ using the previous change $\hat{K}_{n,t+1}$ and data on investment spending $X^K_{n,t}$ and payments to capital $\rho_{n,t} K_{n,t}$.

Shocks. We now describe how we back out the exogenous shocks. In changes, our vector of shocks at time t is given by

$$\hat{\Psi}_t = \{\hat{r}_{n,t}, \hat{A}_{n,t}, \hat{\nu}_{n,t}, \hat{d}_{ni,t}, \hat{\delta}_{on,t}\}$$

Given paths for changes in capital $\hat{K}_{n,t}$, the equations describing the static equilibrium in changes deliver the following equations to infer the shocks using our data.

Table 4 Parameters and calibration

Parameters	Meaning	Value	Source/Target
β	Discount factor	0.987	Real ρ of 5%
θ	Elasticity of trade/financial flows w.r.t. barriers	2	Simonovska (2014), Kose (2006)
ψ	Elasticity of labor supply w.r.t. real wage	2	Hall (2009)
ϕ	Elasticity of substitution between equity and debt	13	Micro-evidence
δ	Depreciation capital stock	0.02	
α^K	Curvature investment	0.55	Eaton et al. (2016)
α	Elasticity of output w.r.t. capital input	1/3	1 - labor share
α^X	Elasticity of output w.r.t. intermediate inputs		2
ζ	Funding share of parent	0.4	median in Orbis
Shocks			
$\hat{r}_{n,t}$	Financial shock		Investment
$\hat{A}_{n,t}$	Productivity shock		Real GDP
$\hat{d}_{ni,t}$	Trade cost shock		Trade flows
$\hat{\delta}_{ni,t}$	Shock to cost of technology transfer		MNE flows

Notes: Table summarizes calibration strategy.

- Using the law of motion of capital, we back out country-specific financial shocks:

$$\hat{r}_{n,t} = (\frac{\hat{P}_{n,t}\hat{K}_{n,t}}{\hat{X}^K_{n,t}})^{\alpha^K} \frac{\hat{K}_{n,t+1} - (1-\delta)}{\hat{K}_{n,t} - (1-\delta)} \tag{20}$$

which requires data on changes in investment spending and prices.

- We back out productivity shocks by deriving the dual of total factor productivity from the expression for trade shares in equation 15:

$$\hat{A}_{n,t} = \frac{1}{\hat{P}_{n,t}}(\hat{\pi}_{nnn,t})^{1/\theta}\hat{c}_{n,t}\hat{r}_{n,t} \tag{21}$$

which requires data on changes domestic trade shares $\pi_{nnn,t}$ and prices. We construct changes in unit costs using

$$\hat{c}_{n,t} = (\hat{\rho}_{n,t})^{\alpha(1-\alpha^X)}(\hat{w}_{n,t})^{(1-\alpha)(1-\alpha^X)}(\hat{P}_{n,t})^{\alpha^X}$$

and we construct changes in factor payments as

$$\hat{w}_{n,t} = \frac{w_{n,t}L_{n,t}}{w_{n,t-1}L_{n,t-1}}\frac{L_{n,t-1}}{L_{n,t}}$$

$$\hat{\rho}_{n,t} = \frac{Y_{n,t} - w_{n,t}L_{n,t}}{Y_{n,t-1} - w_{n,t-1}L_{n,t-1}}\frac{1}{\hat{K}_{n,t}}$$

which requires requires data on wage payments $w_{n,t}L_{n,t}$ and nominal GDP $Y_{n,t}$.

- We back out aggregate demand shocks using:

$$\hat{P}_{n,t}\hat{C}_{n,t} = \hat{\nu}_{n,t}$$

which requires data on changes in the nominal value of consumption $\hat{P}_{n,t}\hat{C}_{n,t}$.

- We back out changes in trade costs for each exporter-importer pair using the symmetry of trade costs ($d_{xi} = d_{ix} \quad \forall x, i$), equation 15 and data on trade flows:

$$\hat{d}_{xi,t} = (\frac{\hat{\pi}_{xx,t}\hat{\pi}_{ii,t}}{\hat{\pi}_{xi,t}\hat{\pi}_{ix,t}})^{1/2\theta} \tag{22}$$

where we define $\pi_{xi,t} \equiv \sum_{o=1}^{N} \pi_{oxi,t}$.

- We back out changes in costs of technology transfer for each owner-exporter pair using the symmetry of transfer costs ($\delta_{ox} = d_{xo} \quad \forall x, o$), equation 15 and data on sales of multinational enterprises:

$$\hat{\delta}_{ox,t} = (\frac{\hat{\pi}_{xx}\hat{\pi}_{oo}}{\hat{\pi}_{ox}\hat{\pi}_{xo}})^{1/2\theta} \tag{23}$$

where we define $\pi_{ox,t} \equiv \sum_{i=1}^{N} \pi_{oxi,t}$.

4.3 Data

We take data on investment spending, trade flows, nominal GDP, nominal consumption and sales of MNEs from OECD's Activities of Multinational Enterprises. We take the share of wage payments in nominal GDP, as well as price deflators, from Penn World Tables 9.1. Our sample covers the global economy from 2005 to 2016, and contains 25 countries.[27] We provide more details on data sources in the Online Appendix.

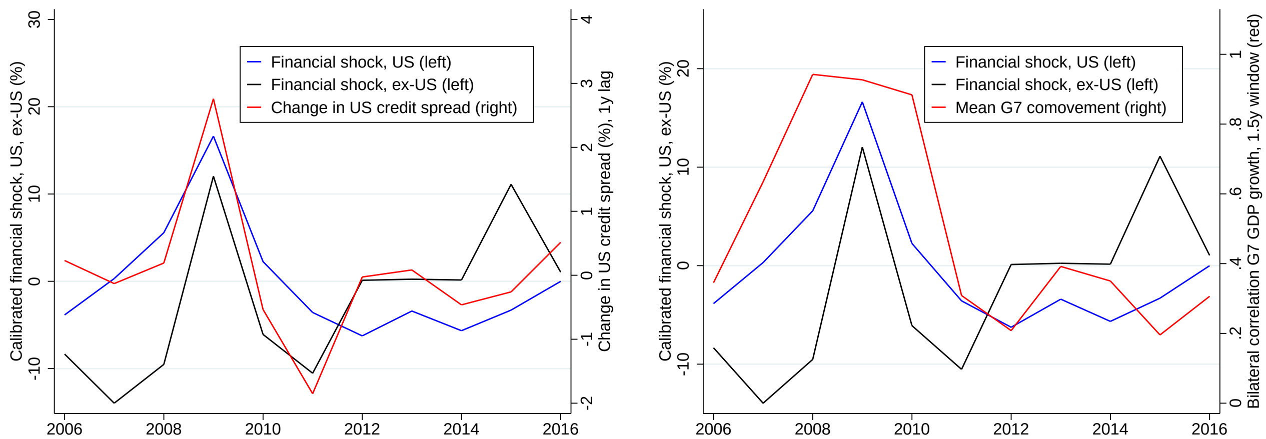
4.4 Paths of Calibrated Shocks

Before discussing quantitative results, we check the paths of our calibrated shocks.[28] Figure 6(a) plots the calibrated value of financial shocks for the US and non-US countries over time. In the figure, we compare these shocks to the change in the US credit spread of (Gilchrist and Zakrajšek, 2012), which we do not target in our calibration. The calibrated financial shock for the US tracks its empirical counterpart surprisingly well, peaking in 2009 during the Great Financial Crisis. In Figure 6(b), we plot the same calibrated financial shocks against global GDP comovement. Again, the shocks increase during periods when GDP growth is highly correlated, such as the 2008-2010 period.

