Debt in Tiered-Production Networks∗

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Abstract

Firms simultaneously choose sourcing and capital structure, forming a production network and imbuing it with credit risk. When firms increase leverage, they offload the increased financial risk by diversifying their supply. Suppliers that default do not deliver products to customers, so risky debt upstream reduces expected production downstream. The risky debt and supplier reliance introduce debt overhang in tiered production. The overhang affects equilibrium pricing within the network and decreases the aggregate firm value relative to a riskless benchmark. Because of the network structure, increasing competition among suppliers generates ambiguous effects on final output and may not alleviate the debt-overhang problem. Empirically, I instrument for changes in leverage with changes in corporate tax rates and find a 1.4-percentage-point increase in leverage leads to a 10% higher chance of adding an additional supplier.

Keywords: Production Networks, Capital Structure, Debt Overhang, Supply Disruption

JEL Classifications: G32, D85

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1 Introduction

Firm capital structure and supply chain decisions are intertwined. Firms establish supply-chain relationships, forming a production network. The observed production network in the United States account for over half of all public firm production. Thus, a firm’s credit risk can have large and far-reaching consequences for other firms in the network. The extant literature has considered the interaction between the capital structure of a single firm and its customers or suppliers. If shocks to a firms’ suppliers spill over in the network, for example, to suppliers’ suppliers, such analysis may be insufficient. Financing, production and supply network decisions will then be co-determined for all firms in the network. Recognizing that firms produce in networks and adjust to economic shocks with both capital structure and sourcing introduces a new mechanism through which leverage may affect equilibrium risk and production.

Compared to spot markets for inputs, a network formed by supply-chain contracts better represents the actual production process. In practice, a firm’s feasible set of suppliers may be restricted by quality, specialization, or geographic distance. Moreover, fixed costs to establish new relationships in the form of negotiation costs, legal fees, or relationship-specific investments also prohibit firms from taking on an infinite number of suppliers. The resulting discrete network introduces a risk distribution channel that would not exist with spot markets for inputs. The production-network structure explicitly models network spillovers in bankruptcy.\(^1\)

In this paper, I develop a model to study leverage, credit risk, and network formation where firms choose capital structure and establish supply relationships through incomplete contracts. Because firms can only contract on prices and quantities, not on capital structure or default restrictions, the model introduces a new notion of debt overhang in tiered production that is distinct from the under-investment issue formalized by Myers (1977). In

\(^1\)In prior literature, these spillovers were considered “indirect costs” of financial distress and modeled by a parameter that affects the bankruptcy recovery rate. For example, see Leland (1994), Strebulaev (2007), and He and Xiong (2012).
that model, investment benefits debt, while equity is in charge of investment decisions and bears the cost. Unlike the dynamic inefficiencies featured in standard debt overhang, debt overhang in tiered production arises even in a static setting. The overhang comes from risky debt and tiered production, a structure that captures multiple stages of production where goods flow from primary raw materials producers down to final consumption goods producers. Through the tiered production structure, firm-level choices of sourcing and capital structure generate network-level effects.

At the firm level, leverage and supply diversification interact through the cost of default. Increasing debt increases the probability of default while diversifying supply reduces it. In response to exogenous shocks to the network, firms simultaneously adjust along both margins, balancing operational risk by choosing sourcing and financial risk by choosing debt. For example, increasing the corporate profits tax rate increases the incentive of using debt. Firms use more debt, which increases the probability of default. To mitigate the higher credit risk, firms simultaneously add more suppliers. On the other hand, increasing in the number of competitors directly increases the firms’ credit risk. In response, firms decrease debt while also adding new suppliers. The firm-level responses of both sourcing and debt change both the amount of risk and its propagation in the network.

The network equilibrium delivers three implications not apparent at the firm level. First, debt overhang in tiered production arises because firms are unwilling to incur higher private production costs in order to benefit downstream producers. The overhang affects ex ante pricing and expected output. The option to default serves as a commitment device to truncate unfavorable realizations of random production costs. Firms default when realized production costs are high, disrupting operations and depriving customers of inputs to production. Reducing credit risk benefits both a firm’s creditors and customers, but is costly to its equity due to the possibility of operating with higher production costs. The amount of debt a firm uses acts as an incentive-compatibility constraint because firms must be induced to produce with higher expected profits. Customers know that a supplier with more debt is
more likely to default but is unable to contract around it. So they expect to produce less. The network equilibrium accounts for this incentive-compatibility constraint as well as the negative externality of risky supplier debt on customer firms.

Second, I provide a counterfactual example where increasing competition among suppliers exacerbates the debt overhang in tiered production. Although standard microeconomics theory predicts that increased competition in input markets should increase output, in a network with risky debt, increasing competition can decrease expected output. Firms compete in both input and output markets, bidding up input prices and decreasing output prices. Both the higher input prices and lower output prices decrease their expected profit, making them more risky. In equilibrium, the impact of higher risk can dominate the impact from having more producers, reducing production for all downstream firms. In the model, this competition effect also means that allowing firms to more easily diversify operational risk by reducing supply-chain contracting costs can decrease firm value in equilibrium, a result that is not apparent with partial-equilibrium logic.

Third, vertical integration can be justified even with competitive markets. I present a counterfactual example where the resulting conglomerate internalizes the debt overhang in tiered production that arises from decentralized firm actions. Ownership alleviates the incomplete contracts. The reduction in financial risk in the production network introduces another source of gains from vertical consolidation. Therefore, vertical consolidation can be justified, contrary to standard industrial organization models which discourages vertical integration in competitive markets.\(^2\)

The model results at the firm-level and network-level are consistent with the data. To empirically identify the relationship between capital structure and supply-chain decisions, I instrument for changes in leverage with increases in state corporate tax rates, and study the corresponding supply-chain responses. The exogenous changes in tax rates mitigates biases

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\(^2\)Vertical-integration efforts that claim synergies using transfer prices at marginal cost understate the true opportunity cost of production, because the inputs from subsidiaries may be sold at a higher price. This understatement in opportunity cost can result in excess output and capacity decisions, described in Williamson (1971), Hart and Grossman (1986), and Hart et al. (1990).
from reduced-form regressions, because both leverage and sourcing are chosen simultaneously and could be driven by confounding variables. In the model, firms increase leverage and the number of suppliers in response to higher corporate profits taxes. Empirically, I find a 1.4-percentage-point increase in long-term book leverage increases the probability that a firm adds an additional supplier by 10%. At the network level, I find leverage increases monotonically down production tiers, consistent with model predictions with one firm per tier.

The paper contributes by specifying a new channel for studying operational and financial risk management, incorporating what is typically considered an indirect cost of financial distress. It introduces a concept of debt overhang in tiered production and characterizes how adjustments along two dimensions of risk affect equilibrium. Studying either leverage or supply-chain variables in isolation misses network equilibrium pricing and quantity effects. The network-level results also motivate the existence of more sophisticated supply chain contracts that can alleviate the debt overhang in tiered production. Contracts that permit transfer payments to suppliers can reduce debt overhang in tiered production by enticing them to take less risky debt.

After discussing the relevant literature, the remainder of the paper is structured as follows: Section 2 presents the basic three-tier model with optimal capital structure choice and endogenous production-network formation, Section 3 discusses model results, Section 4 shows the empirical relevance of network-level results using reduced-form relationships and firm-level results using an instrumental variables approach, Section 5 studies a counterfactual world with no risky debt and increased competition, and Section 6 concludes.

1.1 Related Literature

The extant literature in finance, operations management, and economics all provide a foundation for this paper. By studying the effects on customers, suppliers, or workers, Titman and Wessels (1988), Opler and Titman (1994), Banerjee et al. (2008), and Hortacşu
et al. (2013) documented the large magnitude of “indirect costs” of bankruptcy discussed in Titman (1984). Taking these costs of bankruptcy into account, Hennessy and Livdan (2009) propose a bargaining theory of leverage. I propose an alternative approach using a competitive price setting mechanism and a network structure that simultaneously introduces debt overhang in tiered production and quantifies the equilibrium effects of these negative spillovers.

The counterfactual exercises in this paper that considers different network compositions follow prior studies that focus on product market competition and leverage. For example, Hellmann and Puri (2000), Campello (2003), and MacKay (2003) study the relationship between leverage and product market competition. These studies conclude that higher debt lowers product market competition. In this paper, risky debt takes on a similar role, manifesting as a reduction in demand for inputs and reduced supply for output.

Although I focus on the incentive to diversify supply, existing research has documented benefits to both supply concentration and diversification. Gadde and Mattsson (1987) study the stability of network relationships, Wagner and Bode (2006) study supply-chain disruptions, and Babich et al. (2012) provide a review of research on optimal suppliers. Patatoukas (2012) shows firms with few major customers have better accounting rates of returns, and suggests the returns are premia due to being exposed to more severe supply disruptions.

Modeling disruptions from upstream to downstream firms emphasizes supply shocks rather than demand shocks. On one hand, macroeconomic studies such as Long and Plosser (1983), Acemoglu et al. (2012), and Carvalho and Gabaix (2013) use this direction of disruption propagation from suppliers to customers. Barrot and Sauvagnat (2016) find that supply disruptions impose substantial costs on customers and other suppliers in the network as well. On the other hand, Shea (2002), Kelly et al. (2013), and Ahern and Harford (2014) focus on upstream propagation from customers to suppliers. Whether shocks primarily propagate upstream, downstream, or in both directions depends on the existing legal structure, the price-setting mechanism, and timing. A firm’s annual growth rates may depend on customer
growth rates as in Kelly et al. (2013), whereas its intra-year production can be subject to supply disruptions modeled in this paper.

2 Model

I develop a static three-period, three-tier network model. The three tiers consist of primary, intermediate, and final producers. The tiered-production modeling assumption stems from two empirical features of production networks: multiple distinct stages of production and the absence of cycles. Firm output flows down in one direction down a supply chain, from primary to intermediate to final producers. Compared to a general network setup, the benefit of the tier-structure restriction is the possibility of a recursive solution method. The structure follows from operations research, such as Bimpikis et al. (2015).

Firms operate in a common production network but are unable to make decisions as a single cohesive unit. However, they know the network structure and are cognizant of each other’s leverage and sourcing decisions. The decentralized nature of production and sourcing decisions resembles supply chains in practice. Firms understand their suppliers’ leverage and sourcing will affect their own expected profits through potential supply disruptions.

