Cultural interconnectedness in supply chain networks and change in performance: An internal efficiency perspective

Abstract
We propose the conceptualization of cultural interconnectedness in a supply chain network. As a multiplex network structure, cultural interconnectedness refers to the extent of inter-linking in organizational cultures of supply chain members. Complementing ongoing research on supply chain networks, we propose and test the effects of cultural interconnectedness—conditional on production, inventory, and marketing efficiencies—on the next-period *change* in performance. Our sample consists of supply chain networks of 3,434 publicly traded firms representing an unbalanced panel of 28,461 firm-year observations from 2001 to 2017. Controlling for current period performance (return on assets) and growth opportunities (Tobin's Q) and change in performance and change in growth opportunities, cultural interconnectedness is not directly associated with a change in return on assets in the next period, however, it strengthens the relationship between production efficiency or inventory efficiency and change in return on assets in the next period, but not for marketing resource efficiency. Based on recent advances in social network econometrics, our findings are robust to controlling for spatial autocorrelation in supply chain networks, endogeneity, and spillovers among supply chain network partners, and also for LASSO regressions. Lack of direct effects of cultural interconnectedness, but support for moderation effects for production and inventory efficiencies, imply that cultural interconnectedness is a necessary but not a sufficient condition to improve performance. Production and inventory efficiencies perhaps represent the necessary circuitry for the efficacy of cultural interconnectedness in supply chains. The findings inform operations managers on the role of cultural interconnectedness among supply chain partners.

Keywords: interconnectedness; culture; supply chain; performance change

1. Introduction

The role of networks in the supply chains was originally proposed by Choi et al. (2001), and a variety of studies in operations management have focused on the role of structural characteristics of supply chain networks (e.g., Bellamy et al. 2020; Bellamy et al. 2014; Park et al. 2018). Marshall et al. (2016) call to improve the fit between culture and operations management practices. Research has also focused on congruence or deviance in culture among dyads (Cadden et al. 2013; Cheung et al. 2011; Ireland and Webb 2007; Marshall et al. 2015; Nyaga et al. 2013) or triads (Cadden et al. 2013; Cheung et al. 2011; Ireland and Webb 2007; Marshall et al. 2015; Nyaga et al. 2013) of supply chain members. The value of fit in organizational cultures among supply chain members cannot be overstated, especially in increasingly turbulent environments where greater levels of cultural fit at the supply chain network level could help reduce transaction costs, improve coordination, strengthen trust, enhance flexibility, and resilience, and improve overall performance.

Zooming out of dyadic or triadic cultural fit between the focal firm and supply chain members, we meld the social network literature with literature on organizational culture to propose a framework of cultural interconnectedness among supply chain members (Smith and Christakis 2008). We use the concept of interconnectedness in the social network literature to develop a multiplex supply chain network framework. The multiplexity stems from the ongoing supply chain relationship along with the degree of organizational culture in each node of the network (Gomez et al. 2013; Klimek and Thurner 2013; Szell et al. 2010).[1] In the proposed conceptualization of a multiplex network, the level-1 network is the network of supply-chain partners over which weights by the culture of each supply chain network partner is included to derive the measure of the degree of cultural interconnectedness. The interconnectedness in cultural values provides a second-order knowledge, information, and resource flow mechanism that strengthens the association between the existing basis of efficiencies and change in firm performance.

To measure the organizational culture of each supply chain member, we draw on recent advancements in the measure of organizational culture using the machine learning approach (Li et al. 2020). The measure of the organizational culture of supply chain members is based on scores for the top-five corporate cultural values—*innovation*, *integrity*, *quality*, *respect*, and *teamwork*--proposed by Guiso et al. (2015b) and Guiso et al. (2015a). The definition of organizational culture is rooted in O'reilly and Chatman (1996) (1996, p. 160), the definition of corporate culture is "a system of shared values (that define what is important) and norms that define appropriate attitudes and behaviors for organizational members (how to feel and behave)." We focus on interconnectedness in culture among supply chain partners and do not propose a measure of supply chain level culture; instead, our measure of interconnectedness is at the supply chain network.

We ask whether cultural interconnectedness is useful in improving the strength of association between the three widely used efficiency types—production, inventory, and marketing resource efficiency

[1] Unless otherwise stated we refer to cultural interconnectedness, as interconnectedness.

(Modi and Mishra 2011)—and change in performance. Interconnectedness in culture among supply chain partners could be valuable in improving cultural fit among supply chain members to strengthen the effects of internal efficiencies (Dowty and Wallace 2010; McAfee et al. 2002; Zhang and Cao 2018). We focus on change in performance, instead of the level of performance to specify a more robust test of the degree to which cultural interconnectedness facilitates changes in firm performance. To derive robust inferences based on recent advancements in econometrics of social networks, our findings are robust to controlling for spatial autocorrelation networks, endogeneity in network partner presence, and spillovers. In our sample of 3,434 firms representing an unbalanced panel of 28,461 firm-year observations from 2001 to 2017 cultural interconnectedness strengthens the relationship between production efficiency or inventory efficiency, but not marketing resource efficiency, and change in return on assets.