[27]Specifically, our data cover Austria, Belgium, Brazil, Canada, Switzerland, Chili, China, Germany, Denmark, Spain, Finland, France, United Kingdom, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, Sweden, United States and South Africa. They also cover Taiwan, PoC, and a Rest of the World that reflects all other countries.

[28]We plot the paths of all calibrated shocks by country in the Online Appendix.

Figure 6 Calibrated Financial Shocks, US Credit Spread and Global Comovement



Notes: Figures plot the model's calibrated financial shocks (left axis) against the change in the US change in the corporate credit spread of Gilchrist and Zakrajšek (2012) (a, right axis) and global comovement (b, right axis). Quarterly real GDP data data are from the OECD. Credit spread data are from Favara et al. (2016).

4.5 Quantitative Exercises

Armed with the quantitative framework and the estimates of the key parameter ϕ, we are now ready to assess the quantitative importance of financial linkages within multinationals for the global business cycle. We perform two sets of exercises in this section. First, we perform an impulse response exercise that we use to answer the questions: (i) how much does a foreign financial shock raise financing costs in the local economy? (ii) what is the typical impact of a foreign financial shock on output? Second, we compute a counterfactual in which we shut down financial linkages within multinationals during the 2005-2016 period, and we assess how much pairwise growth correlations would decrease when multinational subsidiaries do not get funding from their parents.

4.5.1 Impulse Responses and Mechanisms

We start out by examining the direct impact of foreign financial shocks on countries' financing costs and output. First, we assess the direct impact of a 1% increase in financing costs for all parent firms of foreign subsidiaries on a given country's financing costs. We express the change in financing costs for domestic producers as weighted average of the change in the weighted average cost of capital:

$$\pi^F_{x,t-1} \cdot \left([\zeta 1.01^{1-\phi} + (1-\zeta)]^{1/(1-\phi)} - 1 \right) \tag{24}$$

where $\pi^F_{x,t-1}$ is the share of sales by foreign subsidiaries as a share of total sales by firms producing in country x. This expression shows that the direct impact of is increasing in the presence of foreign subsidiaries and the funding share of parents, ζ. It is decreasing in the degree of substitution between foreign and domestic funds, ϕ.

Panel A of Table 5 reports the values of the impulse responses in (24), using data from 2015. In our sample, the mean direct impact of a 1% foreign financial shock on domestic financing costs is 0.071, implying a direct pass-through of about 7%. This mean masks substantial heterogeneity, however. The reported impact is about twice as large in high-income countries (0.08) as in emerging countries (0.04). In some countries, foreign shocks account for a much larger share of financial shocks. In countries like the United Kingdom, Ireland and Luxembourg, the direct impact exceeds 0.1.

Which countries have the largest foreign impact? We compute impulse responses using equation 24, but now with a financial shock coming from individual countries. Panel A of Table 5 shows that the impact of a 1% increase in financing costs in the median country is negligible, raising financing costs in other countries by less than 0.001% on average. The impact of some larger high-income countries, however, is substantial. A financial shock in the US increases financing costs by 0.024% on average, 0.027% in high-income countries, and 0.012% in emerging economies. Germany, France and the United Kingdom also have a large external impact, though substantially smaller than the US.

Next, we evaluate the direct impact of foreign financial shocks on output. We suppress indirect general equilibrium effects by fixing wages and setting $\alpha = 0$. We then solve for the change in a country's real GDP in response to foreign financial shocks. Panel B of Table 5 reports the change in domestic GDP in response to a 1% drop in foreign GDP caused by an exogenous increase in financial shocks, either in all foreign countries or in one country individually. Again, we use data from 2015. On average, if GDP drops by 1% in the rest of the world, GDP decreases by 0.36 % in the typical country. This impact is somewhat larger in high-income countries (0.38 %) and smaller in emerging economies (0.29 %).

Which countries are most vulnerable to external shocks? Figure 7(a) plots the impulse response in output of different economies in response to a 1% finance-driven drop in output in the rest of the world. Countries in which foreign firms account for the largest share of sales tend to be most vulnerable. Economies more closed to foreign multinationals, such as Japan, Korea and China, tend to exhibit a smaller impact of a foreign financial shock.

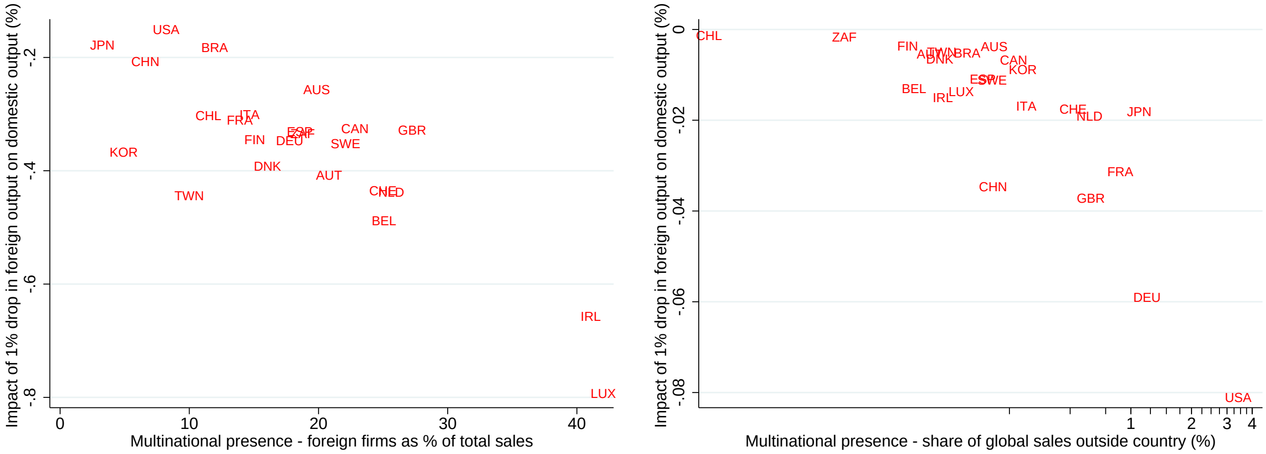
Figure 7(b) plots, for each country, the average impact of a financial shock on output in other economies. The impact of economies that account for a small share of sales by multinational subsidiaries, such as Chile and South Africa, tends to be small. A finance-driven output shock in countries with a large foreign presence, such as the US, have the largest external impact. On average, output in other economies declines by 0.08% in response to a 1% output shock in the US, and by 0.06% and 0.04% when the shock comes from Germany and the UK, respectively. In contrast, the output impact of a financial shock in the median country is negligible, amounting to less than 0.001% of output in the typical economy. These results highlight how interdependence between most individual country pairs is minimal, because bilateral multinational ties tend to be small. The most integrated countries, however, are significantly more affected by foreign financial shocks.