The focus on supply disruptions is grounded in existing US bankruptcy law. The key friction in this paper is the inability to contract on all contingencies of suppliers; suppliers may default. In practice, firms typically form connections using legally binding supply-chain contracts that specify prices, quantities, duration, and some contingencies. Violating these terms and conditions results in legal consequences. Therefore, firms are careful when

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3These observations are obscured when studying industry-level networks. Even the most detailed 389 industries from the Bureau of Economic Analysis are different from firm data in Compustat. For example, in 2007, the transitivity measure was 98.6% for industry networks compared to less than 0.6% for firm networks, and reciprocity was 92% for industry network compared to less than 0.5% for firm networks. See Table 1.

4The tier structure avoids loops that plague Eisenberg and Noe (2001), who study the existence of an equilibrium without endogenous network formation or capital structure. Other studies place different restrictions on the network structure. For example, Kranton and Minehart (2000) uses a bipartite network of buyers and sellers while Oberfield (2014) uses a set up where firms require one intermediate good to produce.

5For example, on November 12, 2013, Starbucks announced a payment of $2.8 billion (>18% of revenue) in damages to Kraft Foods to settle a legal dispute over its termination of a supply agreement.
establishing new relationships. Deciding on suppliers means committing to potential supply disruptions. Suppliers that default may cancel delivery orders, thereby starting a chain effect as downstream firms have a shortage of raw materials. However, the bankruptcy shock does not fully propagate upstream because of the US Uniform Commercial Code and bankruptcy laws, critical suppliers to bankrupt customers can file claims to recover payments for the goods delivered, typically joining the ranks of unsecured creditors. When a customer defaults, trade creditors can either choose to hold their junior credit claim or sell the claim through a section 363 sale process. Ivashina and Iverson (2014) find that the average recovery rate for trade credit is 34.1%, while the average recovery rate of the trade credit claim when sold is 52.5%. In Chapter 11 restructuring, the fulcrum debt typically seeks the cooperation of trade creditors to facilitate the value of the firm as a going concern, being paid in full or at a higher recovery rate than bondholders (Erens and Hoffmann (2013)). Even if suppliers are not able to fully recover payments, downstream shocks are likely to dominate upstream shocks. Therefore, firms are more likely to actively choose their suppliers rather than customers.

2.1 Network Structure

An example network is shown in Figure 1. Production tiers are labeled based on the distance to final consumers. The Final Producer is in Tier 1, Intermediate Producers are in Tier 2, and Primary Producers are in Tier 3.

The number of firms in each tier is assumed to be exogenous, capturing the relative short-run scarcity of suppliers. The model can be extended to include an arbitrary number of tiers.

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6In practice, prepayments, deposits, returned goods, and warranty claims may actually make the supplier owe the customer.

7According to US law, customer firms that default are subject to Section 503b9 (aka “20 Day Claims”) of the Bankruptcy Code. The Uniform Commercial Code also provides a reclamation right for suppliers to recover their supply if it still exists, or payments otherwise. This right of suppliers to submit claims in bankruptcy court as a junior creditor was expanded in 2005 with the Bankruptcy Abuse Prevention and Consumer Protection Act.

8This definition follows the operations literature studying the Bullwhip Effect in supply chains, the phenomenon of increasing swings in inventory upstream due to downstream demand uncertainty (e.g., Lee et al. (1997) and Chen et al. (2000)). It is not present in this paper.
without affecting the main economic intuition. Larger networks contain more intermediate producers across multiple tiers, but both firm-level and network-level mechanisms still apply.

The model allows for an arbitrary number of primary and intermediate producers, but only one final producer. The assumption of a single final producer is necessary for the recursive solution method outlined in Section 3. The network captures the production of a single final product.

To further simplify the model, I assume firms in each tier are ex-ante symmetric and face the same prices. Ex post, firms almost surely have different realized production costs. The symmetry purges the model from confounding factors stemming from heterogeneity across firms within the same production tiers.

2.2 Production

A supply-chain contract specifies the fraction of a supplier’s output that a customer commits to purchase, as well as the fixed transaction price.\(^9\) When a firm \(j\) decides on

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\(^9\)Prices between firms are usually agreed upon prior to production. For example, in Clark-Cutler-McDermott’s bankruptcy filing, the court posts, “The Debtors generate more than 80% of their revenue from sales to General Motors through unprofitable contracts.” These contracts imposed losses of up to $30,000 a day, for an accumulated $12 million loss since 2013. For more information, see case number 16-41188 from the United States Bankruptcy Court / District Court of Massachusetts.
sourcing from a supplier $i$, it submits an order $w_{ji}$ that specifies the fraction of supplier $i$’s output that it commits to purchasing. The supply contract in this model does not admit covenants or contingencies that coerce or bribe suppliers to produce more or take on less debt.\footnote{In practice, these legally binding contracts specify prices, quantities, duration, and various contingencies. Although the model does not consider other features apart from quantity and price, it provides a framework through which to rationalize the existence of these other attributes that can mitigate these incomplete contracts.}

Firm profits take the following form:

\begin{align*}
\text{Tier} & & \text{Gross Profits} & = & \text{Revenue} & - & \text{Procurement Cost} & - & \text{Production Cost} \\
3 & & \pi_i & = & p_3 x_i & - & 0 & - & c_i x_i^2 \\
2 & & \pi_j & = & p_2 x_j & - & p_3 \sum_{i \in \text{Tier 3}} w_{ji} x_i & - & c_j x_j^2 \\
1 & & \pi_k & = & p_1 x_k & - & p_2 \sum_{j \in \text{Tier 2}} w_{kj} x_j & - & c_k x_k^2
\end{align*}

Gross profits consist of revenue from outputs sold, raw-material procurement costs, and quadratic production costs. The quadratic production cost generates incentives for firms to manage their supply variability, and also introduces diminishing returns to scale.\footnote{Basu and Fernald (1997) study firm- and sector-level returns to scale, and conclude firms seem to either have constant or slightly decreasing returns to scale. On the other hand, Syverson (2004) finds firms in the cement industry have constant returns to scale. Nonetheless the quadratic cost is a useful modeling assumption.} Firm value in the first period consists of expectations over uncertain supply, as well as production costs distributed

\[ c_j \sim U [c, \bar{c}] \]

that are drawn in the second period, where $0 < c < \bar{c} < \infty$.

Production is linear in raw materials. For example, intermediate producer $j$’s realized output $x_j$ is a linear combination of its supply:

\[ x_j = \sum_{i \in \text{Tier 3}} w_{ji} x_i. \]
Other factors of production such as labor and capital are not explicitly modeled in the production function. Instead, they are thought of as part of the convex production-cost parameter \( c_i \) of the firm.

### 2.3 Pricing & Timing

Despite the discreteness of the network structure, prices between firms are set competitively. Even if the network has only one supplier and one customer, the supplier does not act like a monopoly, nor does the customer act like a monopsony.\(^{12}\) This choice of price-setting mechanism captures the idea that firms face more competition than what is observed in the network. In practice, prior to establishing a new supply relationship, firms get quotes from multiple potential suppliers. The firm decides on a supplier based on the collection of quotes it received. Therefore, the observed network underestimates the amount of competition in the sourcing process. Compared to competitive markets, non-competitive markets introduce incentives for transfer payments to reduce supplier risk, but can distort the price-setting process in either direction depending on whether the supplier or customer market power dominates. Although Banerjee et al. (2008) and Hennessy and Livdan (2009) both argue for a bargaining theory of leverage, some of their empirical evidence is also consistent with competitive supply-chain effects in this paper.

In the first period, the production network is formed and prices between firms are set in equilibrium to clear the sourcing market. Once set, the network and prices become fixed. But unlike the price of production inputs, final output price is set in the third time period to clear the realized final output market,

\[
p_1 = \gamma - \alpha x_k,
\]

where \( \gamma \) is the choke price of final output, and \( \alpha \) captures the sensitivity of realized output

\(^{12}\)For example, Arya et al. (2008) show that firms may choose common suppliers to affect a rival’s costs.
prices to realized output $x_k$ for final producer $k$. Because the network contains only one final producer, the linear inverse demand can be thought of as the residual demand for a specific product in a market where multiple final products compete. The fixed price setup for raw materials from period one through period three can also be micro-founded as a commitment device that forbids suppliers from holding up customer firms in later periods by threatening bankruptcy.

Knowing the pricing mechanism and network structure, firms choose sourcing and capital structure in the first period to maximize equity value. Because debt markets are competitive, maximizing equity value ex ante is equivalent to maximizing firm value. The firm value consists of the value from operations, the value from the interest tax shield, and the bankruptcy cost. Although a firm can avoid production costs in bankruptcy, it does not gain any revenues, and its creditors must still pay raw-material costs according to the supply-chain contract. More explicitly, consider an intermediate producer $j$ whose objective function $V_j$ in period one is

$$\max_{D_j \geq 0} V_j = \{0 \leq w_{ji} \leq 1\}_{i \in \text{Tier 3}}$$

$$V_j = q_j \pi_j^* + q_j r_j D_j - (1 - q_j)(1 - \tau) p_3 \frac{n_3}{n_2} \mu_3, \quad (1)$$

where $q_j$ is the probability that firm $j$ does not default, $\pi_j^*$ is the expected profits conditional on remaining in production, $r_j D_j$ is the total face value of debt, $n_k$ is the number of firms in Tier $k$, $\mu_3$ is the expected Tier 3 output, and $p_3$ is the price of Tier 3 output. Revenue, production costs, and tax benefits only accrue when the firm remains in operation, whereas procurement costs net of taxes emerge regardless of whether the firm defaults. Other types of producers face a similar objective function, but primary producers do not have suppliers and only optimize over debt.

In the second period, each firm realizes its private production costs and decides whether to default. Bankruptcy truncates unfavorable realizations of production costs because a
firm ceases production in bankruptcy. Equity receives a payoff of zero while creditors cover the procurement costs. This assumption effectively makes the procurement costs senior to the existing creditors.\textsuperscript{13} If a firm does not default, it commits to producing in the third period. Its supply is uncertain, subject to primary producers’ production costs and supplier default decisions. Risky debt affects the riskiness of production for downstream firms because suppliers provide zero inputs for downstream firms. This disruption lowers the expected supply. Bankruptcy is inefficient because equity imposes a cost on creditors and downstream customers. The first inefficiency arises because although expected gross profits may be positive, equity will choose to default if they are not higher than debt obligations. The second inefficiency arises because a firm’s bankruptcy deprives customers of raw materials.