We aim to make the following contributions. First, adding to Cameron and Quinn (2011) conceptualization of cultural congruence and complementing research in the supply chain on congruence or deviance among supply chain partners, we hypothesize the moderating role of cultural interconnectedness among the supply chain partners. Interconnectedness in cultural values among interconnected supply chain partners improves the effects of efficiency types in driving performance changes. By sharing common cultural systems, supply chain partners through dense interconnectivity can be "clear about and focused on the same values and sharing the same assumptions simply eliminates many of the complications, disconnects, and obstacles that can get in the way of effective performance" (Cameron & Quinn, 2006, p. 73). Interconnectedness allows for the dense circuitry necessary to lower incongruence and strengthen the alignment of supply chain goals. Cultural interconnectedness allows consideration of the increasingly complex and interdependent nature of supply chain interconnections necessary to compete in increasingly turbulent environments. If the supply chain represents an inter-organizational network, it is apt to assess the role of network interconnectedness of a multiplex cultural network, in addition to the networked basis of a supply chain.

Second, interconnectedness in culture provides an additional mode of coordination and governance. Past studies on supply chain coordination focus on two modes of coordination—control and cooperation (Fugate et al. 2006; Xu and Beamon 2006). The control element focuses on the contracts, incentives, and monitoring systems, whereas cooperation focuses on the pursuit of shared goals based on equality and rooted in the collaborative pursuit of goals based on reciprocity. In an interconnected supply chain network, cultural interconnectedness adds the needed mechanism that is a lubricant that smoothens control and cooperation through shared values and beliefs. The increasingly congruent cultural systems among employees across culturally interconnected supply chains add a second-order mechanism to improve trust, coordination, and control.

In the following Section 2, we first propose our theoretical framework. In Section 3, we present our sample and research methodology. In Section 4 we present our results and robustness checks. In Section 5 we present theoretical and managerial implications along with limitations and directions for future research.

2. Theoretical background and hypotheses

2.1 Culture and supply chains

Organizational research has found broad support for the benefits of organizational culture in driving firm performance (Adler and Jelinek 1986; Cui and Hu 2012; Sarooghi et al. 2015; Witherspoon et al. 2013). According to Schein (1990) organizational culture is defined as "A pattern of basic assumptions, invented, discovered, or developed by a given group, as it learns to cope with its problems of external adaptation and internal integration that has worked well enough to be considered valid and, therefore is to be taught to new members as the correct way to perceive, think, and feel in relation to those problems." (page 111). Though culture remains less studied in operations management research, according to Marshall et al. (2016), culture does make an important contribution of decision making in managing operations and improves the effectiveness of operation practices.

Our study is among the first to propose the role of cultural similarity in a supply chain measured by the degree of interconnectedness in similar cultural values among supply chain participants. Our conceptualization is rooted in the proposition from Cameron and Quinn (2011) who proposed that congruency in cultures improves performance to a greater extent than in-congruency in culture among supply chain members. Specifically, we posit that interconnectedness in culture among supply chain members could significantly improve performance outcomes, conditional on the focal firm efficiency in the three broadly studied areas of production, inventory, and marketing resource efficiency (Modi and Mishra 2011).

Building from Schein (2010) cultural interconnectedness among supply chain members can be a powerful force that could be leveraged when internal efficiency in operations is higher. If cultural interconnectedness is influential in improving access, flow, and recombination of supply chain assets, then organizations with higher operational efficiency—production, inventory, and marketing efficiencies—should realize a higher performance improvement. Compared to the mean effects in typical hypotheses around efficiency and performance we focus on the *change* in performance. Before proposing the moderation hypotheses, we discuss cultural interconnectedness in greater detail to set the backdrop for its moderation effects. The conceptual model is presented in Figure 1.

-------------Insert Figure 1 about here------------

2.1.1. Cultural interconnectedness in a supply chain network

The logic of the value of interconnectedness in culture among supply chain members is construed as follows. First, after controlling for the weighting in supply chain relationships based on exchanged goods and services, cultural similarity can improve the flow of knowledge and information in the supply network at large as the common language, symbols, and norms of behaviors that go well beyond the operations functions could help improve and strengthen the supply chain exchanges. Cultural interconnectedness helps further link employee mindsets, practices, and intangible assets across supply chain partners, creating additional operational and supply chain synergies. Stronger interconnectedness in culture provides the necessary channels and conduits based on reinforcing and recurring loops in the supply network that help improve interconnectedness and sharing of routines and resources. The congruency in culture afforded by interconnectedness in culture among supply chain members plays a pivotal role in developing, implementing, and sustaining a joint supply chain strategy aimed at strengthening performance.

Cultural interconnectedness among the supply chain members further improves speed and accessibility to information, knowledge, and resources (Dyer and Nobeoka 2000). Both directly through connections of the focal firm and indirectly through interconnections among other supply chain members; allowing for transmission, collation, and recombination of knowledge that may lower costs, improve lead times, and enhance flexibility (Al-Laham et al. 2011). Higher cultural interconnectedness could improve the overall supply chain responsiveness as it allows for improved ability to manage uncertain demand, shorten product life cycles, and strengthen knowledge spillovers. The circuitry of knowledge and routines and the plumbing of resource flows in densely interconnected supply chain partners help develop dense relationships, improving the flow of routines, resources, and knowledge (cf. hub-spoke model). Building from research on supply chain networks (Bellamy et al. 2020; Bellamy et al. 2014; Park et al. 2018), interconnectedness in culture among supply chain partners allows for improved knowledge exchange, collaboration, pooling of resources, and operational and supply chain problem-solving. If culture forms the undergird of values and belief system in a supply chain that helps not only improve trust but may also helps further develop supply chain specific resources to improve competitiveness. Though interconnectedness could be criticized for redundancy (Echols and Tsai 2005), cultural interconnectedness in the supply chain can beneficial as firms do not revaluate and realign their supply chain relationships often (compared to say, alliance networks), further improving performance.