Table 5 Impulse Responses of Financial Shocks and Output

Location of parent		Location of subsidiary	
⇓	All countries	High-income countries	Emerging economies
	Panel A: Financial impact		
Rest of world	0.071	0.078	0.045
Median country	0.001	0.001	0.001
US	0.024	0.027	0.012
Germany	0.009	0.010	0.004
France	0.006	0.007	0.003
United Kingdom	0.005	0.005	0.006
	Panel B: Output impact		
Rest of world	0.36	0.38	0.29
Median country	0.008	0.010	0.006
US	0.081	0.088	0.059
Germany	0.059	0.070	0.026
France	0.031	0.037	0.014
United Kingdom	0.037	0.044	0.016

Notes: Table reports averages of the impulse response exercises presented in section 4.5.1. In Panel A, we report the average impulse responses in terms of financial shocks as computed using equation 24. All numbers are in percentage terms, responding to a 1% foreign financial shock (Panel A) or a 1% foreign output shock as a result of foreign financial shocks (Panel B), in the location of left column.

Figure 7 Output Response and Multinational Presence



Notes: Figures plot output responses from foreign financial shocks against local and foreign multinational presence. Figure (a) plots the output response of the domestic economy from a financial shock that depresses output in the rest of the world by 1% against the share of domestic sales that accrues to foreign firms. Figure (b) plots the average impact on output in other countries as result of a 1% drop in domestic output against the share of global sales (ex domestic economy) that accrues to domestic multinationals.

4.5.2 Counterfactuals

As a second set of exercises, we explore to what extent financial linkages within multinationals can account for the observed correlation between countries' GDP growth. We ask the questions: through the lens of our model, how much of the correlation between countries' GDP growth rates is driven by common shocks, and how much by propagation through financial linkages within multinationals? We shut down financial linkages in our model by setting $\zeta = 0$ so that multinational subsidiaries are only financed by local financial intermediaries. As a result, there are no financial flows between countries. We then solve, for each year of our data, the static equilibrium using hat algebra.[29] We summarize these equilibria in section A.1 of the Appendix.

Table 6 summarizes the model's ability to account for the positive cross-country growth correlations in the data. The row labeled 'Model' reports the summary statistics for the calibrated correlations of GDP growth over the period 2005-2016 for the 25 countries in our

[29]We do not consider a dynamic counterfactual for the following reason. By setting ζ to zero, we do not only reduce comovement of financial costs between countries, but also increase output in countries where the calibrated financial shock is lower for non-multinational firms than for multinational subsidiaries. As a result, shutting down financial linkages leads to a divergence in GDP growth between countries. In a dynamic equilibrium, this effect is magnified because countries with higher counterfactual GDP growth invest more. As such, counterfactual growth correlation in a dynamic counterfactual are dominated by changes in trend growth compared to changes in the transmission of financial shocks.

sample. The row labeled 'No Financial Linkages' reports the counterfactual correlations. On average, correlations drop by 15 to 20 % in the counterfactual relative to the calibrated model. The mean pairwise correlation decreases from 0.59 to 0.50 in the counterfactual, whereas the median drops from 0.65 to 0.53. These patterns hold for individual countries as well. For pairs that include the US, the average growth correlation drops by about 30 %. For pairs including Germany, France, and the UK, the average growth correlation decreases by 10%, 10%, and 20%, respectively.

Table 6 Calibrated and Counterfactual Growth Correlations

		All country pairs				
		Mean	Median	Std. dev.	Min.	Max.
Model		0.59	0.65	0.28	-0.63	0.97
No Financial Linkages		0.50	0.53	0.29	-.70	0.95
		Pairs involving larger source countries				
Model	US	0.58	0.71	0.31	-0.25	0.92
No Financial Linkages		0.41	0.50	0.32	-0.34	0.88
Model	Germany	0.72	0.78	0.23	0.15	0.96
No Financial Linkages		0.66	0.71	0.22	0.18	0.95
Model	France	0.74	0.81	0.24	0.17	0.97
No Financial Linkages		0.67	0.71	0.24	0.09	0.95
Model	UK	0.67	0.75	0.27	0.02	0.92
No Financial Linkages		0.55	0.62	0.27	-0.06	0.88

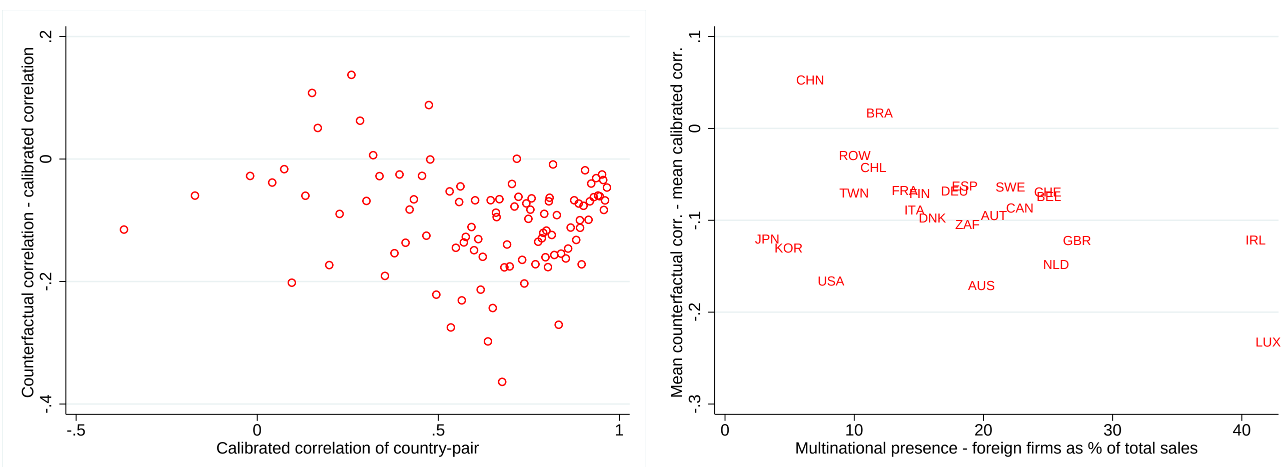
Notes: This table reports summary statistics for calibrated and counterfactual growth correlations of country-pairs for the 2005-2016 period. The rows labeled 'Model' report the correlation between two countries' GDP growth as calibrated to the actual data. GDP data are from Penn World Table 9.1. The rows labeled 'Model' report the correlation between two countries' GDP growth in a counterfactual in which we set $\zeta = 0$, shutting down financial linkages within multinationals.

Eliminating financing within multinationals leads to convergence in cross-country growth correlations, as the growth correlation for country-pairs with the highest calibrated correlations decrease the most in the counterfactual. Figure 8(a) plots, for bins of country-pairs, the change in growth correlation against the initial calibrated growth correlation. For pairs with calibrated growth correlation smaller than 0.2, the counterfactual correlation is only 0.05 points lower. In contrast, for pairs with a calibrated growth correlation between 0.2

and 0.6, this decline equals 0.07 points, while counterfactual growth correlations are 0.11 points smaller for pairs with calibrated growth correlations larger than 0.6.

Financial linkages within multinationals are particularly important in accounting for business cycle correlations of countries in which foreign firms make up a large share of sales, such as the United Kingdom, the Netherlands, and Ireland. For some of these countries, the average growth correlation with other economies decreases by almost 40 % in our counterfactual. Figure 8(b) plots, for each country in our sample, the average change in bilateral growth correlations against the share of sales that accrue to foreign subsidiaries in each country. On average, a country with a 10 percentage points higher share of foreign sales has an average counterfactual correlation that is 0.03 points lower than the average calibrated growth correlation.

Figure 8 Calibrated and Counterfactual Growth Correlations



Notes: Left figure plots, for bins of country-pairs, the change in growth correlation against the initial calibrated growth correlation. Right figure plots the average change in bilateral growth correlations (change between counterfactual correlation and calibrated correlation) against the share of sales that accrue to foreign subsidiaries in each country. Data on sales shares are from AMNE.