In the third period, primary producers decide how much output to produce given its production cost. Other producer types do not choose their quantity, and can only produce based on the supply they receive. If a non-primary producer remains in operation, it commits to producing and honoring all supply contracts even if this commitment means producing at a loss. Equity owners are assumed to have deep pockets and to be able to finance this loss. Given the static nature of this model setup, equity holders can lose their limited liability protection in the third period. However, this assumption can be rationalized by considering this set up as a sub-game of a repeated game in which equity owners expect returns through time. Losses can occur if a firm’s supply is unexpectedly large and the firm produces at a marginal cost higher than its output prices. If a firm defaults, its equity holders receive a payoff of zero while creditors must cover the cost of raw-material procurement. This assumption ensures production disruption only propagates downstream.

\textsuperscript{13}In the United States, suppliers of bankrupt firms can file administrative expense claims and reclamation rights. Both actions reduce the value to existing creditors. One caveat is that this model does not feature different seniority of debt. With seniority, the senior debt are unaffected by supplier claims while junior debt take all the losses. Regardless, the total value to existing creditors still decrease.
2.4 Equilibrium

**Definition 1.** A supply chain equilibrium is defined as a collection of \( \left( \mu_i, \{ w_{ji} \}, \{ p_i \}_{i \neq 1}, \{ D_i \} \right) \) of sourcing decisions, capital structure, expected output, and prices for each firm where \( w_{ji}, p_i, D_i \geq 0 \) and

1. (Primary Output Optimality). In the third period, conditional on not defaulting, a primary producer \( i \) in Tier 3 chooses output \( x_i \) such that
   \[
   x_i = \arg \max_{x_i \geq 0} p_3 x_i - c_i x_i^2,
   \]
   corresponding to an expected output \( \mu_i = \mathbb{E} [x_i] \).

2. (Optimal Bankruptcy) In the second period, a firm \( i \) declares bankruptcy if the value of equity \( V_i^E < 0 \).

3. (Sourcing and Debt Optimality) A firm \( j \) in Tiers \( k \in \{1, 2\} \) satisfy
   \[
   D_j, \{ w_{ji} \}_{i \in \text{Tier } k+1} \in \arg \max_{D_j, \{ w_{ji} \}_{i \in \text{Tier } k+1}} V_j^E + V_j^D,
   \]
   and all primary producers \( i \) in Tier 3 satisfy
   \[
   D_i \in \arg \max_{D_i} V_i^E + V_i^D.
   \]

4. (Raw-Materials Market Clearing) First period sourcing markets for all raw materials clear, \( \sum_{j \in \text{Tier } 2} w_{ji} = 1 \ \forall i \in \text{Tier } 3 \) and \( \sum_{k \in \text{Tier } 1} w_{kj} = 1 \ \forall j \in \text{Tier } 2 \).

5. (Final Output Market Clearing) The ex-post final-consumption-good market clears,
   \[
   p_1 = \gamma - \alpha x_k,
   \]
   where \( x_k \) is the realized output of the final producer firm \( k \) in Tier 1.
6. (Competitive Debt Pricing). The face value of $1 of debt for firm $j$ in Tier $k \in \{1, 2\}$ is

$$r_j = \frac{D_j + (1 - q_j)(1 - \tau)p_{k+1} \sum_{i \in \text{Tier } k+1} w_{ji} \mu_{k+1}}{q_j D_j},$$

where $q_j$ is the probability of survival, and $p_{k+1}$ is the price of Tier $k + 1$ output, and $\mu_{k+1}$ is the expected Tier $k + 1$ output. The face value of $1$ of debt for firm $i$ in Tier $3$ is

$$r_i = \frac{1}{q_i}.$$

Network equilibrium is defined in terms of optimality conditions in each time period for all producers. Prices are set competitively and clear the sourcing market. The equilibrium condition specifies a system of two polynomial equations that determine the prices $p_2$ and $p_3$ given the exogenous parameters. Due to the symmetry assumption, the model primitives boil down to the number of firms in each tier and the distribution of production costs.

The inverse demand price function for final output is known to all firms in the network and serves as a boundary condition for prices. At a realized production level of $x_k = 0$, no output is sold and the price of the final output will be the choke price $\gamma$.

Debt pricing takes into account the probability of survival and the dilution effect when equity defaults. Creditors anticipate having to cover supplier payments in bankruptcy. Because primary producers do not have suppliers, debt pricing only includes the probability of survival.

3 Model Results

The model is solved backwards, accounting for each firm’s optimal choice of bankruptcy, capital structure, and sourcing. Model results consist of two sources of externalities. The first is at the firm-level, where equity imposes a cost on creditors due to limited liability. Equity defaults if expected profits are less than debt obligations, even if they are positive.
The second is at the network-level, where a supplier’s bankruptcy deprives downstream firms of inputs to production, reducing their profits.

Therefore, the resulting economic mechanisms in this model vary in scope. Firm-level results highlight the economic mechanism driving firms to trade off financial and operational risk. Network-level results highlight the impact of debt overhang in tiered production through supply-disruption externalities. All equilibrium discussions only consider equilibria where all firms produce with some strictly positive probability. If firms always default, prices are indeterminate. Appendix A provides derivations and proofs of all corollaries, lemmas, and propositions.

3.1 Firm-level Decisions

To illustrate the core interaction of endogenous supply-chain formation and capital structure, I discuss firm-level results focusing on an intermediate producer \( j \). The incentives discussed for the intermediate producers epitomize the economic trade-offs for all producers. These firm-level interactions constitute the building blocks of all equilibrium network results.

3.1.1 Default

Equity has limited liability. It defaults in the second period when the expected profits is less than the debt payments. Lemma 1 characterizes the optimal default rule in the second time period. It follows from the specification of the net profit function, because expected profits are a strictly decreasing function of the production-cost parameter \( c_i \) for all production tiers. The threshold splits production costs into the region a firm chooses to remain in operation and the region where it defaults.

Lemma 1. For every firm \( j \), a unique default threshold \( c^*_j \) exists for which it declares bankruptcy if \( c_j > c^*_j \).

For an intermediate firm \( j \), supply orders to every potential supplier \( i \) in Tier 3 affect the default threshold:
\[ c_j^* = \frac{\text{expected supply effect}}{\text{supply variability effect}} = \frac{(p_2 - p_3) \sum_{i \in \text{Tier 3}} w_{ji} \mathbb{E}[x_i] - r_j D_j}{\mathbb{E}\left[ \left( \sum_{i \in \text{Tier 3}} w_{ji} x_i \right)^2 \right]} . \] (2)

The default threshold consists of three economic components: expected supply, supply variability, and debt obligations. Firms default when the relative option value of default exceeds the value of staying in operation. Increasing debt or the cost of debt decreases the expected firm value in operation and increases distress probability. On the other hand, increasing sourcing has offsetting effects. Submitting a larger supply order increases the expected supply, but also increases supply variability. Which effect dominates depends on whether the firm considers submitting a larger supply order to an existing supplier or new supplier. Submitting a larger order to an existing supplier makes supply more concentrated, whereas submitting a larger order to a new supplier diversifies the supply. The relative importance of these effects also interacts with the level of debt the firm uses.

Decreases in the default threshold \( c_j^* \) correspond to decreases in the probability of survival \( q_j \). The default threshold exists for every firm, but may be outside the support of the production cost distribution. Therefore, the probability of survival of a firm \( j \) is

\[
q_j = \begin{cases} 
1 & \text{if } \bar{c} < c_j^* \\
\frac{c_j^* - c}{\bar{c} - c} & \text{if } c \leq c_j^* \leq \bar{c} \\
0 & \text{otherwise.}
\end{cases}
\]

It is linear in the default threshold when \( c_j^* \in [c, \bar{c}] \) because of the uniform distribution of production costs. The default threshold also appears in the expected production costs conditional on remaining in operation. Both the probability and conditional expectation of production costs appear in the marginal cost of sourcing and leverage.
**Lemma 2.** At any symmetric equilibrium, $\frac{\partial q_j(w_{ji},D_j)}{\partial w_{ji}} < 0$ when $w_{ji} \geq w_{ji}^*$, $D_j \leq D_j^*$, and $0 < q_j < 1$, where $w_{ji}^*$ is the equilibrium level of sourcing and $D_j^*$ is the equilibrium debt level.

The supply-variability effect dominates the expected supply effect if the supply order $w_{ji}$ is large and the level of debt $D_j$ is not too high. Lemma 2 states that at the optimal debt level $D_j^*$ or less, submitting a larger order to an existing supplier $w_{ji} \geq w_{ji}^*$ decreases the probability of firm survival, all else being equal. Supply variability affects the firm-survival probability through the expected cost of production, a component of the marginal cost of production. When submitting a larger order, the amount of supply variability changes. The impact of a larger order size $w_{ji}$ on the probability of survival also diminishes as the marginal impact of diversification gets muffled by total supply variance. Figure 2 illustrates the effect of larger order sizes on the probability of survival. For high values of debt, the probability of survival can increase with larger order sizes.

![Figure 2: Survival and Sourcing](image)

The figure shows the probability of firm survival when increasing the supply order to one firm while holding other supply orders fixed. In this set up, the optimal supply order is $w = 0.5$.

Increasing debt decreases the probability of firm survival but also affects the marginal impact of sourcing on the survival probability. The slope in Figure 2 changes because the expected supply effect net of debt obligations loads on supply variance. In equation (1),
supply variability interacts with the numerator term. More debt reduces the loading on the supply variability, reducing the impact of a larger supply order on the default probability.

While debt affects the marginal incentives for sourcing through the survival probability, capital structure and sourcing also interact in the expected production cost in operation. Because the bankruptcy threshold also corresponds to the expected cost of production in operation, the interaction between leverage and sourcing can be decomposed into different components of firm value, discussed below.