Cultural interconnectedness improves the accrual of operational knowledge by improving both internal and external supply chain knowledge generation. The shared value and belief systems further help improve internal experimentation, strengthen operational systems, help leverage cross-boundary knowledge necessary to develop products, improving operational routines, and strengthen vicarious learning. With increasing interconnections, firms realize more interconnections and knowledge recombination possibilities that help develop the newer supply chain and operational ideas and applications. Cultural interconnectedness may strengthen the level of trust, reduce opportunistic behavior, and improve resource sharing. Strengthening the exchange of tacit knowledge, cultural interconnectedness strengthens the access and combination of tacit and diverse knowledge.

As one of the early efforts to theorizing cultural interconnectedness in supply chain networks, we aim to build a theoretical conceptualization to assess whether shared cultural practices in a supply chain result in performance benefits. Our baseline premise from (Dowty and Wallace 2010) definition of culture is "a way of doing business" where the greater interconnectedness in doing business may improve supply chain performance (page 57). Where increasing interconnectedness in culture results in "fairly enduring multileveled, organized work context entailing the following: organizing values, norms, taken-for-granted assumptions, behavioral regularities, rituals, practices, procedures, patterns of discourse, use of symbols, way identity is constructed" (Peterson et al. 2011) (2011, p. 4) to improve fidelity in operational and supply chain activities.

2.1.2. Cultural interconnectedness and production efficiency

Improving production efficiency entails coordination and execution of a diverse set of tasks to improve efficiency in the conversion of raw materials to finished goods (Modi and Mishra 2011). Manufacturing organizations focused on implementing a variety of production methods such as cycle time reduction, flexibility, maintenance optimization, process re-engineering among others. As these approaches aim at strengthening production efficiency, culturally interconnected supply chain members may provide an added mode of coordination and inflows to lower waste, strengthen value-added activities, and imbue manufacturing practices necessary to improve performance through improve production efficiency (Heikkilä 2002; Reiner and Hofmann 2006; Yang et al. 2011). Improving production efficiency and performance association requires a focus on developing cost advantages that are rooted in a complex web of operational routines and resources.

Typically, rooted in the tacit knowledge accumulated over time, culturally interconnected supply chain members could improve help further move the production efficiency frontier outward to improve performance (Schoenherr et al. 2014; Wu and Lin 2013). With changing market conditions and competitive challenges culturally interconnected supply chain members can provide additional modes for helping production efficiency improve performance. Cultural interconnectedness morphs transactional and contractual exchanges to richer exchanges of knowledge, skills, and flows that help operations function to further strengthen their association with supply chain partners to improve stock and flow, develop common and collaborative forecasting methods rooted in a greater exchange of tacit knowledge and improve convergence in production planning and lower variability and exceptions in performance. Based on the above discussion we propose that the relationship between property, plant and equipment (PPE) efficiency[2] and performance will be stronger under greater interconnectedness among supply chain members.

Hypothesis 1. Interconnectedness in culture among supply chain members reinforces the positive association between PPE efficiency and performance change.

2.1.3. Cultural interconnectedness and inventory efficiency

Inventory efficiency refers to the extent to which the inventory turnover of the focal firm is higher than its competitors. Inventory efficiency is indicative of how well internal and external demand management capabilities are coordinated (Balakrishnan et al. 2004; Hill and Scudder 2002; Sahin and Robinson Jr 2005). Higher inventory efficiency relative to competitors not only indicates a firm's ability to forecast and manage materials more effectively but also reflects a firm's ability to manage the flow of materials. Inventory efficiency through improved information flow, information sharing, and resource management indicate improved sharing of information among supply chain partners (Netessine and Zhang 2005). Higher inventory efficiency indicates leanness, and more interconnected cultural networks could help improve material flow (Davies and Joglekar 2013; Dehning et al. 2007), productivity (Eroglu and Hofer 2011), and lower forecasting errors (Michalski 2009).

Cultural interconnectedness among supply chain members could improve the interfacing and flow of information to improve returns from inventory efficiency. Through an improved flow of information, increasing fidelity in information exchange, and improved understanding of operations of supply chain partners, cultural interconnectedness could improve inventory management (Cachon and Fisher 2000; Lee and Billington 1992). Though inventory efficiency driving higher financial performance through

[2] Production efficiency is a standardized measure of sales generated for every dollar invested in net property, plant, and equipment (PPE) adjusted for industry sales-to-PPE ratio.

improved coordination through IT and operations systems (JIT), cultural interconnectedness adds another dimension of coordination and communication to not only improve the improve holding costs, lower obsolescence costs, and improve the general concordance and coordination in managing inventory. Cultural interconnectedness may improve information flows in the production process, strengthens JIT systems, helps improve the alignment of incentives in supply chain contracts through increasingly 'clan' type cultural values that not help manage supply chain disruptions better but may also improve flexibility in meeting diverse customer needs. Based on the above discussion we propose that the relationship between inventory efficiency[3] and performance will be stronger under greater interconnectedness among supply chain members.