5. Conclusions, Policy Implications and Future Research

How do cross-border financial linkages transmit and amplify economic shocks across countries? We examine the role of cross-border financial linkages between firms in driving the global business cycle. We incorporate financial linkages into a multicountry general equilibrium framework and derive sufficient statistics for the impact of external financial shocks on domestic output. We then provide the first micro-evidence of the transmission of financial shocks within US multinationals during the 2008-09 crisis and assess the macroeconomic implications of financial linkages within multinationals. Accounting for financial linkages within multinationals substantially increases comovement of GDP growth, especially between countries that have strong multinational ties. This quantitative result is an order of magnitude larger than output comovement in standard quantitative models that connect countries through trade linkages only.

Our results have implications for monetary and macroprudential policy and macroeconomic surveillance. They suggest that policymakers abstracting from financial linkages within multinationals underestimate the global spillovers of financial shocks. We stress that generally, financial linkages not only transmit financial shocks but also facilitate the efficient international allocation of capital. It is therefore key to preserve the benefits of increased financial integration while minimizing financial distress through macroprudential oversight, including policy coordination and collaboration (IMF, 2013). Our framework can serve as a first step towards the analysis of macroprudential policy in the context of international integration of between-firm financial and trade linkages.

This paper focuses on financial linkages within multinationals, but our theoretical framework can be used to study the role of other types of financial shocks and linkages that may be quantitatively important for business cycle comovement. When a multi-establishment firm is financially constrained, then a cash flow shock to one of its establishments will increase the cost of capital for the entire firm (e.g. Giroud and Mueller, 2019); a demand shock in one region has the potential to lower factor demand in other regions through this channel. Our quantitative analysis can also be extended by including other types of international financial linkages like portfolio flows (e.g. Jotikasthira et al., 2012) and interbank flows (e.g. Hale et al., 2016). We leave these extensions for future research.

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A. Appendix

This Appendix covers the extended framework with intersectoral input-output linkages, proofs and derivations, as well as additional figures and tables from the empirical evidence and quantitative results. We cover additional literature, data details and replication exercises in the Online Appendix, available on marijnbolhuis.info.

A.1 Models

A.1.1 Framework with Intersectoral Input-Output Linkages.

There are J domestic intermediate goods, each of which serves as an input for the production of the consumption good and intermediate goods. We index intermediate goods using $j, j' \in \{1, .., J\}$. The consumption good is aggregated as:

$$Y^G \equiv F(Y^1, .., Y^J)$$

We assume $F(\cdot)$ is continuously differentiable, increasing and concave in all arguments, and exhibits constant returns to scale. We normalize the price of Y^G to one. Production of a domestic intermediate good by a representative firm takes the form:

$$Q^j = z^j F_j(L^j, \{x_n^{jj'}\}_{j'=1}^J, \{x_i^j\}_{i=n+1}^N) \tag{25}$$

$F_j(\cdot)$ is continuously differentiable, increasing and concave in all arguments, and exhibits constant returns to scale with respect to L^j and $\{x_n^{jj'}\}_{j'=1}^J$.

Equilibrium. Given fundamentals $\{\bar{P}_i\}_{i=n+1}^N, \bar{L}, z^j, \{\bar{r}_{n'}\}_{n'=n}^N, D$, an equilibrium is a collection of prices $P^j, w, \{r_{n'}\}_{n'=n}^N$, allocations $L, x^{jj'}, \{x_{n'}^j, b_{n'}\}_{n'=n}^N, Y, C, Y^G$, and quasi-rents Π such that :

- The representative final goods aggregator picks the allocation $\{Y^{j'}\}_{j'=1}^J$ that solves
  $1 \equiv \min_{\{Y^{j'}\}_{j'=1}^J} \sum_{j'=1}^J P^{j'} Y^{j'} \quad s.t. \quad F(Y^1, .., Y^J) = 1$
- The representative sectoral producer picks the allocation $L^j, \{\{x^{jj'}\}\}_{j'=1}^J \{b_i^j\}_{i=n}^N$ that solves
  $P^j \equiv \min_{L^j, \{x^{jj'}\}_{j'=1}^J} u^j(wL^j + \sum_{j'=1}^J P^{j'} x^{jj'}) \quad s.t. \quad z^j F_j(L^j, \{x^{jj'}\}_{j'=1}^J) = 1$
  and
  $\min_{\{b_i^j\}_{i=1}^N} \sum_{i=1}^N r_i b_i^j \quad s.t. \quad 1 = G(\cdot)$
- The intermediaries maximize profits such that the zero-profit condition (4) holds

- C satisfies the consumer budget constraint (7)
- The accounting identity (6) holds
- The current account is balanced (8)
- The factor market clears such that $\sum_{j'=1}^{J} L^{j'} = \bar{L}$.
- Each sectoral goods market clears: $Q^j = Y^j + \sum_{j'=1}^{J} x^{jj'} \quad \forall j \in \{1, .., J\}$

A.1.2 Planner's Problem

First, we define output wedges:

$$(1 - \tau_{ox,t}) = \frac{1}{u_{ox,t}}$$

$$u_{ox,t} = [\zeta_{ox,t}(1 + \bar{r}_{o,t})^{1-\phi} + (1 - \zeta_{ox,t})(1 + \bar{r}_{x,t})^{1-\phi}]^{1/(1-\phi)}$$

The planner's objective at date 0 is to maximize

$$W = \sum_{n=1}^{N} \eta_n V_n$$

taking $K_{n,1}$ and fundamentals (incl. labor endowments) as given, subject to the constraints:

- Labor supply of the household cannot exceed the labor endowment:

$$L_{n,t} \leq \bar{L}_{n,t}$$

- The sum of labor and capital assigned to each variety producer cannot exceed total supply:

$$\sum_{o=1}^{N} \int_0^1 L_{on}^{\omega} d\omega \leq L_{n,t}$$

$$\sum_{o=1}^{N} \int_0^1 K_{on}^{\omega} d\omega \leq K_{n,t}$$

- For each variety, output cannot exceed what is implied by technology (note the output wedge):

$$Y^{\omega}_{ox,t} \leq (1-\tau_{ox}) z^{\omega}_{ox,t} \delta_{ox} \left(\frac{K^{\omega}_{ox,t}}{\alpha(1-\alpha^X)}\right)^{\alpha(1-\alpha^X)} \left(\frac{L^{\omega}_{ox,t}}{(1-\alpha)(1-\alpha^X)}\right)^{(1-\alpha)(1-\alpha^X)} \left(\frac{x^{\omega}_{ox,t}}{\alpha^X}\right)^{\alpha^X} \quad ; \quad \alpha, \alpha^X \in [0,1]$$

- The world's use of each variety cannot exceed output:

$$\sum_{m=1}^{N} d_{xm,t} X^{\omega}_{xm,t} \leq Y^{\omega}_{ox,t}$$

where $X^{\omega}_{xm,t}$ is country m's absorption of variety ox^{ω} from country x.