3.1.2 Debt and Supply Diversification

Higher debt incentivizes a firm to seek new suppliers. To see this, consider the marginal benefit of submitting an order to a new supplier at different levels of debt. Also, recall from equation 1 that firm value for an intermediate producer $j$ can be decomposed into three components: the value of the firm from operations, the value of the interest tax shield, and bankruptcy costs. Introducing a new supplier affects the value of operations through the expected profits given survival $\pi^*_j$, and affects all three components through the probability of bankruptcy $q_j$. The marginal benefit of a new supplier is a function of debt $D_j$ and is defined as

$$MB_{New\ Supplier}(D_j) = V_{New\ Supplier}^j(D_j, w^*_j) - V_j(D_j),$$

where $V_{New\ Supplier}^j$ is the value of the firm when it submits an optimal supply order $w^*_j$ to a new supplier given the existing equilibrium values. This definition holds the supply order to existing suppliers and the output distribution fixed. Focusing on an intermediate supplier, Proposition 1 shows the incentive for intermediate producers to diversify their supply. A similar intuition applies to final producers who use risky debt.

**Proposition 1.** At any symmetric equilibrium, $MB_{New\ Supplier}(D_j)$ for firms in Tier 2 increases with debt.

Intermediate producer firm value increases because with a new supply order it decreases
financial risk. Submitting a new order at an existing equilibrium increases the probability of survival as the benefits from higher expected supply dominate the supply variability effect. The increase in survival probability increases with the level of debt that the firm uses. When the probability of survival increases, the firm is more likely to survive and receive expected profits from production, but the expected cost of production conditional on survival also increases. However, the effect from the higher probability of survival dominates the expected production cost effect due to the uniform distribution assumption, because changes in the probability of survival correspond linearly to changes in expected production costs conditional on survival. The value of the tax shield also increases, and increasing debt slightly increases the gain from the tax shield even more as firms enjoy both the benefit from higher survival and higher interest deductibility. Bankruptcy costs also decrease with a higher survival probability. Therefore, submitting a new supply order increases all facets of firm value.

Figure 3 illustrates the marginal benefit from adding an additional supplier at an existing equilibrium. A different interpretation of this marginal benefit is the amount that a firm is willing to pay to add a new supplier. The firm submits the optimal supply order without internalizing the fact that adding an additional supplier will affect equilibrium prices and output. The difference in firm values can be decomposed into changes of each of the three components in firm value.

The marginal benefit for a new supplier also depends on whether the suppliers’ outputs are correlated. Figure 4 shows the willingness to pay decreases with the correlation in suppliers as the diversification benefits are dampened. For a network equilibrium to be stable and observed in practice, the fixed costs of establishing new relationships must exceed firms’ willingness to pay to add additional suppliers. These firm-level mechanisms, combined with market-clearing constraints, generate the debt overhang in tiered production that affects the network equilibrium.
Figure 3: Marginal Benefit Decomposition
The correlation of supplier output in this illustration is $\rho = 0$.

Figure 4: Impact of Supply Correlation
The correlation of supplier output in this illustration is $\rho = 0, 0.5, 0.8$ for low, medium, and high.

3.2 Network-level Results

When firms offload financial and operational risk, they can reduce their distress probability but expand the channel through which disruptions propagate. In equilibrium, both prices and quantities in the network react to the debt overhang in tiered production. Supply
disruptions downstream affect equilibrium prices upstream. Firms in the production network form expectations as to whether the incentive-compatibility constraint from debt will hold.

Firms in different production tiers face varying degrees of price and quantity stickiness. Although primary producers can adjust their optimal output, they face sticky prices due to legally binding supply-chain contracts. Meanwhile, final output prices adjust to clear the realized final-good market. Flexible prices and quantities increase the value of remaining in operation, so they increase the opportunity cost of bankruptcy. Intermediate producers sandwiched between primary and final producers face both inflexible prices and quantities.

**Corollary 1.** If \( q_k > 0 \) for every Tier \( k \), then prices strictly increase down the production tiers.

For firms to choose to remain in operation with some positive probability, they must expect to make positive profits. Therefore, Corollary 1 is a necessary condition for \( q_k > 0 \) for every Tier \( k \).

### 3.2.1 Comparative Statics

Although the tiered-production structure imposes a dependency between output across tiers, input markets can be studied in isolation to see the partial-equilibrium effects of different variables. These input-market illustrations in Figure 5 depict how multiple goods markets interact and how firm-level results affect network equilibrium values. The figure shows the primary- and intermediate-goods markets that clear in time 1 equilibrium, illustrated in terms of graphs with total output \( n_k \mu_k \) for Tier \( k \) on the horizontal axis and price \( p_k \) on the vertical axis. Variables that shift each curve are labeled with their directional impact. The supply curve comes from the production technology, whereas the demand curve comes from equilibrium-sourcing conditions. Given the optimal sourcing decisions, expected input demanded can be expressed in terms of expected output, probability of survival, and prices.
In the primary-goods market, supply increases in the number of primary producers $n_3$, all else being equal. The demand of primary output increases in the number of intermediate producers $n_2$ due to higher competition. In addition, variables that increase the riskiness of an intermediate firm decrease demand. Firm-level mechanisms that lead firms to balance supply variance and debt cause adjustments in an intermediate firm’s supply variance $\sigma_2^2$ and debt $D_2$ that lead to multiple shifts in the demand for primary goods.

In the intermediate-goods market, the debt overhang in production manifests as a negative shift in supply. All else being equal, variables that increase intermediate producers’ probability of default decrease supply. Unlike the other variables, an increase in the number of intermediate producers $n_2$ generates two offsetting direct effects. It increases the number of firms producing intermediate output, but also increases riskiness of each firm at a given level of debt $D_2$ and supply variance $\sigma^2$. Off equilibrium, either effect may dominate. However, Corollary 2 shows that firms following the optimal debt policy leads to the expected output effect dominating, so total intermediate-goods supply increases.

**Corollary 2.** *Under the optimal risky debt policy, increasing the number of intermediate producers increases total intermediate-goods supply, all else being equal.*

The increase in risk depends on the existing level of debt. At high levels of debt, increasing competition affects riskiness more than linearly, resulting in a decrease in total expected intermediate output.\(^{14}\) Firms following the optimal risky debt policy reduce their debt in response to increased competition $n_2$. Despite the decrease in debt, their riskiness still can increases and each individual firm’s probability of survival $q_2$ decreases. The expected production for each firm decreases, but altogether with more producers the total supply of all intermediate output in the network increases.

\(^{14}\)Solving for where $\frac{\partial c}{\partial n_2} = 0$ gives the threshold that if $r_2D_2 > \frac{1}{7}(p_2 - p_3)n_3\mu_3$ then $\frac{\partial c}{\partial n_2} < 0$. 
Figure 5: Raw Material Markets

\( n_k \) is the number of firms in Tier \( k \), \( p_k \) is the price of Tier \( k \) output, \( \mu_k \) is the expected output of a firm in Tier \( k \), \( \sigma_k^2 \) is the variance of supply to a firm in Tier \( k \), \( D_k \) is the debt level of a firm in Tier \( k \), \( \gamma \) is the choke price of final output, and \( \alpha \) is the sensitivity of final price to realized output. Primary producers are in Tier 3, intermediate producers are in Tier 2, and the final producer is in Tier 1.

The tiered structure and production function provide a precise mechanism that places discipline on both the qualitative and quantitative properties of network spillovers. Moreover, the network equilibrium cannot be solved sequentially for each market, because firms adjust both sourcing and capital structure. Both supply and demand curves shift multiple times when moving from one equilibrium to another. Output must also be consistent across the production tiers.

3.2.2 Firm Fundamentals

Because one tier’s output is used as another tier’s input, moments of the output distribution satisfy recursive definitions in Lemma 3. The lemma follows directly from the linearity of expectations and the tiered-network structure of production. Realized output varies due to the random production cost and default decisions.

Lemma 3. (Production-Network Equilibrium Output) Let \( \mu_k \) be the first moment and \( \hat{\theta}_k \) be
the second moment of output for a firm in Tier \(k\). Then

\[
\mu_3 = \frac{p_3}{2} \frac{(\ln \bar{c} - \ln c)}{(\bar{c} - c)}
\]
\[
\mu_2 = \frac{n_3}{n_2} q_2
\]
\[
\mu_1 = \mu_2 n_2 q_1
\]
\[
\hat{\theta}_3 = \frac{p_3^2}{4cC}
\]
\[
\hat{\theta}_2 = \frac{n_3 \hat{\theta}_3}{n_2 n_2}
\]
\[
\hat{\theta}_1 = q_1 n_2 ((n_2 - 1) q_2 + 1) \hat{\theta}_2,
\]

where \(q_k\) is the probability that a firm in Tier \(k\) does not default.

The probability of a firm in Tier \(k\)’s survival \(q_k\) affects the output distribution and depends on debt. On the other hand, optimal debt also depends on firm fundamentals.

**Corollary 3.** In any symmetric equilibrium, the correlation of output among firms in Tier 3 is \(\rho_3 = 0\) and for firms in Tier 2 is

\[
\rho_2 = \begin{cases} 
0 & \text{if } q_2 = 0 \\
\frac{q_2 \hat{\theta}_2 - \mu_2^2}{\hat{\theta}_2 - \mu_2^2} & \text{otherwise.}
\end{cases}
\]

Although firms draw production parameters independently, in a symmetric equilibrium, intermediate producer outputs are positively correlated due to shared suppliers. Variation in realized output from each supplier transmits to each intermediate firm. Corollary 3 states the output correlation among primary and intermediate producers. Primary producer outputs are uncorrelated because they draw costs independently and do not share suppliers. Meanwhile, although intermediate firms also draw costs independently, a pair will produce exactly the same amount if they both make the same default decision. If they do not default, they produce the same positive amount. If they default, they both produce zero. The case in which they both default do not contribute to the covariance. Intermediate firms always
default when the probability of survival $q_2$ is 0. In that case, intermediate output is not random. Both the first moment $\mu_2$ and second moments $\hat{\theta}_2$ of intermediate output are 0, and $\rho_2$ is set to 0. As the probability of survival for an intermediate firm increases, the correlation of output increases because they are more likely to produce the exact same positive amount. No output correlation for final producers exists because only one firm is present.

Whether the sourcing and capital-structure decisions interact depends on whether firms take on risky debt, discussed below.

### 3.2.3 Capital Structure

Given different exogenous parameter values, one of two equilibria exists. In the first equilibrium, firms take on debt so that their default threshold for the cost is exactly $\bar{c}$, corresponding to a survival probability 1. In the second equilibrium, non-primary producers may take on risky debt. Whether the network features risky or risk-less equilibria depends heavily on the production-cost parameters. Because of the option value to default, increasing the variance of the production-cost distribution makes firms more likely to use risky debt.