Hypothesis 2. Interconnectedness in culture among supply chain members reinforces the positive association between inventory efficiency and performance change.

2.1.4. Cultural interconnectedness, marketing resource efficiency, and performance change

Previous research shows that culture influences consumer-oriented behaviors to improve financial performance (Alvarado and Kotzab 2001; Min and Mentzer 2000). By improving employee attitudes, climate, and commitment to customer service, cultural interconnectedness could meaningfully improve returns from marketing resource efficiency (Webster 1991). Cultural interconnectedness may further improve the influence of control systems, procedures, and authority (Alvesson 2012; Bates et al. 1995) and strengthens strategic and tactical decisions related to marketing resource efficiency. Cultural interconnectedness influences creativity and opportunity seeking and improves consistency, predictability, and efficient performance (Hogan and Coote 2014). Culturally interconnected supply chain members may further empower employees to improve the cooperative environment necessary to strengthen marketing-related outcomes.

[3] Inventory efficiency is a standardized measure of sales-to-inventory ratio adjusted for industry sales-to-inventory ratio.

Cultural interconnectedness could be influential in improving allocation, leveraging, and recombination of marketing-related resources. Given brand equity, servitization and customer satisfaction are increasingly the basis of competitive advantage for manufacturing firms, greater cultural interconnectedness may not only help improve alignment with customer needs, but it may also improve value propositions to improve revenues and strengthen brand loyalty (Lam 2007; Palumbo and Herbig 2000). Cultural interconnectedness may allow the focal firm to better access, interpret, and leverage marketing resources to improve marketing capabilities (Keskin 2006; Krush et al. 2015; Madhavaram and Hunt 2008) that in turn may improve firm performance. With manufacturing firms facing increased competition in the recent decades, cultural interconnectedness could improve understanding of avenues to improve customer satisfaction, product innovation, and leveraging the marketing knowledge pools in the supply chain to improve performance. Based on the above discussion we propose that the relationship between marketing efficiency[4] and performance will be stronger under greater interconnectedness among supply chain members.

Hypothesis 3. Interconnectedness in culture among supply chain members reinforces the positive association between Marketing resource efficiency and performance change.

3. Sample and Method

3.1. Sample

To test the proposed hypotheses we develop a supply chain network from supply chain identifiers in the historical CRSP and Compustat company fields on the WRDS platform. Consistent with recent works on supply chain networks in operations management, the supply chain relationships are coded by the reported cost of goods sold among firms in the supply chain network.

[4] Marketing efficiency is a standardized measure of sales and general administrative (SG&A)-expenses-to-sales ratio adjusted to industry SG&A-expenses-to-sales ratio.

Each node of the network is then matched with a culture measure from Li et al. (2020). The resulting ego network measures are weighted by culture similarity among the nodes and the focal firm. In total, the data includes 8,164 firms from 2001 to 2017 representing 371,422 total nodes. After casewise deletion, our final sample includes 3,434 firms representing an unbalanced panel of 28,461 firm-year observations from 2001 to 2017. All variables are winsorized at 2% on each tail.

3.2 Measures

3.2.1. Dependent variable

Causality in the current context is difficult to ascertain, though in the additional analysis we make a concerted effort to control for spatial autocorrelation, endogeneity, and spillovers. We also specify LASSO regression to lower concerns for specification bias in the inclusion of variables in the model. Despite these methodologies, endogeneity is difficult to fully rule out.

We use an outcome variable less encumbered by simultaneity bias, specifically, the change in return on assets (ROA) from t+1 to t+2, and control for the change in ROA from t to t+1, and ROA at time t. This approach allows us to control for the magnitude of ROA at (t), and also control for the impact of ongoing ROA improvement actions in year t that led to improvements in year t+1. Overall, assessing the effects of interconnectedness on the change from t+1 to t+2 lowers the simultaneity bias. In the controls, we also include Tobin's Q (t) and change in Tobin's Q from t to t+1, to proxy a variety of growth opportunities realized by the firm.

3.2.2. Predictor variable—cultural interconnectedness in a supply chain network.

The measure of cultural interconnectedness builds for the organization-level culture of each supply chain member. We draw on the measure of organizational culture from Li et al. (2020), who develop the measure of culture using machine learning methods and validating it across a wide range of firm outcomes. The measure is based on the word embedding model, a natural language model based on artificial neural networks, from 209,480 earnings call transcripts for the five corporate cultural values of *innovation*, *integrity*, *quality*, *respect*, and *teamwork* across 62,664 firm-year observations from 2001 to 2018. The measure based on Li et al. (2020), shows strong discriminant validity by its components, specifically, innovation is related to R&D and patents, and also associated with "operational efficiency, risk-taking, earnings management, executive compensation design, firm value, and deal-making". Before Li et al. (2020), the measure of culture was survey-based and typically cross-sectional. In line with a review by (Guiso et al. 2015a, 2018) and interview evidence in (Graham et al. 2016), the measure of organizational culture based on a semi-supervised machine learning approach is consistent with Guiso et al. (2015a, 2018) who proposed that innovation, integrity, quality, respect, and teamwork, express a core corporate value. Li et al. (2020) measure is an important methodological advancement in finance and accounting literature and is well validated to ensure that earnings calls are not merely "cheap talk" by using a combination of (hundreds to thousands) phrases for each cultural value. The word embedding method used in Li et al. (2020) learns the meaning of adjacent words to reduce the use of buzzwords and also employs a weighting scheme that puts lower weights on more frequently occurring words.