- Country n's total absorption of each variety cannot exceed what it absorbs from each source country:

$$X^{\omega}_{n,t} \leq \sum_{i=1}^{N} X^{\omega}_{ni,t}$$

- Final good absorption in country n cannot exceed the implied aggregate output of the aggregator:

$$X_{n,t} \leq \left(\int_0^1 (X^{\omega}_{n,t})^{(\sigma-1)/\sigma} d\omega\right)^{\sigma/(\sigma-1)}$$

- The sum of household consumption, intermediate input use and investment cannot exceed country n's absorption of the final good:

$$C_{n,t} + \int_0^1 \sum_{o=1}^{N} x^{\omega}_{on,t} d\omega + I_{n,t} \leq X_{n,t}$$

- Capital in next period cannot exceed what is implied by investment and the current capital stock:

$$K_{n,t+1} \leq (1+\bar{r}_{n,t})^{-\alpha^K} (I_{n,t})^{\alpha^K} (K_{n,t})^{1-\alpha^K} + (1-\delta) K_{n,t}$$

Finally, we assume that the preference and technology parameters ensure that the planner's problem is bounded.

A.1.3 Decentralized Equilibrium of Dynamic Model

Equilibrium Relationships

Variety producers. The cost of a bundle of inputs in country x when the owner is from country o:

$$c_{ox,t} = \rho_{x,t}^{\alpha(1-\alpha^X)} w_{n,t}^{(1-\alpha)(1-\alpha^X)} P_{x,t}^{\alpha^X} [\zeta_{ox,t} r_{o,t}^{1-\phi} + (1-\zeta_{ox,t}) r_{x,t}^{1-\phi}]^{1/(1-\phi)} \tag{26}$$

Aggregators. The price index in country x that results from the aggregator optimally sourcing varieties is given by:

$$P_{i,t} = [\sum_{o=1}^{N} \sum_{x=1}^{N} (A_{o,t})^{\theta} (c_{ox,t} \delta_{ox,t} d_{xi,t})^{-\theta}]^{-1/\theta} \tag{27}$$

The share of expenditure of country i on goods produced in country x with owners from country o is given by:

$$\pi_{oxi,t}^{j} = \frac{(A_{o,t})^{\theta} (c_{ox,t} \delta_{ox,t} d_{xi,t})^{-\theta}}{\sum_{o'=1}^{N} \sum_{x'=1}^{N} (A_{o',t})^{\theta} (c_{o'x',t} \delta_{o'x',t} d_{x'i,t})^{-\theta}} \tag{28}$$

Household. The household optimally chooses employment and consumption such that:

$$L_{x,t} = (\frac{w_{x,t}}{P_{x,t}})^{\psi} \tag{29}$$

$$P_{n,t} C_{n,t} = \eta_n \nu_{n,t} \tag{30}$$

Financial Intermediaries. Profits of financial intermediaries are zero:

$$r_{n,t} = 1 + \bar{r}_{n,t} \tag{31}$$

Static Equilibrium. Given fundamentals (Θ, Ψ_t) and household absorption, a static equilibrium consists of a vector of prices $\{w_{n,t}, \rho_{n,t}, r_{n,t}, P_{n,t}\}$ such that:

- variety producers minimize costs such that unit costs are given by (26) ;
- aggregators minimize costs such that trade shares are given by (28) and the price indices by (27);
- the household maximizes utility such that employment and consumption spending are given by (29) and (30) ;

- financial intermediaries arbitrage profits to zero (31
- markets clear such that the following hold:
  - $Y_{ox,t} = \sum_{i=1}^{N} \pi_{oxi,t} X_{i,t}$
  - $X_{n,t} = C_{n,t} + I_{n,t} + \alpha^X \sum_{o=1}^{N} Y_{on,t}$
  - $w_{n,t} L_{n,t} = (1-\alpha)(1-\alpha^X) \sum_{o=1}^{N} Y_{on,t}$
  - $\rho_{n,t} K_{n,t} = \alpha(1-\alpha^X) \sum_{o=1}^{N} Y_{on,t}$

  where $Y_{on,t}$ is the value of production by firms in country n with an owner from country o, and X_i is the value of country i's total spending.

Dynamic Equilibrium. Given fundamentals, a dynamic equilibrium consists of a series of static equilibria such that:

- investment $I_{n,t}$ satisfies
  $\frac{P_{n,t}}{r_{n,t}}(\frac{I_{n,t}}{K_{n,t}})^{1-\alpha^K} = \beta\alpha^K[\rho_{n,t+1} + \frac{(1-\alpha^K)P_{n,t+1}I_{n,t+1}}{\alpha^K K_{n,t+1}} + \frac{(1-\delta)P_{n,t+1}}{\alpha^K r_{n,t+1}}(\frac{I_{n,t+1}}{K_{n,t+1}})^{1-\alpha^K}]$
- the law of motion of capital holds.

Stationary Equilibrium. A stationary equilibrium is a dynamic equilibrium in which fundamentals are constant and capital stocks have settled down to constant levels K_n such that
$\frac{I_n}{K_n} = (\frac{\delta}{\bar{r}_n})^{1/\alpha^K}$
$\frac{\rho_n K_n}{X_n^K} = \frac{1-\beta+\beta\delta\alpha^K}{\beta\delta\alpha^K}$

A.1.4 Equilibrium of Dynamic Model in Changes

Equilibrium in Changes. We can summarize an equilibrium in changes as follows. Given shocks and $\hat{K}_{n,t}$, changes in the vector of prices $\{\hat{w}_{n,t}, \hat{\rho}_{n,t}, \hat{r}_{n,t}, \hat{P}_{n,t}\}$ solve

- $\hat{c}_{ox,t} = \hat{\rho}_{x,t}^{\alpha(1-\alpha^X)} \hat{w}_{x,t}^{(1-\alpha)(1-\alpha^X)} (\hat{P}^{j'})^{\alpha^X} [(1-\lambda_{ox,t-1})\hat{r}_{x,t}^{1-\phi} + \lambda_{ox,t-1})\hat{r}_{o,t}^{1-\phi}]^{1/(1-\phi)}$
- $\hat{\pi}_{oxi,t} = (\frac{\hat{c}_{ox,t}\hat{\delta}_{ox,t}\hat{d}_{xi,t}}{\hat{A}_{o,t}\hat{P}_{i,t}})^{-\theta}$
- $\hat{P}_{i,t} = [\sum_{o=1}^{N}\sum_{x=1}^{N} \pi_{oxi,t-1}(\hat{A}_{o,t}^{j})^{\theta}(\hat{c}_{ox,t}^{j}\hat{\delta}_{ox,t}\hat{d}_{xi,t}^{j})^{-\theta}]^{-1/\theta}$
- $\hat{L}_{x,t} = (\frac{\hat{w}_{x,t}}{\hat{P}_{x,t}})^{\psi}$
- $\hat{P}_{x,t}\hat{C}_{x,t} = \hat{\nu}_{x,t}$

- $\hat{X}^K_{n,t}$ solves

  $\frac{1}{\beta}\frac{\hat{K}_{n,t}}{\hat{K}_{n,t}-(1-\delta^K)} = \alpha^K\frac{\hat{\rho}_{n,t}\hat{K}_{n,t}\rho_{n,t-1}K_{n,t-1}}{X^K_{n,t-1}} + \hat{X}^K_{n,t}[(1-\alpha^K) + \frac{1}{\hat{r}_{n,t}}(\frac{\hat{P}_{n,t}\hat{K}_{n,t}}{\hat{X}^K_{n,t}})^{\alpha^K}\frac{1-\delta^K}{\hat{K}_{n,t}-(1-\delta^K)}]$