If the exogenous parameters do not admit an interior solution for debt, firms choose the riskless level of debt defined in Lemma 4. The riskless level of debt is the minimum amount of debt firms will use.

**Lemma 4.** In a symmetric equilibrium, firms in each tier have a minimum amount of debt $D(1)$, $D(2)$, and $D(3)$ defined as

\[
D_3 = \frac{p_3^2}{4\bar{c}}
\]

\[
D_2 = (p_2 - p_3) \frac{n_3}{n_2} \mu_3 - \bar{c} \frac{\sigma_2^2}{n_2^2}
\]

\[
D_1 = (\gamma - p_2) \frac{n_2}{n_1} \mu_2 - (\bar{c} + \alpha) \frac{\sigma_1^2}{n_1^2},
\]

where all firms never default.
The riskless debt capacity depends only on equilibrium firm fundamental, and does not interact directly with sourcing through distress probability. In this case, increasing the firm’s corporate profits tax rate does not affect optimal capital structure. With riskless debt, firms never default but still have uncertain output. Output variance stems from primary producers. Each primary producer adjusts output in the third time period based on its private production cost drawn in the second time period. However, with no financial risk, the expected value and variance output are the same for the entire production chain.

Proposition 2 gives the expression for the optimal debt at each level given firm fundamentals. Like the riskless level of debt, the optimal amount of debt increases with expected supply levels and decreases with supply variability. But unlike the risk-less amount of debt, risky debt interacts with sourcing incentives. Given the model set up, primary and intermediate producers may use risky debt, but primary producers never take on credit risk. Primary producers internalize the cost of debt fully through their ability to choose production quantities in Time 3, because tax benefits only accrue to firms in operation.

Given a level of debt, firm value is concave with respect to sourcing. Given a collection of supply orders, firm value is also concave with respect to debt. In an equilibrium with riskless debt, the first property suffices to guarantee an existence of a symmetric equilibrium. However, with risky debt, the interaction between sourcing and debt must also satisfy second-order conditions, detailed in Appendix A.

**Proposition 2.** In a symmetric equilibrium,

1. The optimal level of debt $D_k$ for a firm in Tier $k$ is

$$
D_3 \; = \; D_3 \\
D_2 \; = \; \max \left\{ \frac{1}{(1 + \tau) r_2} \left( (\tau p_2 - p_3) \frac{n_3}{n_2} \mu_3 - \tau \frac{\sigma_2^2}{n_2^2} \right) \right\} \\
D_1 \; = \; \max \left\{ \frac{1}{(1 + \tau) r_1} \left( (\tau \gamma - p_2) n_2 \mu_2 - \tau (\alpha + \xi) \sigma_1^2 \right) \right\},
$$

where $D_3$, $D_2$, and $D_1$ are the risk-less debt capacity defined in Lemma 4.
2. Prices satisfy two polynomial equilibrium conditions defined in Appendix A.

Figure 6: Leverage across Producer Types
The figure above shows the leverage ratio across producer types in a network with one firm in each tier. The exogenous parameters are \( \tau = 0.35, \bar{c} = 10, \underline{c} = 0.1, P_0 = 100, \) and \( \alpha = 2. \)

Figure 6 shows the optimal leverage ratios in a simple production network with one firm in each tier. The numerical example satisfies the equilibrium conditions for prices, capital structure, and output consistency. Given the exogenous parameters, the intermediate producer takes on risky debt, whereas primary and final producers use riskless debt. In this example, final producers use the most leverage and primary producers use the least leverage. Although all production costs are identically distributed \( U[\underline{c}, \bar{c}] \), the price flexibility for the final producer generates the largest debt capacity. In this example network, the price flexibility for the final producer matters more than quantity flexibility for primary producers.

In this example, intermediate firms take on risky debt, whereas other producers use only riskless debt, because the relative value of the option to default is highest for the intermediate producer. Without the choice to default, intermediate producers face fixed
output prices contracted in the first period, while it also faces fixed quantities coming from primary producers in time period three. Apart from sourcing, it has no other margin for flexibility.

Even with identically distributed production costs for all firms in the network, the example shown endogenously generates a monotonic ranking in both firm value and leverage ratios that matches the pattern observed in Compustat data from 1980 to 2014. The empirical pattern and economic mechanism driving this effect in the model is also consistent with empirical findings in Acunto et al. (2015) who show firms with more flexible prices use more leverage. This result is similar to the results in Gornall and Strebulaev (2015), who show low leverage use for firms and high leverage use for banks due to a similar financing supply-chain structure. However, the supply dependence between tiers makes this model markedly different.

4 Empirical Evidence

Studying the empirical effects of supply chains on capital structure requires data on both on network connections and financial statements. I use the Compustat database because firm-level connections for key customers and capital structure data are readily available. In the United States, a public firm must report the name of all major customers who represent 10% or more of the firm’s sales. The network data are constructed by matching customer names with company names using several different string-matching algorithms.

I group firms into three production types: primary producers, intermediate producers, and final producers. Primary producers are firms that have supplied products to other firms at least once since 1980 but have never been important customers of other public firms. Final producers are firms that have been customers of some other firm at least once since

\[15\text{ Although other data sources such as CapitalIQ and Bloomberg Revere provide more firm connections by including private firms, they do not provide clean balance sheet data.} \]

\[16\text{ The SFAS No. 176 requirement mandates firm disclosure of significant customers. Appendix B discusses the mandatory disclosure in more detail.} \]
1980, but have never been suppliers of other public firms. Intermediate producers are those that have had both customers and suppliers at least once since 1980. Chains with two tiers consist of only primary and final producers.

The classification of production tiers trades off between more precise measures of distance from final consumers and data availability. Table 1 reports the summary statistics, and a more thorough discussion of the summary statistics, sample-selection process, representativeness of the sample, and potential issues with the data can be found in Appendix B. All empirical result tables can be found in the Empirical Tables section.\textsuperscript{17}

4.1 Leverage across Producer Types

The production networks in the United States mostly consist of chains with one node in each tier, and show a pattern consistent with the model results using the same cost distribution for all producer types. Table 3 shows that final producers use more leverage than intermediate producers, whereas intermediate producers use more leverage than primary producers. The differences across the three different groups are statistically significant. Final producers have 9.2 percentage points more long-term market leverage and 6.7 percentage points more long-term book leverage compared to primary producers. Primary producers use 6.2 percentage points less leverage than final producers, and intermediate producers use 1.6 percentage points less leverage than final producers when controlling for tangibility, return of assets, and the market-to-book ratio.

The differences in leverage across the tiers of production are also related to industry effects of leverage. Using 3-digit SIC definitions, industries whose average distance to final

\textsuperscript{17}Simulation methods can be used to study the representativeness of the sampled graphs compared to the underlying structure. For example, Ahmed et al. (2014) study the properties of sampled graphs, characterizing issues based on specific types of mis-measurement and computational constraints.
consumers is lower uses more leverage, as shown in Figure 12. Table 4 shows that industries that an industry whose average tier is one unit farther away from final consumers uses 7.6 percentage points less leverage. The tier structure captures 5.6% of the total variation in average industry leverage. The relationship is robust to taking averages across industries by year, and then including year fixed effects. Moreover, the production-network framework presented is consistent with earlier studies such as Baker (1973) and Boquist and Moore (1984).

4.2 Leverage and Supply Diversification

If firms simultaneously choose capital structure and sourcing to balance financial and operational risk, then observed leverage and supply-chain characteristics are endogenous. Reduced-form relationships between debt and supply-chain decisions may also reflect confounding factors that affect both outcome variables. For example, firms that increase their number of suppliers may be expecting higher productivity and simultaneously lever up to invest. To mitigate this concern, I use a quasi-experiment setting to study the impact of exogenous increases in marginal corporate tax rates between 1979 and 2013 on the use of debt. Then, I focus on the relationship between instrumented changes in leverage with changes in supply-chain variables.\textsuperscript{18} Using this approach, I find a 1.4- to 1.6-percentage-point increase in long-term leverage increases the probability of adding another supplier by 10%. Moreover, I also find customers are 10% more likely to drop suppliers whose leverage increases by about 2.8 percentage points.

To isolate changes in debt due to exogenous marginal corporate profits tax increases, I use a standard difference-in-differences method to estimate changes in long-term book leverage. The study focuses on long-term debt use because short-term debt typically includes trade

\textsuperscript{18}The first stage of this study is the main result from Heider and Ljungqvist (2015), who find an increase in leverage of 40 basis points for a 1-percentage-point increase in the state corporate income tax rate. They also provide a thorough documentation of the sample construction and institutional setting for corporate tax increases. The main results in this paper rely on a strict subset of data compared to their sample. I only use firms for which I have supply-chain data. Nonetheless, the resulting point estimates are similar and also statistically and economically significant.
credit and is related to working capital, which may have a mechanical relationship with the number of suppliers or customers. The analyses use book leverage because it is less susceptible to the critique in Welch (2004) that market-leverage ratios can change even if firms do not take any action to change their capital structure.

The coefficient of interest $\gamma$ is the relationship between instrumented changes in leverage and supply-chain variables. The empirical specification controls for standard firm-level variables used in the capital-structure literature, including profitability (proxied by return on assets), firm size (log total assets), tangibility (ratio of PP&E divided by total assets), and investment opportunities (market-to-book ratio). To control for local economic conditions in which a firm operates, the empirical specification also includes the state GDP growth and unemployment rate. The instrumental variables regressions take the following form:

$$Y_{ijst} = \alpha_i + \beta'X_{it-1} + \varphi'Z_{sjt} + \gamma\widehat{Lev}_{ijst} + \varepsilon_{isjt}$$

$$Lev_{ijst} = \kappa_i + \delta'X_{it-1} + \pi'Z_{sjt} + \xi 1\{\text{Tax Change}\}_{t-1} + \nu_{isjt}$$

where $i$, $j$, $s$, and $t$ index firms, industries, state, and years respectively. The outcome variable $Y_{ijst}$ is either the number of suppliers or the number of customers a firm has, $Lev_{ijst}$ is the long-term book leverage ratio, $\alpha_i$ and $\kappa_i$ are firm fixed effects, $X_{it-1}$ is the set of firm-level controls, and $Z_{sjt}$ is the set of industry and state controls. The industry and state controls include state-level economic variables as well as 3-digit SIC by year fixed effects.\(^\text{19}\) To focus on more direct comparisons, I also restrict the control group to consist of only firms with headquarters in states neighboring those being treated.