3.2.3. Network measures

Our predictor variable is cultural interconnectedness among supply chain members. *Interconnectedness* is based on adapting Burt's (1992) redundancy measure, which measures the extent to which a firm's direct ties are interconnected.

$$IC_{it} = \frac{\sum_j \sum_q p_{iqt}\, I_{jqt}}{n_{it}}, \tag{1}$$

where n_{it} denotes the ego network size of firm i in year t, and $p_{iqt} = n_{it}^{-1}$ (the proportion of node i's costs incurred in maintaining the relationship with node q in period t). Figure 2 shows an example of two firms TGC industries with high cultural interconnectedness and Advanced energy industries with lower cultural interconnectedness.

------------Insert Figure 2 about here-------------

3.2.4. Moderator variables

Inventory efficiency. Based on Modi and Mishra (2011), inventory efficiency is measured relative to industry inventory efficiency; that is, for firm *i* at time *t* (year):

$$IE_{it} = \frac{\left(\frac{Sales_{it}}{Inventory_{it}}\right) - \mu\left(\frac{Sales_t}{Inventory_t}\right)}{\sigma\left(\frac{Sales_t}{Inventory_t}\right)} \quad (2)$$

Where μ is the industry (at SIC2) mean sales to inventory ratio at time *t* (year), and σ is the standard deviation in sales to inventory for the industry (at SIC2) at time *t*. The intuition is as follows: The numerator measures the degree to which firm *i*'s inventory efficiency deviates from mean industry inventory efficiency. Because inventory efficiency varies from industry to industry, the difference in the numerator is normalized by the standard deviation of inventory efficiency in the industry. This allows for a standardized measure of inventory efficiency comparable across industries.

Production efficiency: Production efficiency is the sales generated for every dollar invested in net property, plant, and equipment (PPE), and is adjusted for the mean industry (at SIC2) ratio of sales to net PPE. The difference is divided by the standard deviation of sales to net PPE in the industry (Modi and Mishra 2011) in year *t*:

$$PE_{it} = \frac{\left(\frac{Sales_{it}}{NetPPE_{it}}\right) - \mu\left(\frac{Sales_t}{NetPPE_t}\right)}{\sigma\left(\frac{Sales_t}{NetPPE_t}\right)} \quad (3)$$

Similar to the measure of inventory efficiency, production efficiency is a standardized measure comparable across industries.

Marketing resource efficiency. Consistent with Modi and Mishra (2011), SG&A efficiency is operationalized similarly to the previous two efficiencies:

$$Marketing\ resource\ efficiency_{it} = \frac{\left(\frac{Sales_{it}}{SG\&A_{it}}\right) - \mu\left(\frac{Sales_t}{SG\&A_t}\right)}{\sigma\left(\frac{Sales_t}{SG\&A_t}\right)} \quad (4)$$

3.2.5. Control variables.

We control for *betweenness centrality in culture* based on the measure proposed by Freeman et al. (1979):

$$B_{it} = \sum_{j \neq i, i \neq k} \frac{g_{ijkt}}{g_{jkt}}, \quad (8)$$

where g_{jkt} is the total number of shortest geodesic paths linking firms j and k in year t and g_{ijkt} is the count of the geodesics that contain i in year t. The normalized version is

$$B_{it}^{*} = \frac{B_{it}}{(N_t - 1)(N_t - 2)/2} \tag{5}$$

where N_t refers to the network size in year t. We modify Betweenness Centrality in (8) as follows:

$$B_{it} = \sum_{j \neq i, i \neq k} \frac{\tilde{g}_{ijkt}}{\tilde{g}_{jkt}}, \tag{6}$$

where $\bar{g}_{jkt}$ is the total *length* of shortest geodesic paths linking firms j and k in year t and $\tilde{g}_{ijkt}$ is the *length* of the shortest geodesic paths that contain i in year t. The "length" is measured using the average culture of firms $i, j,$ and k in year t. We replace it by

$$IC_{it} = \frac{\sum_j \sum_q \tilde{p}_{iqt}}{n_{it}}, \tag{7}$$

where $\tilde{p}_{iqt}$ is the culture from firm q to i.

Eigenvector centrality in culture Based on Borgatti and Li (2009) eigenvector centrality is operationalized as:

$$E_{it} = \frac{\sum_j I_{ijt} E_{jt}}{\lambda}, \tag{8}$$

where $I_{ijt} = 1$ if firms i and j are connected at period t and zero otherwise, for some constant λ (the maximal eigenvalue as in Bonacich, 1972). Normalized eigenvector centrality is

$$E_{ijt}^{*} = \frac{\lambda^{-1} \sum_j I_{ijt} E_{ijt}}{\max\limits_{i,j} \quad (E_{it}, E_{jt})}. \tag{9}$$

We control for a log of sales, cash flows, debt ratio, change in Tobin's Q from t to t+1, Tobin's Q, firm age. Cash flow is the sum of income before extraordinary items and depreciation and amortization expenses divided by total assets. The debt ratio is long-term liabilities divided by total assets. Tobin's Q is calculated as (*at* + (*csho* * *prcc_f*) - *ceq*)/(*at*), where *at* is the assets, *csho* represents the net number of all common shares outstanding at year-end, excluding treasury shares and scrip. *prcc_f* is the annual closing price, and *ceq* is the common equity. Firm age is years since IPO. We control for year fixed effects and time-trends by two-digit SIC code (year × sic2 dummies).