- Market clearing:
  - $\hat{w}_{n,t}\hat{L}_{n,t}w_{n,t-1}L_{n,t-1} = (1-\alpha)(1-\alpha^X)Y_{n,t}$
  - $\hat{\rho}_{n,t}\hat{K}_{n,t}\rho_{n,t-1}K_{n,t-1} = \alpha(1-\alpha^X)Y_{n,t}$
  - where $Y_{n,t}$ solve

    $Y_{n,t} = \sum_{o=1}^{N}\sum_{i=1}\hat{\pi}_{oni,t}\pi_{oni,t-1}X_{i,t}$

    $X_{i,t} = \hat{w}_{n,t}\hat{L}_{n,t}w_{n,t-1}L_{n,t-1} + \hat{\rho}_{n,t}\hat{K}_{n,t}\rho_{n,t-1}K_{n,t-1} - \hat{X}^K_{n,t}X^K_{n,t-1} + \alpha^X Y_{i,t}$

and $\hat{K}_{n,t+1}$ solve:

$\frac{\hat{K}_{n,t+1}-(1-\delta)}{\hat{K}_{n,t}-(1-\delta^K)} = \hat{r}_{n,t}(\frac{\hat{X}^K_{n,t}}{\hat{P}_{n,t}\hat{K}_{n,t}})^{\alpha^K}$

A.2 Proofs and Derivations

A.2.1 Proofs

Proof of Lemma 1. We show the proof for the general case with intersectoral linkages. The one-sector case follows naturally.

The optimality conditions for the firm's problem, given u^j, are:

$$u^j w L^j = z^j \sigma_L^j P^j F_j(\cdot)$$

$$u^j P^{j'} x_n^{jj'} = z^j \sigma_x^{jj'} P j F_j(\cdot) \quad \forall j, j'$$

$$u^j \bar{P}_i x_i^j = z^j \sigma_{x,i}^j P^j F_j(\cdot) \quad \forall i$$

where

$$\sigma_L^j = \frac{\partial \ln F_j(\cdot)}{\partial \ln L^j}$$

$$\sigma_x^{jj'} = \frac{\partial \ln F_j(\cdot)}{\partial \ln x_n^{jj'}}$$

$$\sigma_{x,i}^j = \frac{\partial \ln F_j(\cdot)}{\partial \ln x_i^j}$$

With an output wedge, these conditions become:

$$w L^j = (1-\tau^j) z^j \sigma_L^j F_j(\cdot)$$

$$P^{j'} x_n^{jj'} = (1-\tau^j) z^j \sigma_x^{jj'} P^j F_j(\cdot) \quad \forall j, j'$$

$$\bar{P}_i x_i^j = (1-\tau^j) z^j \sigma_{x,i}^j P^j F_j(\cdot) \quad \forall i$$

It is thus clear that the same allocations will be generated under:

$$(1-\tau^j) = \frac{1}{u^j}$$

■

Proof of Lemma 2. The first part of the proof is similar to that of Lemma 1 in Liu (2019).

First, we define some objects. Let β be the $J \times 1$ expenditure share for the consumption good, i.e.

$$\beta^j \equiv \frac{P^j Y^j}{\sum_{j'=1}^{J} P^{j'} Y^{j'}}$$

Let $\Sigma \equiv [\sigma_x^{jj'}]$ be the $J \times J$ matrix of equilibrium production elasticities for domestic intermediate inputs. Let $\mu \equiv [\mu^j]$ be the $J \times 1$ vector of sectoral **influence**, an elasticity-based measure of sectoral importance:

$$\mu' \equiv \beta'(I - \Sigma)^{-1}$$

Total differentiation of the two cost minimization problems with respect to z^j, P^j and w gives

$$d \ln P^j = -d \ln z^j + \sigma_L^j d \ln w + \sum_{j'=1}^{J} \sigma_x^{jj'} d \ln P^j$$

$$0 = \sum_{j'=1}^{J} \beta^{j'} d \ln P^{j'}$$

Putting the first condition in matrix form and solving for $d \ln P$:

$$d \ln P = (I - \Sigma)^{-1}[-d \ln z + \sigma_L \cdot d \ln w]$$

Pre-multiplying by β' and using the second condition:

$$\beta'(I - \Sigma)^{-1}[\sigma_L \cdot d \ln w] = \beta'(I - \Sigma)^{-1} d \ln z$$

So for any arbitrary sector j, we have, in matrix form:

$$\frac{d \ln w}{d \ln z^j} = \frac{\beta'(I - \Sigma)^{-1} e^j}{\beta'(I - \Sigma)^{-1} \sigma_L}$$

where e^j is a vector with the j-th element equal to one and zero otherwise. Note that the numerator equals the sector's influence μ^j, so it suffices to show that $\beta'(I-\Sigma)^{-1}\sigma_L = 1$. To see this, note that with constant-returns-to-scale, for any sector j, we have

$$\sigma_L^j + \sum_{j'=1}^{J} \sigma_x^{jj'} = 1$$

In matrix form:

$$\Sigma\mathbf{1} + \sigma_L = \mathbf{1}$$

which can be rearranged such that

$$(I - \Sigma)^{-1}\sigma_L = \mathbf{1}$$

and so

$$\beta'(I - \Sigma)^{-1}\sigma_L = \beta'\mathbf{1} = 1$$

where the last equality uses $\sum_{j'=1}^{J} \beta^{j'} = 1$. We are left with:

$$\frac{d\ln w}{d\ln z^j} = \mu^j$$

The proof then follows since by the income approach $Y = w\bar{L}$ and from the fact that the supply of $\bar{L}$ is fixed. Note that if there is only one sector, influence is simply the input output multiplier:

$$\mu = \iota$$

■

Proof of Proposition 1. First, we show the impact through financial linkages. Note that up to a first order, $(1 - \tau^j)$ acts as a Hicks-neutral productivity shock. Combining Lemma 1 and Lemma 2 gives

$$\frac{d\ln Y}{d\ln u^j} = \mu^j \frac{d\ln u^j}{d\ln r_i}$$

We are thus left to show that the second term equals λ_i. Applying Shephard's lemma to the funding problem in 3, we have

$$\frac{du^j}{dr_i} = b_i^j$$

It then follows that

$$\frac{d\ln u^j}{d\ln r^i} = b_i^j \frac{r_i^j}{u^j} = \frac{r_i b_i^j}{\sum_{n'=n}^{N} r_{n'} b_{n'}^j}$$

$$\frac{d\ln Y}{d\ln r_i} = \mu^j \lambda_i^j$$

Again, the one-sector version follows where $\mu = \iota$.