I find that when corporate profits taxes rise, firms increase leverage by an average of 2.3 percentage points. This leverage increase is most likely due to firms actively wanting to increase leverage as opposed to an increase in credit supply, because during the sample, the corporate profits taxes and bank taxes change in the same direction. Using continuous

\(^{19}\) Industries are defined by 3-digit SIC rather than 4-digit SIC so that sufficient variation exists within industries. With 4-digit SIC definitions, many “industries” contain only one firm.
changes in tax rates rather than indicators reveals a 1-percentage-point increase in the corporate profits tax rate corresponds to an average increase of 70 basis points in long-term book leverage.\textsuperscript{20}

The main empirical results in Table 5 show that when firms increase leverage by 1.4 to 1.6 percentage points, the probability of establishing a new supply relationship increases by 0.1. Moreover, Table 6 shows that when leverage increases by about 3.2 percentage points, the probability of losing one important customer increases by 10%. I interpret the latter result as key customer firms choosing to drop the supplier due to its higher risk of default from higher debt.

[Table 5 and 6 Roughly Here]

Empirically, changes in corporate profits taxes do not seem to be weak instruments. The point estimate of the corporate profits tax-increase indicator is statistically significant at the 5% level when looking at tax increases of at least 0%, and significant at the 1% level for larger tax-increase thresholds. The F-statistic for tax increases of at least 1% is 15.69, above the rule of thumb of 10 proposed in Staiger and Stock (1997). Section B.6 in Appendix B shows more robustness tests.

5 Counterfactuals

The counterfactuals study the role of risky debt financing in the production network, changes in network composition, and vertical consolidation across producer types. To highlight the impact of these features, I discuss results relative to a benchmark production chain with one firm in each tier.

\textsuperscript{20}The 70-basis point leverage change that I find is higher than the 40-basis-point increase found in Heider and Ljungqvist (2015). Relative to their sample, the final sample in this study contains firms with on average more assets, higher tangible, and lower book-to-market ratio. The final sample over-represents both small and large firms, and under-represents medium-sized firms compared to the full Compustat sample. Because of the selection in the tails, whether to expect results larger or smaller than Heider and Ljungqvist (2015) is not ex ante obvious.
5.1 The Role of Risky Debt

How does risky debt financing affect the production network? To study this question, I compare a network that only permits riskless levels of debt with the same network that allows risky debt. Debt overhang in tiered production reduces surplus to creditors as well as customers. Introducing risky debt affects both prices and quantities. In the first period, risky debt represents a reduction in demand for primary goods and supply for intermediate goods. Primary output and price decrease due to the leftward shift in demand. Primary producers receive a lower price and expect to produce less, decreasing their firm value. Intermediate output decreases but prices increase due to the reduced supply of intermediate goods. For final producers, they expect to produce less, and their input costs increase, unambiguously making them worse off. Allowing firms to use risky debt increases the firm value of the intermediate producer at the expense of the primary and final producers.

![Firm Value Chart](image)

**Figure 7: Impact of Risky Debt**

The parameters are $\tau = 0.35$, $c = 10$, $\bar{c} = 0.1$, $P_0 = 100$, and $\alpha = 2$.

5.2 Network Composition

Changing the network composition generates price and quantity effects for all production tiers. The overall impact on capital structure can be decomposed into those coming from

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output prices, input prices, expected supply, supply variability, and the combined interaction of all these changes. These equilibrium changes stem from both primary- and intermediate-goods market mechanisms discussed in Section 3. These results show that changes to the production-network composition can lead firms to increase debt while decreasing credit risk, highlighting the importance of isolating the origin of leverage changes for empirically identifying the underlying economic mechanism.

Equilibrium network considerations in this paper also build on intuition from prior studies, such as Fee and Thomas (2004) who study the impact of horizontal mergers on supplier and customer firms and find mergers that result in a higher concentration of suppliers is associated with larger cash-flow margins for suppliers.

To isolate each of the four price and quantity effects, I consider changing parameters from the old to new equilibrium values one at a time. I calculate the capital-structure impact coming from each parameter for all three tiers. The combined interaction of all equilibrium changes is defined as the residual changes in debt that ensures the adding-up constraint. The results are presented in Figure 8, which presents the levels of debt in both the old and new equilibrium. The discussion goes through the economic mechanisms and is explicit about which effects are due to the specific exogenous parameter values chosen in the illustration.

5.2.1 Additional Primary Producer

Introducing another primary producer decreases primary-producer debt but increases intermediate- and final-producer debt. Adding another primary producer increases the supply of primary-tier output, resulting in lower primary output prices and higher expected primary output. In equilibrium, the intermediate producer sources supplies from both primary producers equally. This sourcing choice translates into a decrease in supply variability. At the given level of debt, financial risk decreases. Because firms adjust on two margins, choosing both sourcing and leverage, they endogenously choose to offset the decrease in
operational risk by increasing their financial risk. However, they will not increase their financial risk so much that it is higher than in the previous equilibrium. Therefore, both the lower credit risk and supply variability increase primary-goods demand. The increase in expected supply and demand increases expected primary-good production. The equilibrium price effect of primary output depends on the distribution of costs, but in this illustration, the supply effect dominates and primary prices decrease.

![Figure 8: Introducing One Additional Primary Producer](image)

Based on a network with one firm in each tier with another network with two primary producers, one intermediate producer, and one final producer. The parameters are $\tau = 0.35, \delta = 10, \zeta = 0.1, P_0 = 100$, and $\alpha = 2$.

In the intermediate market, decreases in input prices and financial risk increase supply. The reduction in intermediate firm default also increases supply variability for final producers. When intermediate firms default, they reduce the output variability of intermediate output by truncating a part of the output distribution. Therefore, demand for intermediate goods decreases due to higher supply variability. With the increase in supply and decrease in demand, the equilibrium intermediate price unambiguously decreases. But equilibrium expected intermediate output could increase or decrease depending on which effect dominates.
The relative elasticity of supply and demand both depend on the coefficient of variation of the production cost. Given the exogenous parameter values in the illustration, the supply effect dominates; intermediate expected output rises.

For final producers, higher expected output increases firm value. The linear inverse demand for final output approaches a more inelastic region, so profits unambiguously increase. The lower input prices and higher expected final output both increase debt capacity, whereas higher supply variability decreases debt capacity.

Overall, primary producers have a lower firm value, but intermediate and final producers have higher firm values. Primary producers do not change their leverage ratios, whereas intermediate and final producers increase their leverage ratios. The increase is largest for intermediate producers who get the most direct gain from increased competition among primary producers.

5.2.2 Additional Intermediate Producer

Unlike for primary producers, increasing the number of intermediate producers in the network can generate counter-intuitive results. In the illustration, introducing another intermediate producer increases primary-producer debt, decreases intermediate producer debt, and decreases final producer debt. Higher intermediate competition makes final production actually decrease, harming aggregate firm value.

In the primary-goods market, demand increases due to the increased competition for inputs among intermediate producers. They bid up prices for primary output. However, all the primary output in the network is split between two intermediate firms. Despite the increase in total primary output in the network, each intermediate firm receives less supply than in the old equilibrium. The lower supply decreases an intermediate producer’s expected profits and increases its probability of default, in response to which, each intermediate producer reduces debt. Despite less leverage, in equilibrium each intermediate firm has more credit risk than before. Given less expected inputs and increased equilibrium default probability,
each intermediate producer’s expected production decreases. Although the increase in the number of intermediate producers increases, the shift out in supply is countered with leftward shifts due to higher credit risk and higher input prices. The net shift in intermediate-goods supply depends on the cost distribution.

Figure 9: Introducing One Additional Intermediate Producer

Based on a network with one firm in each tier with another network with one primary producer, two intermediate producers, and one final producer. The parameters are $\tau = 0.35$, $\bar{c} = 10$, $\underline{c} = 0.1$, $P_0 = 100$, and $\alpha = 2$.

In this example, the increased competition and firm-level adjustments manifest as a negative shift in intermediate good supply. On the other hand, the final producer is able to diversify its supply by sourcing from two suppliers, but supply variability is affected by two off-setting components: increased variability transmitted from the primary producers and decreased variability from the diversification. Which effect dominates depends on the cost distribution. In the example shown in Figure 9, the diversification effect dominates and final-producer supply-variability decreases, leading to an increase in intermediate-goods demand. In equilibrium, intermediate price increases. Although total expected intermediate output and supply variability are theoretically ambiguous, they both decrease given the
The firm value for both intermediate and final producers decreases.

The example that increasing intermediate-producer competition can result in lower expected final production is surprising, but Proposition 4 of Bimpikis et al. (2015) demonstrates a similar result. Studying a firm in isolation may capture the partial-equilibrium changes in optimal debt, but will miss the equilibrium effects coming from price and quantity adjustments. Changing the network composition changes competition within tiers and across tiers. One tier may benefit at the cost of another. For example, introducing another intermediate producer increases prices for primary producers. However, the increased credit risk decreases the expected output for intermediate producers, harming final producers.

### 5.3 Vertical Consolidation

The impact of the decentralized tier structure can be compared against a hypothetical monopolistic firm whose gross profits function follows:

\[
\pi = p(1)x - \tilde{c}x^2,
\]

where \(x\) is the realized output and \(\tilde{c}\) is the production cost drawn from a uniform sum (Irwin-Hall) distribution of three variables i.i.d. \(U[\underline{c}, \overline{c}]\). This conglomerate faces the same inverse demand function for final output \(p(1) = P_0 - \alpha x\), but is also able to coordinate the output and pricing of raw materials. The conglomerate’s production cost is a sum of three random variables, each corresponding to the production cost required for each tier of production. The hypothetical firm chooses its optimal production in Time 3, can choose to go bankrupt in Time 2, and chooses its capital structure in Time 1.