4. Results

Table 1 presents the descriptives, and tables A1 and A2 present descriptives by year and industry.

Table 2 presents the fixed effects estimates. PPE efficiency is positively associated with change in ROA from t+1 to t+2 (Model 2: $\beta = 0.0239$, $p < 0.01$). We do not find a direct association between inventory efficiency and the outcome variable and find a negative association for Marketing resource efficiency (Model 2: $\beta = -0.0152$, $p < 0.05$).

-----------Insert Tables 1-4 and Figures 3 and 4 about here----------

Hypothesis 1 proposed that interconnectedness in culture among supply chain members reinforces the positive association between inventory efficiency and performance (Model 5: $\beta = 0.0084$, $p < 0.05$). Figure 3(a) presents to support the hypothesis, that is, with increasing cultural interconnectedness in the supply chain, higher levels of PPE efficiency (dashed line) is upward sloping and its confidence intervals do not overlap with the downward sloping line for lower levels of PPE efficiency (solid line).

Hypothesis 2 proposed that interconnectedness in culture among supply chain members reinforces the positive association between inventory efficiency and performance (Model 5: $\beta = 0.0163$, $p < 0.01$). Figure 3(b) supports the hypothesis. With increasing cultural interconnectedness, higher levels of inventory efficiency (dashed line) is upward sloping and its confidence intervals do not overlap with the downward sloping line for lower levels of inventory efficiency (solid line).

Hypothesis 3 proposed that interconnectedness in culture among supply chain members reinforces the positive association between Marketing resource efficiency and performance, however, this hypothesis was not supported (Model 5: $\beta = -0.0021$, $p > 0.10$).

4.1. Robustness checks

4.1.1. Spatial autocorrelation, network-based endogeneity, and spillover adjustment

We further test whether including controls for Spatial autocorrelation, network-based endogeneity, and spillover adjustment affects the results. In Appendix B, we present the estimation models for spatial autocorrelation among supply chain members (B.1) and network-based endogeneity among supply chain members (B.2).

In Table 3, we use the same fixed-effects specification used in our main specification, but with six additional controls: (i) interconnectedness (spatial autocorrelation and endogeneity adjusted); (ii) eigenvector centrality in culture (spatial autocorrelation and endogeneity adjusted); (iii) betweenness centrality in culture (spatial autocorrelation and endogeneity adjusted); (iv) interconnectedness (spillover adjusted); (v) eigenvector in culture (spillover adjusted); and (vi) betweenness centrality in culture (spillover adjusted). The logic for the inclusion of these controls is similar to that of the control function approach (Petrin and Train 2010; Wooldridge 2015). We estimate these additional controls using the proposed approaches in Appendix B, using a spatial stochastic frontier model based on Bayesian techniques , and include the estimated variables as controls in the regression. Additionally, inefficiency measures are estimated using a network stochastic approach as we detail in Appendix B.

After adding these six controls for spatially correlated, spillovers adjusted and endogeneity adjusted measures and using the fixed-effects estimates similar to Table 2, the effects are consistent with the main inferences and supported in Table 2 and supported in Figure 4.

4.1.2 LASSO regression

Our estimates could be biased by the variables we include in the specification. We use LASSO regression, a widely used methodology in machine learning for assessing variable selection. We use three types of LASSO regressions: double selection model, partialling out regression, and cross-fit partialling out model (Ahrens et al. 2020). In Table 4, based on LASSO regression the effects are consistent with the main effects in Table 2. We note that spatially correlated, spillovers adjusted and endogeneity adjusted measures from Table 3 are not included here, and only the controls in Table 2 are included.

For the analysis presented in sections 4.1.3 and 4.1.4, the variables used in Table 2 are used throughout and the same fixed-effects specification is used.

4.1.3 Alternate outcome variables

In addition to ROA, we assess the effects of the proposed hypotheses for return on assets (ROA) and return on equity (ROE). However, in Table A3 we do not find support for the hypotheses for these two outcomes, confirming the effects of the outcome, return on assets, more proximal to operational activities.

4.1.4. Non-linear effects

In Table A4, we test for the squared term for cultural interconnectedness (model 1) and the interaction effects for the squared term for efficiency measures (model 2). We do not find support for the effects of squared terms.

5. Discussion

Our analysis robust to a variety of alternate specifications, and more importantly to controls for spatial autocorrelation, endogeneity, and spillovers in networks, shows beneficial effects of cultural interconnectedness on improvements in return on assets in the next year. The findings do not support the non-linear effects nor do the findings show improvements in other outcome variables. Note that we control for lagged effects of return on assets and change in return on assets in the current period and also for growth opportunities (Tobin's Q and change in Tobin's Q in the current period). Cultural interconnectedness shows beneficial effects on change in return on assets for production efficiency and inventory efficiency. However, we did not find support for its moderation effects for marketing resource efficiency.