We're left to show the impact through trade linkages. Note that the change in import prices affect sectoral prices in ways similar to input-augmenting productivity shocks. We quickly go through a proof like that of Lemma 2. Total differentiation of the two cost minimization problems with respect to $\bar{P}_i$, P^j and w gives

$$d\ln P^j = \sigma_L^j d\ln w + \sum_{j'=1}^{J} \sigma^{jj'} d\ln P^{j'} + \sigma_i^j d\ln \bar{P}_i$$

$$0 = \sum_{j'=1}^{J} \beta^j d\ln P^{j'}$$

Combining the two conditions in matrix form:

$$\frac{d\ln w}{d\ln \bar{P}_i} = \frac{\beta'(I-\Sigma)^{-1}e^j}{\beta'(I-\Sigma)^{-1}\sigma_L}\sigma_i^j$$

Using $\beta'(I-\Sigma)^{-1}e^j = \mu^j$, $\beta'(I-\Sigma)^{-1}\sigma_L = 1$ and $Y = w\bar{L}$, it follows that:

$$\frac{d\ln Y}{d\ln \bar{P}_i} = \sum_{j'=1}^{J} \mu^{j'}\sigma_i^{j'}$$

With one sector, this implies

$$\frac{d\ln Y}{d\ln \bar{P}_i} = \iota\sigma_i$$

We can proxy σ_i using the imports from i as a share of sales. If financial frictions are small, the FOC from the firm problem implies

$$\sigma_i = \frac{\bar{P}_i x_i u}{Y^G} \approx \frac{\bar{P}_i x_i}{Y}$$

■

Proof of Proposition 2. Differentiate $\frac{d\ln Y}{d\ln r_i} = -\iota(\lambda_i + \sigma_i)$ with respect to $\ln r_i$:

$$\frac{d^2\ln Y}{d\ln(r_i)^2} = -\iota[(\lambda_i+\sigma_i)\frac{d\ln\iota}{d\ln r_i} + \frac{d\ln\sigma_i}{d\ln r_i} + \frac{d\ln\lambda_i}{d\ln r_i}]$$

The first two terms are zero since we assume that $F(\cdot)$ is Cobb-Douglas, so that ι and σ_i are constant. We're left to unpack the third term. Differentiate $\sum_{n'=1}^{N}\lambda_{n'} = 1$ and rearrange:

$$\lambda_i \frac{d\ln\lambda_i}{d\ln r_i} = -\sum_{n'\neq i}\lambda_{n'}\frac{d\ln\lambda_{n'}}{d\ln r_i}$$

Add $(1-\lambda_i)\frac{d\ln\lambda_i}{d\ln r_i}$ to both sides:

$$\frac{d\ln\lambda_i}{d\ln r_i} = -\sum_{n'\neq i}\lambda_{n'}\frac{d\ln\lambda_{n'}/\lambda_i}{d\ln r_i}$$

Plugging this into our expression for $\frac{d^2\ln Y}{d\ln(r_i)^2}$ gives:

$$\frac{d^2\ln Y}{d\ln(r_i)^2} = \iota\lambda_i\sum_{n'\neq i}^{N}\lambda_{n'}\frac{d\ln\lambda_{n'}/\lambda_i}{d\ln r_i}$$

■

Proof of Corollary 1. With $G(\cdot)$ CES, we have

$$\lambda_{n'} = \zeta_{n'}^{\phi} r_{n'}^{1-\phi}$$

Taking the logs of the ratio with λ_i, then differentiating with respect to $\ln r_i$ gives

$$\frac{d\ln\lambda_{n'}/\lambda_i}{d\ln r_i} = \phi - 1$$

which equals zero in the Cobb-Douglas case ($\phi = 1$). Plugging this into the result of Proposition 2 and combining this with Proposition 1 gives

$$\frac{d\ln Y}{d\ln r_i} + \frac{d^2\ln Y}{d\ln(r_i)^2} = -\iota[\lambda_i - \lambda_i(1-\lambda_i)(\phi-1) + \sigma_i]$$

■

A.2.2 Derivations

$G(\cdot)$ **as CES.** If funding sources aggregate using a standard CES with weights ζ_i, the firm problem becomes:

$$u \equiv \min_{\{b_{n'}\}_{n'=n}^{N}} \sum_{n'=1}^{N} r_{n'}b_{n'}$$

subject to

$$G(\cdot) = [\zeta_{n'}^{1/\phi}(b_{n'})^{(\phi-1)/\phi}]^{\phi/(\phi-1)} = 1$$

Taking the ratio of the first-order conditions of any two arbitrary funding sources i and i':

$$b_i = b_{i'}(r_{i'})^{\phi}(\zeta_{i'})^{-1}(r_i)^{\phi}\zeta_i$$

Substituting this into the constraint and rearranging gives:

$$b_{i'} = (r_{i'})^{-\phi}\zeta_{i'}[\sum_{n'=1}^{N}\zeta_{n'}(r_{n'})^{1-\phi}]^{(\phi/(1-\phi)}$$

Computing the unit costs and rearranging gives

$$u = [\sum_{n'=1}^{N}\zeta_{n'}(r_{n'})^{1-\phi}]^{1/(1-\phi)}$$

We now show the two extreme cases. For Leontief, we have

$$\lim_{\phi\to 0} u = \lim_{\phi\to 0}[\sum_{n'=1}^{N}\zeta_{n'}r_{n'}^{1-\phi}]^{1/(1-\phi)} = \sum_{n'=1}^{N}\zeta_{n'}r_{n'}$$

For the case where $\phi \to \infty$, we proceed in two steps. First take logarithms and use L'Hopital's rule:

$$\lim_{\phi\to\infty}\ln u = \lim_{\phi\to\infty}\frac{\sum_{n'=1}^{N}\zeta_{n'}(r_{n'})^{1-\phi}}{1-\phi} = \lim_{\phi\to\infty}\frac{\sum_{n'=1}^{N}\zeta_{n'}(r_{n'})^{1-\phi}\ln r_{n'}}{\sum_{n'=1}^{N}\zeta_{n'}(r_{n'})^{1-\phi}}$$

Assuming that the distribution of r_ω^k is bounded, divide by $\min\{r_\omega^k\}^{1-\phi}$ on both sides:

$$\lim_{\phi\to\infty}\frac{\sum_{n'=1}^{N}\zeta_{n'}(r_{n'}/\min\{r_i\})^{1-\phi}\ln r_{n'}}{\sum_{n'=1}^{N}\zeta_{n'}(r_{n'}/\min\{r_i\})^{1-\phi}} = \ln\min\{r_{n'}\}$$

Hence $\lim_{\phi\to\infty} u = \min\{r_{n'}\}$ since the limit of a logarithmic equals the logarithm of the limit.

Reduced Form Estimates of Aggregate Effect. We derive the following. Under the assumptions

A1 *The aggregate effect equals the sum of direct sales effects measured at each subsidiary.*

A2 *The least affected firms did not experience a shift to their loan supply during the crisis.*

the aggregate change in sales ΔS is given by

$$\Delta S = \int s_\omega^{obs.}(1-\exp\{-\gamma(\Delta M_\omega - \Delta M_1)\})d\omega$$

Derivation. Let $s_\omega^{obs.}$ denote the sales of the subsidiary during the crisis, and let s_ω^{cf} denote the counterfactual sales of the same subsidiary in the absence of the financial shock.

The aggregate change in sales as a result of the financial shock is then given by

$$\Delta S = \int (s_\omega^{obs.} - s_\omega^{cf}) d\omega$$

Given the assumptions and the reduced form result, we can compute this term. First, rewrite as

$$\Delta S = \int s_\omega^{obs.} (1 - \frac{s_\omega^{cf}}{s_\omega^{obs.}}) d\omega$$

Note that

$$\ln \frac{s_\omega^{obs}}{s_\omega^{cf.}} - \ln \frac{s_1^{obs}}{s_1^{cf.}} = (\beta_0^{obs.} + \gamma \Delta M_\omega + \nu_\omega^{obs.}) - (\beta_0^{cf} + \nu_\omega^{cf}) - (\beta_0^{obs} + \gamma \Delta M_1 + \nu_1^{obs.}) + (\beta_0^{cf} + \nu_1^{cf})$$

where ΔM_1 is the loan supply shifter of the least affected firms. Using A1-A2 so that $\ln s_1^{obs.} + \nu_1^{obs} = \ln s_1^{cf} + \nu_1^{cf}$:

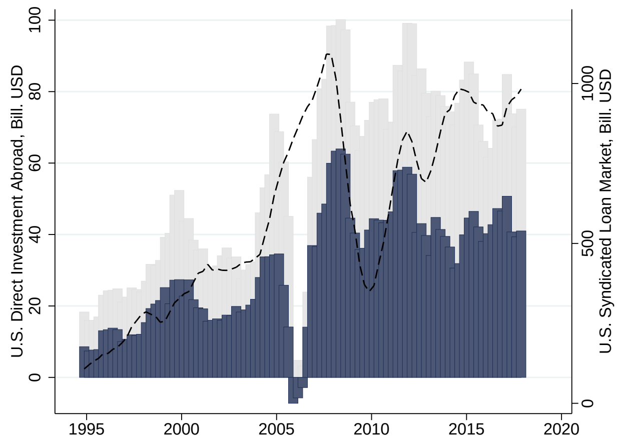
$$\ln \frac{s_\omega^{obs}}{s_\omega^{cf.}} = \gamma(\Delta M_\omega - \Delta M_1) + (\nu_\omega^{obs.} - \nu_\omega^{cf})$$

Inserting this into the equation for the change in aggregate sales, and applying the law of large numbers to the exogenous idiosyncratic shocks ν gives our desired result:

$$\Delta S = \int s_\omega^{obs.} (1 - \exp\{-\gamma(\Delta M_\omega - \Delta M_1)\}) d\omega$$

A.3 Additional Figures and Tables

Figure A.1 US Syndicated Loan Market and Outward Foreign Direct Investment



Notes: Figure plots the size of US syndicated loan market (dashed line, right axis) and US outward foreign direct investment (left axis) over time. Dark bars is investment in Europe only. Dip in 2005 is due to an increase in repatriated profits that were temporarily taxed at a lower rate under the American Jobs Creation Act of 2004. Data on syndicated loans are from Dealscan. We take a 1 year rolling average to purge seasonality. Data on US outward foreign direct investment are from the Bureau of Economic Analysis.

Table A.1 Balancing of Borrower Characteristics

	Quintile $\Delta \ln M_\omega$					Std. Dev.
	1st	2nd	3rd	4th	5th	
Growth sales sector, domestic firms, 07-09, mean	0.18	0.34	-0.37	-0.03	0.46	0.85
Growth sales sector, foreign firms, 07-09, mean	-3.9	-3.4	-5.8	-4.5	-3.2	2.9
Growth sales country, domestic firms, 07-09, mean	-1.1	-1.0	-0.7	-1.4	-0.7	2.0
Growth sales country, foreign firms, 07-09, mean	-4.4	-4.3	-3.7	-5.2	-3.9	4.9
Sales parent, 2007, B.$, mean	7.5	9.4	23.7	40.0	11.2	21.7
Sales subs., 2007, B.$, mean	0.05	0.09	0.31	0.17	0.23	0.38
Year of last syndicate, mean	2005.6	2005.8	2006.6	2006.0	2005.4	1.5

Notes: Table provides summary statistics of borrower characteristics by quintiles of the treatment variable.

Table A.2 The Effect of a Financial Shock on Subsidiary Sales: Non-Financial Subsidiaries Only

	(1)	(2)	(3)
Dependent variable: (log) sales of subsidiary $\ln s^{j}_{\omega,n,t}$			
$\Delta \ln M^{j}_{\omega} \times 1_{t\in\{09,10\}}$	0.0985**	0.119**	0.134***
	(0.0323)	(0.0309)	(0.0303)
Observations	2,070	2,070	2,064
R-squared	0.993	0.993	0.993
Controls	NO	YES	YES
Subsidiary FE	YES	YES	YES
Country-Year FE	YES	YES	YES
Sector-Year FE	NO	NO	YES
# of subsidiaries	344	344	344
# of countries	22	22	22
β_{Oster}			0.120
δ_{Oster}			9.55

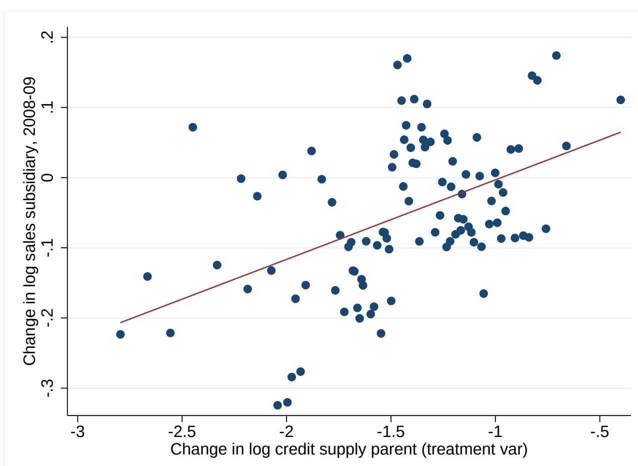
Notes: We restrict the sample to subsidiaries of which the parents are not active in Finance and Insurance (NAICS code 52) or Real Estate Rental and Leasing (NAICS code 53). See Table 2 for other details on the sample and standard errors.

Table A.3 Treatment Effect in Changes - Regression Framework

	(1)	(2)	(3)
Dependent variable: change (log) sales of subsidiary $\ln s^j_{\omega,n,2008-09}$			
$\Delta \ln M^j_\omega$	0.102***	0.115***	0.125***
	(0.0211)	(0.0166)	(0.0186)
Observations	403	403	402
R-squared	0.144	0.157	0.180
Controls	NO	YES	YES
Country FE	YES	YES	YES
Sector FE	NO	NO	YES
# of countries	22	22	22

Robust standard errors in parentheses, clustered by country of subsidiary.

Figure A.2 Treatment Effect in Changes - Binned Scatterplot



Notes: Figure visualizes the treatment effect in changes of the regression framework in Table A.3. Each dot represents about four observations. Scatterplot uses baseline controls, country fixed effects, and sector fixed effects.

Table A.4 The Effect of a Financial Shock on Subsidiary Sales: Additional Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: (log) sales of subsidiary $\ln s^j_{\omega,n,t}$								
$\Delta \ln M^j_\omega \times 1_{t\in\{09,10\}}$	0.0988**	0.121**	0.130***	0.136***	0.115***	0.123***	0.122***	0.123***
	(0.0263)	(0.0307)	(0.0269)	(0.0287)	(0.0249)	(0.0272)	(0.0238)	(0.0262)
$\Delta \ln M^j_\omega \times 1_{t\in\{09,10\}} \times 1_{j=serv.}$	0.140							
	(0.0747)							
$\Delta \ln M^j_\omega \times 1_{t\in\{09,10\}} \times 1_{USbank}$		0.00477						
		(0.0240)						
Observations	2,412	2,412	2,286	1,968	2,160	2,148	2,274	1,224
R-squared	0.994	0.994	0.993	0.993	0.994	0.994	0.993	0.995
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Subsidiary FE	YES	YES	YES	YES	YES	YES	YES	YES
Country-Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Sector-Year FE	YES	YES	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses, clustered by US parent and time period.

Notes: In column (1), we interact our treatment with a dummy equal to one if the parent of the subsidiary is classified as a services firm. In column (2), we interact our treatment with a dummy equal to one if the parent of the subsidiary banks with a US lender. In columns (3)-(7), we drop subsidiaries in Germany, France, Spain, Italy and the Netherlands from our sample (in that order). In column (8), we restrict the analysis to only subsidiaries that are based in those countries. See Table 2 for other details on the sample and standard errors.