Depending on whether debt is risky, the tiered structure of production can give rise to a power law distribution in realized output. Battiston et al. (2007) and Delli Gatti et al. (2010) have discussed the ability of tiered network models to produce power law
distributions in realized output, but the endogenous probability of default for each firm in the production network influences the length of the tail of the realized output distribution. Figure 10 shows the distribution of realized output for conglomerate production and risky tiered production for three network structures. The plots are generated with the same set of exogenous parameters. The conglomerate realized distribution is more like a normal distribution.\textsuperscript{21}

![Figure 10: Realized Output Distributions](image)

The parameters are $\tau = 0.35, \bar{\varepsilon} = 10, \xi = 0.1, P_0 = 100$, and $\alpha = 2$. “Tiered” stands for the decentralized tiered-production network. All tiered production in this illustration contain risky debt.

A vertical consolidation of the production network increases aggregate firm value by eliminating double marginalization, aggregating knowledge of production costs, and synchronizing the capital structure. The integration increases expected output and reduces its coefficient

\textsuperscript{21}As the number of production tiers increases, the cost distribution for the conglomerate becomes normal. The normality can be derived through the Central Limit Theorem for uniform sums.
of variation. Gains from eliminating double marginalization arise because with the option to default, firms expect to make a profits in production. Sharing production costs allows the conglomerate to produce the optimal level of output in the third time period. Because of this coordination, the conglomerate also internalizes the debt overhang in tiered production. The conglomerate can bypass the limited commitment issues between decentralized firms, committing to a level of debt that is not risky. The resulting conglomerate issues more debt while reducing financial risk.

Although I introduce one additional source of gains from vertical integration, this counterfactual does not explicitly consider the associated costs such as legal fees for M&A activities, coordination costs in integration, and insulation from new production technologies. Alternative contracts that permit transfers from customers to suppliers can reduce the debt overhang in tiered production while avoiding the drain on capital and management resources that would arise in a direct vertical consolidation. Rather than vertical consolidation, in practice firms can use other methods like joint ventures, strategic alliances, technology licenses, asset ownership, and franchising as a means to coordinate along the supply chain without explicit vertical integration. For example, Breza and Liberman (2016) provide empirical evidence that the regulation of feasible financial contracts affects the organizational form of a firm. Nonetheless, the reduction in the debt overhang in tiered production is another thing to consider when making the make versus buy decision in practice.

6 Conclusion

This paper models the relationship between optimal capital structure and network formation. It introduces the concept of debt overhang in tiered production, and provides a framework for studying the relationship between operational and credit risk. Allowing firms to take risky debt can decrease aggregate firm value through spillovers to customer firms. Firms balance operational and financial risk, adjusting along both margins similar to house-
holds adjusting consumption and labor supply. As final consumption goods become more complex and productive assets become more specialized, the production work requires more production tiers and coordination across decentralized firms, accentuating the issues raised in this paper.

The model can generate facts observed in the data, including matching average leverage across production tiers, the relationship between debt and the marginal benefit of supply diversification, and a power law for realized sales. Empirically, the paper documents previously unexplored features of production networks that motivate a simple production network model.

Three extensions of to this paper stand out. First, the model can be used to study optimal contracting between firms. Second, it can also be used to explore optimal network structures given different objective functions of maximizing supply-chain profits or consumer surplus. Third, follow-up work can also explore how other operational risks interact with financial risk.
References


7 Empirical Tables & Figures

Figure 11: Tier Classifications

The figure above shows the number of firms classified as primary, intermediate, or final producers across time. Final producers are firms whose cumulative in-degree is at least 1, and out-degree is zero. Primary producers are firms whose cumulative in-degree is zero and out-degree is at least 1. Intermediate producers are firms whose cumulative in-degree and out-degree are both at least 1.
### Table 1: Network Features & Summary Statistics

The table below shows features of the production network data as well as summary statistics of the variables of interest, including leverage and the number of customers and suppliers a firm has. Statistics are reported across years. Customer sales, customer weights, and supplier weight similarity measures are defined as the cosine similarity.

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A: Aggregate Network Features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Number of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firms</td>
<td>976</td>
<td>2365</td>
<td>1731.97</td>
<td>339.62</td>
<td>1726</td>
</tr>
<tr>
<td>Connections</td>
<td>970</td>
<td>2685</td>
<td>2067.26</td>
<td>491.92</td>
<td>2146</td>
</tr>
<tr>
<td>Clusters</td>
<td>69</td>
<td>234</td>
<td>163.37</td>
<td>39.22</td>
<td>163</td>
</tr>
<tr>
<td>Customer Firms</td>
<td>322</td>
<td>725</td>
<td>581.74</td>
<td>119.85</td>
<td>627</td>
</tr>
<tr>
<td>Supplier Firms</td>
<td>681</td>
<td>1773</td>
<td>1257</td>
<td>267.54</td>
<td>1256</td>
</tr>
<tr>
<td>Diameter</td>
<td>3</td>
<td>6</td>
<td>4.26</td>
<td>0.74</td>
<td>4</td>
</tr>
<tr>
<td>Reciprocity (%)</td>
<td>0.00</td>
<td>0.39</td>
<td>0.09</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Transitivity (%)</td>
<td>0.09</td>
<td>0.88</td>
<td>0.38</td>
<td>0.18</td>
<td>0.37</td>
</tr>
<tr>
<td>Similarity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Links</td>
<td>0.40</td>
<td>0.79</td>
<td>0.68</td>
<td>0.07</td>
<td>0.69</td>
</tr>
<tr>
<td>Customer Sales</td>
<td>0.67</td>
<td>1.00</td>
<td>0.94</td>
<td>0.09</td>
<td>0.97</td>
</tr>
<tr>
<td>Customer Weights</td>
<td>0.87</td>
<td>0.96</td>
<td>0.92</td>
<td>0.02</td>
<td>0.91</td>
</tr>
<tr>
<td>Supplier Weights</td>
<td>0.06</td>
<td>1.00</td>
<td>0.81</td>
<td>0.23</td>
<td>0.89</td>
</tr>
<tr>
<td>Turnover (Fraction)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Links Entering</td>
<td>0.19</td>
<td>0.72</td>
<td>0.36</td>
<td>0.11</td>
<td>0.34</td>
</tr>
<tr>
<td>Links Exiting</td>
<td>0.21</td>
<td>0.60</td>
<td>0.32</td>
<td>0.07</td>
<td>0.31</td>
</tr>
<tr>
<td>Supplier Entering</td>
<td>0.10</td>
<td>0.66</td>
<td>0.25</td>
<td>0.10</td>
<td>0.25</td>
</tr>
<tr>
<td>Supplier Exiting</td>
<td>0.14</td>
<td>0.50</td>
<td>0.22</td>
<td>0.06</td>
<td>0.21</td>
</tr>
<tr>
<td>Customer Entering</td>
<td>0.15</td>
<td>0.50</td>
<td>0.25</td>
<td>0.08</td>
<td>0.24</td>
</tr>
<tr>
<td>Customer Exiting</td>
<td>0.15</td>
<td>0.43</td>
<td>0.22</td>
<td>0.06</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Panel B: Pairwise Connection Features &amp; Summary Statistics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frac. Links in Same Industry</td>
<td>0.22</td>
<td>0.29</td>
<td>0.26</td>
<td>0.02</td>
<td>0.26</td>
</tr>
<tr>
<td>Link Duration</td>
<td>1</td>
<td>35</td>
<td>3.24</td>
<td>3.26</td>
<td>2</td>
</tr>
<tr>
<td>Num. Customers Per Firm</td>
<td>0</td>
<td>38</td>
<td>1.21</td>
<td>1.24</td>
<td>1</td>
</tr>
<tr>
<td>Num. Suppliers Per Firm</td>
<td>0</td>
<td>157</td>
<td>1.27</td>
<td>5.32</td>
<td>0</td>
</tr>
<tr>
<td>Long-Term Book Leverage</td>
<td>0.00</td>
<td>1.00</td>
<td>0.18</td>
<td>0.19</td>
<td>0.14</td>
</tr>
<tr>
<td>Long-Term Market Leverage</td>
<td>0.00</td>
<td>1.00</td>
<td>0.18</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Sales (bn)</td>
<td>0.00</td>
<td>483.52</td>
<td>4.73</td>
<td>19.37</td>
<td>0.25</td>
</tr>
<tr>
<td>Assets (bn)</td>
<td>0.00</td>
<td>797.77</td>
<td>5.86</td>
<td>25.25</td>
<td>0.28</td>
</tr>
<tr>
<td>Profitability (ROA)</td>
<td>-60.19</td>
<td>5.39</td>
<td>0.04</td>
<td>0.62</td>
<td>0.11</td>
</tr>
<tr>
<td>Tangibility</td>
<td>0.00</td>
<td>1.00</td>
<td>0.60</td>
<td>0.67</td>
<td>0.46</td>
</tr>
<tr>
<td>Market/Book</td>
<td>0.00</td>
<td>931.79</td>
<td>1.74</td>
<td>8.68</td>
<td>0.97</td>
</tr>
<tr>
<td>State</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP Growth (%)</td>
<td>-10.07</td>
<td>26.97</td>
<td>5.98</td>
<td>3.49</td>
<td>5.70</td>
</tr>
<tr>
<td>Unemployment Rate (%)</td>
<td>2.30</td>
<td>17.79</td>
<td>6.06</td>
<td>2.06</td>
<td>5.73</td>
</tr>
</tbody>
</table>
Table 2: Tier Classifications by Industry