The direct effects of cultural interconnectedness on performance indicate the limited efficacy of such interconnectedness in the absence of internal efficiency. The support for moderation effects but the lack of direct effects of the moderator show that efficiency, specifically, production or inventory efficiency are the necessary conditions for the efficacy of cultural interconnectedness. We construe this finding from the perspective of production and inventory efficiencies as the operations-based 'neural' network of the firm interacting with the supply chain actors. Indirectly supporting this interpretation is the lack of support for the effects of cultural interconnectedness on the marketing resource efficiency and performance relationship. Both support for H1 and H2 and lack of findings H3 imply that cultural interconnectedness is a necessary but not a sufficient condition to improve performance.

5.1. Theoretical implications

Our study has theoretical implications as follows. First, prior literature has generally focused on the dyads or triads in supply chain congruence or deviance in culture. Our proposition of interconnectedness in culture among supply chain members provides a novel theoretical and empirical contribution by highlighting the role of the complete ego network of the other publicly traded supply chain members. With an increased focus on competition among supply chains, focus on the collective levels of culture is an important consideration. The construct of cultural interconnectedness among supply chain members is critical as it zooms out to the role of culture at the supply chain level, but more importantly, helps assess the extent to which the density of interconnections on cultural elements is an important element in improving returns to production and inventory efficiency. Though it is not feasible to control for idiosyncrasies in supply chain relationships, and consistent with supply chain research based on archival data, to control for the contemporaneous firm-supply chain benefits we were judicious in controlling for return on assets and change in return on assets along with Tobin's Q and change in Tobin's Q. Though these controls represent rough proxies they do capture the performance dynamics jointly at the firm, supply chain and the interface of firm and supply chain levels.

Second, our framework contributes to social network literature by focusing on the multiplexity supply chain network based on culture. Supply chain network members embedded in the larger network of partners can develop shared symbols, beliefs, artifacts, and values, in addition to the supply chain hardware and systems. As a second-order model for shared coordination and communication, the multiplex cultural interconnectedness in supply chain networks is an additional basis of competitive advantage. Though much social network literature has focused on the cognitive, relational, and structural elements of a network, cultural interconnectedness provides an added layer that may explain how supply chain participants may sustain cognitive dimension through shared language and narratives that may limit opportunism and add a cognitive dimension to supply chain goals and objectives. Cultural interconnectedness enhances the relational dimension as shared cultural interconnectedness strengthens respect, trust, and interactions. Culture may act as an overarching guiding framework to help develop joint supply chain strategies. Finally, cultural interconnectedness reinforces the structural roles and positions of supply chain partners by improving embeddedness into shared cultural values.

Third, we focused on the three efficiency metrics studied in operations management. The findings build insights into how external interconnectedness in culture can influence the effects of two of the three efficiencies on performance change. We did not find support for effects marketing resource efficiency but find support for two efficiency types directly related to operations. Our outcome variable focused on change in return on assets indicates the value of cultural interconnectedness in driving change in return on assets. Our inferences were not supported for return on sales or return on equity, further indicating the impact on a widely studied indicator of efficiency, return on assets. *Our research offers rich prescriptions to managers on assessing the extent to which the cultural values are interconnected with those of supply chain members*.

Fourth, the role of congruence in densely interconnected members of the supply chain indicates the value of softer elements of governance in the operations management context where much focus remains on the hardwired elements of tasks, tools, and processes. Our findings add a much-needed dimension in partially explaining why some firms realize greater supply chain improvements than others.

5.2. Methodological Implications

Methodologically, our paper draws on recent econometric advancements in social network econometrics. The spatial location of supply chain partners, in terms of cost of goods sold, is based on the evolving characteristics of a network, and as such the autocorrelation in the relationships must be controlled for. Furthermore, the endogeneity in the selection of supply chain partners is equally important. Spillovers (recursive cost of goods sold) are not controlled for in the supply chain network literature. By making room for these controls, we aim to provide an analysis based on recent advancements in econometrics to draw robust inferences. Though past studies have accounted through models on structural endogeneity in simulations based on the Exponential random graph model (ERGM) to derive empirical estimates (Park et al. 2018), the empirical applications accounting for spatial autocorrelation and spillovers, to our knowledge, remains absent. We aim to empirically complement this stream of research.

We also note that we use the fixed-effects regressions to account for the temporal changes in the network characteristics. As stated in Bellamy et al. (2020) and Park et al. (2018) “despite important advances, the majority of empirical studies on supply network phenomena have been based on case studies or cross-sectional data" (page 79).

5.3. Managerial Implications

Our empirical results provide an important set of guidelines for operations managers in general and top management teams in particular. For operations managers, our findings provide an additional element, cultural interconnectedness, as a driver of the degree to which cultural congruence in a densely connected network could provide added performance improvement benefits. The absence of direct effects of cultural interconnectedness, but support for moderation effects for production and inventory efficiencies indicates that cultural interconnectedness is a necessary but not a sufficient condition to improve performance. Firms may not simply realize higher benefits from being embedded in a culturally interconnected supply chain. Production and inventory efficiencies perhaps represent the necessary condition for the efficacy of cultural interconnectedness. The results show that for a one standard deviation increase in cultural interconnectedness and a standard deviation increase in production efficiency, return on asset increases by 0.8%. Whereas the 'bang for the buck' is greater for inventory efficiency where a one standard deviation increase in cultural interconnectedness and a standard deviation increase in inventory efficiency increases return on assets by about 1.63%. Therefore, in allocating resources towards efficiency improvements under higher cultural interconnectedness, improving inventory efficiency enhances return on assets meaningfully.