The table below shows the average tier for each Fama-French industry. The average tiers are defined as the average distance from the final consumer. Primary producers are Tier 3, intermediate producers are Tier 2, and final producers are Tier 1.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Industry</th>
<th>Tier</th>
<th>Rank</th>
<th>Industry</th>
<th>Tier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Retail</td>
<td>1.26</td>
<td>23</td>
<td>Petroleum and Natural Gas</td>
<td>2.39</td>
</tr>
<tr>
<td>2</td>
<td>Restaurants, Hotels, Motels</td>
<td>1.47</td>
<td>24</td>
<td>Shipping Containers</td>
<td>2.40</td>
</tr>
<tr>
<td>3</td>
<td>Tobacco Products</td>
<td>1.48</td>
<td>25</td>
<td>Aircraft</td>
<td>2.41</td>
</tr>
<tr>
<td>4</td>
<td>Beer &amp; Liquor</td>
<td>1.72</td>
<td>26</td>
<td>Computers</td>
<td>2.43</td>
</tr>
<tr>
<td>5</td>
<td>Healthcare</td>
<td>1.74</td>
<td>27</td>
<td>Pharmaceutical Products</td>
<td>2.44</td>
</tr>
<tr>
<td>6</td>
<td>Utilities</td>
<td>1.89</td>
<td>28</td>
<td>Steel Works</td>
<td>2.45</td>
</tr>
<tr>
<td>7</td>
<td>Personal Services</td>
<td>2.02</td>
<td>29</td>
<td>Consumer Goods</td>
<td>2.47</td>
</tr>
<tr>
<td>8</td>
<td>Defense</td>
<td>2.05</td>
<td>30</td>
<td>Machinery</td>
<td>2.52</td>
</tr>
<tr>
<td>9</td>
<td>Chemicals</td>
<td>2.10</td>
<td>31</td>
<td>Electronic Equipment</td>
<td>2.53</td>
</tr>
<tr>
<td>10</td>
<td>Printing and Publishing</td>
<td>2.12</td>
<td>32</td>
<td>Electrical Equipment</td>
<td>2.55</td>
</tr>
<tr>
<td>11</td>
<td>Non-Metallic</td>
<td>2.14</td>
<td>33</td>
<td>Construction Materials</td>
<td>2.55</td>
</tr>
<tr>
<td>12</td>
<td>Wholesale</td>
<td>2.17</td>
<td>34</td>
<td>Construction</td>
<td>2.60</td>
</tr>
<tr>
<td>13</td>
<td>Communication</td>
<td>2.21</td>
<td>35</td>
<td>Measuring and Control Equipment</td>
<td>2.63</td>
</tr>
<tr>
<td>14</td>
<td>Business Supplies</td>
<td>2.27</td>
<td>36</td>
<td>Recreation</td>
<td>2.63</td>
</tr>
<tr>
<td>15</td>
<td>Transportation</td>
<td>2.27</td>
<td>37</td>
<td>Computer Software</td>
<td>2.67</td>
</tr>
<tr>
<td>16</td>
<td>Precious Metals</td>
<td>2.31</td>
<td>38</td>
<td>Business Services</td>
<td>2.69</td>
</tr>
<tr>
<td>17</td>
<td>Candy &amp; Soda</td>
<td>2.31</td>
<td>39</td>
<td>Textiles</td>
<td>2.70</td>
</tr>
<tr>
<td>18</td>
<td>Entertainment</td>
<td>2.33</td>
<td>40</td>
<td>Agriculture</td>
<td>2.70</td>
</tr>
<tr>
<td>19</td>
<td>Food Products</td>
<td>2.33</td>
<td>41</td>
<td>Apparel</td>
<td>2.70</td>
</tr>
<tr>
<td>20</td>
<td>Automobiles and Trucks</td>
<td>2.34</td>
<td>42</td>
<td>Coal</td>
<td>2.72</td>
</tr>
<tr>
<td>21</td>
<td>Shipbuilding, Railroad Equipment</td>
<td>2.35</td>
<td>43</td>
<td>Rubber and Plastic Products</td>
<td>2.85</td>
</tr>
<tr>
<td>22</td>
<td>Medical Equipment</td>
<td>2.37</td>
<td>44</td>
<td>Fabricated Products</td>
<td>2.86</td>
</tr>
</tbody>
</table>
Table 3: Leverage across Producer Types

Regressions are across firms, and standard errors are clustered by firm. Industries are based on 3-digit SIC definitions. Point estimates for the Primary and Intermediate Producer categories in regressions (2), (3), and (4) are relative to the Final Producer leverage.

<table>
<thead>
<tr>
<th>Dependent variable:</th>
<th>Long-Term Market Leverage Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Primary Producer</td>
<td>0.113***</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
</tr>
<tr>
<td>Intermediate Producer</td>
<td>0.170***</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>Final Producer</td>
<td>0.202***</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
</tr>
<tr>
<td>Tangibility_{t-1}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>ROA_{t-1}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>(Market/Book)_{t-1}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>23,656</td>
</tr>
<tr>
<td>Fixed Effects</td>
<td>Year</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.031</td>
</tr>
</tbody>
</table>

*p<0.1; **p<0.05; ***p<0.01
Table 4: Tiers Explaining Industry Effects

The table shows regressions of average leverage ratios on average tier number. Primary producers are Tier 3, intermediate producers are Tier 2, and primary producers are Tier 1. Regressions (5) and (6) are weighted by the number of observations within each observation level. The observations are at the industry level for Regression (5) and industries by years level for Regression (6). Industries are defined by 3-digit SIC codes.

<table>
<thead>
<tr>
<th>Dependent variable: Average Market-Leverage Ratio</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Tier</td>
<td>0.076***</td>
<td>0.071***</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.394***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.029)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>236</td>
<td>3,207</td>
</tr>
<tr>
<td>Fixed Effects</td>
<td>Year</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.056</td>
<td>0.104</td>
</tr>
</tbody>
</table>

*p<0.1; **p<0.05; ***p<0.01
Average distance from final consumer corresponds to production tier. Primary producers are Tier 3, intermediate producers are Tier 2, and Final producers are Tier 1. Industries are defined using 3-digit SIC. The size of the points represents the number of firms in each industry.
Table 5: Long-Term Leverage and Number of Suppliers

The table below shows the relationship between long-term leverage and the number of suppliers. Long-term leverage is instrumented by an indicator of whether a firm’s headquarter state had a corporate profits tax increase, except for column (6) which shows the reduced-form results. All regressions include industry-by-year fixed effects, where industries are defined based on 3-digit SIC. Standard errors are clustered at the state level.

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>( Y_t = \text{Number of Suppliers}_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>( \Delta T^+ &gt; 0% )</td>
<td></td>
</tr>
<tr>
<td>Num Events</td>
<td>30</td>
</tr>
<tr>
<td>Num Affected Firms</td>
<td>1,212</td>
</tr>
<tr>
<td>( \hat{LT} \text{ Book Lev} )</td>
<td>4.500</td>
</tr>
<tr>
<td>ROA(_{t-1})</td>
<td>-0.380*</td>
</tr>
<tr>
<td>(Market/Book)(_{t-1})</td>
<td>-0.001</td>
</tr>
<tr>
<td>In Sale(_{t-1})</td>
<td>0.365***</td>
</tr>
<tr>
<td>In Assets(_{t-1})</td>
<td>0.125</td>
</tr>
<tr>
<td>Unemp Rate(_{t-1})</td>
<td>0.014</td>
</tr>
<tr>
<td>Income(_{t-1})</td>
<td>2.427</td>
</tr>
<tr>
<td>First Stage. = 1 if tax increase in ( t = -1 )</td>
<td>0.010**</td>
</tr>
<tr>
<td>Num Obs</td>
<td>19,162</td>
</tr>
<tr>
<td>( R^2 ) first stage</td>
<td>0.596</td>
</tr>
<tr>
<td>( R^2 ) second stage</td>
<td>0.881</td>
</tr>
</tbody>
</table>

*p<0.1; **p<0.05; ***p<0.01
Table 6: Long-Term Leverage and Number of Customers

The table below shows the relationship between long-term leverage and the number of customers. Long-term leverage is instrumented by an indicator of whether a firm’s headquarter state had a corporate profits tax increase, except for column (6) which shows the reduced-form results. All regressions include industry-by-year fixed effects, where industries are defined based on 3-digit SIC. Standard errors are clustered at the state level.

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>$Y_t = \text{Number of Customers}_t$</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T^+ &gt; 0%$</td>
<td>$\Delta T^+ &gt; 0.5%$</td>
<td>$\Delta T^+ &gt; 1%$</td>
<td>$\Delta T^+ &gt; 2%$</td>
<td>Reduced Form</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Num Events</td>
<td>30</td>
<td>21</td>
<td>18</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Num Affected Firms</td>
<td>1,212</td>
<td>492</td>
<td>465</td>
<td>383</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$LT \text{ Book Lev}$</td>
<td>$-3.559^{**}$</td>
<td>$-3.182^*$</td>
<td>$-2.263^{**}$</td>
<td>$-1.648$</td>
<td>$-0.078$</td>
<td>(1.579)</td>
</tr>
<tr>
<td>$ROA_{t-1}$</td>
<td>$0.225^{**}$</td>
<td>$0.208^{**}$</td>
<td>$0.165^{***}$</td>
<td>$0.136^{**}$</td>
<td>$0.083$</td>
<td>(0.097)</td>
</tr>
<tr>
<td>$(Market/Book)_{t-1}$</td>
<td>$0.002^{***}$</td>
<td>$0.002^{***}$</td>
<td>$0.002^{***}$</td>
<td>$0.001^{***}$</td>
<td>$0.001$</td>
<td>(0.001)</td>
</tr>
<tr>
<td>$\ln Sales_{t-1}$</td>
<td>$-0.128$</td>
<td>$-0.117$</td>
<td>$-0.092$</td>
<td>$-0.075$</td>
<td>$-0.00001$</td>
<td>(0.160)</td>
</tr>
<tr>
<td>$\ln Assets_{t-1}$</td>
<td>$0.160$</td>
<td>$0.145$</td>
<td>$0.110$</td>
<td>$0.087$</td>
<td>$-0.00000$</td>
<td>(0.110)</td>
</tr>
<tr>
<td>$Unemp \text{ Rate}_{t-1}$</td>
<td>$0.057$</td>
<td>$0.051$</td>
<td>$0.035$</td>
<td>$0.025$</td>
<td>$-0.006$</td>
<td>(0.063)</td>
</tr>
<tr>
<td>$Income_{t-1}$</td>
<td>$3.872^{***}$</td>
<td>$3.642^{***}$</td>
<td>$3.083^{***}$</td>
<td>$2.709^{***}$</td>
<td>$0.033$</td>
<td>(1.347)</td>
</tr>
<tr>
<td>First Stage. $= 1$ if tax increase in $t = -1$</td>
<td>$0.011^{**}$</td>
<td>$0.024^{***}$</td>
<td>$0.025^{***}$</td>
<td>$0.025^{***}$</td>
<td>$0.005$</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Num Obs</td>
<td>19,162</td>
<td>19,162</td>
<td>19,162</td>
<td>19,162</td>
<td>19,162</td>
<td></td>
</tr>
<tr>
<td>$R^2$ first stage</td>
<td>0.59</td>
<td>0.596</td>
<td>0.596</td>
<td>0.559</td>
<td>0.479</td>
<td>0.522</td>
</tr>
</tbody>
</table>

*p<0.1; **p<0.05; ***p<0.01