As operations managers consider supply chain relationships, cultural congruence is an important consideration. Though operational and supply chain resources are necessary, shared cultural congruence in the interconnected supply chain is an important consideration in sustaining and developing a supply chain relationship. Such efforts must be developed in concert with upper-level management as shared culture may form the basis of improving performance in other functional areas and improving firm strategy in the longer run.

Despite the potential positive gains interconnectedness in culture among the supply chain members, it is possible that shared culture may result in learning traps and may limit infusion of knowledge. We posit that interconnectedness could further limit the infusion of new knowledge and learning. Greater cultural interconnectedness results in reinforcing values and belief systems that may not only limit future infusion of newer operational and supply chain activities, but it may also increase dependency as supply chain participants continue to exploit operational and supply chain relationships instead of balancing needed exploration that is less encumbered by culture.

Considering both the positive and the negative outcomes of cultural interconnectedness, we posit a positive association due to limited support in the literature on declining returns from increasing cultural congruence (Cadden et al. 2013), and potentially overwhelming benefits of a shared culture in a more stable supply chain relationships. Supply chain relationships are generally collaborative (Arthanari et al. 2015; Bouncken et al. 2015; Wilhelm 2011), resulting in a lower need to sustain relationships to an extent that such relationships have declining returns. In other words, the possibility of cultural interconnectedness resulting in declining returns may be theoretically possible, however, we do not phenomenologically expect declining returns.[5]

5.4. Limitations and Future Research Directions

Overall, our empirical results suggest a contingency-based relationship, noting the need to focus on contingency and not universalistic gains from IT in driving production efficiency. Our findings are not without limitations. First, although we incorporate the production efficiency framework and structural embeddedness framework in our theory development to explain plausible mechanisms, consistent with much of production efficiency and supply chain network research we are unable to parse out micro-dynamics of internal and external firm exchanges of knowledge and resources in the production processes or supply chain exchanges. We neither observe nor analyze the focal firm or partner firm-level mechanisms and call on future work to augment our approach. Second, we use archival data to construct a supply chain network based on the cost of goods sold an approach that also has been used in recent studies. Consistent with these studies we only have access to other members of a supply chain network

[5] We also test for this empirical possibility in the results section.

who are also publicly traded. As such, as in most works mapping supply chain networks, our network is censored in the sense it does not have all the supply chain relationships from privately traded firms. Establishment level census data may be more useful in further elaborating on spatial dependencies and capturing the full extent of the supply chain network.

Our research focuses on the financial outcomes, however, additional outcomes such as improved logistical flexibility, operational resilience, and responsiveness are among the additional outcome variables that are of interest. Shared value systems may drive the pursuit of additional outcomes such as supply chain environmental performance, process innovation, among others. Additionally, though supply chain contracts are generally based on objective criteria, with increasing environmental instability and uncertainty, cultural interconnectedness among supply chain members could form the necessary basis of relational governance, a necessity in increasingly transactional supply chain relationships.

The findings also leave room for the effects of interconnectedness in a culture based on supply chain performance as an aggregate. Though our focus was on firm-related outcomes, richer data on stock and flow of resources in the supply and its effects on the overall supply chain outcomes could further add to the proposed framework. We note that due to variations in accounting practices, corporate holding structures, and variations in managerial discretions in reporting performance (e.g., earnings management) we could not aggregate the available archival data to derive supply chain performance measures. However, future studies could take a mixed-method approach to assess supply chain performance with fine-grained data on the network level flow and weighted performance attributable to supply chain activities.

In conclusion, the findings of our study shed light on an important phenomenon of the interconnectedness of culture among supply chain partners. The shared values, beliefs, symbols, and language create second-order coordination and communication mechanisms that complement strategic and tactical aspects of supply chain management and in the true sense of supply chain, as a networked organization, could be partially improved through interconnected cultural values.

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TABLE 1. Descriptives

	variable	mean	sd	min	max
1	ROA (t+2 minus t+1)	-0.0037	0.2197	-4.1794	4.2812
2	ROA (t+1 minus t)	-0.0008	0.1920	-4.0042	3.6105
3	ROA	-0.0036	0.2236	-4.0088	0.2723
4	Interconnectedness	-0.0118	0.9958	-1.2220	5.3861
5	PPE efficiency	-0.0869	0.3566	-0.9103	2.3800
6	Inventory efficiency	-0.1724	0.3447	-0.7071	2.6557
7	Marketing resource efficiency	0.0724	0.5431	-2.1688	2.4174
8	Eigenvector centrality in culture	0.0268	1.0148	-0.8538	8.5760
9	Betweeness centrality in culture	-0.0004	1.0000	-1.1732	5.5247
10	Log of sale	6.8012	1.9192	0	9.7430
11	Cash flows	0.0417	0.2155	-3.8584	0.2932
12	Debt ratio	0.5167	0.2866	0.0281	4.4022
13	Tobin's Q (t+1 minus t)	-0.0475	1.0501	-19.9052	19.2376
14	Tobin's Q	1.9602	1.4780	0.5667	28.5992
15	Firm age	17.8186	9.4007	1	38

	variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	ROA (t+2 minus t+1)	1													
2	ROA (t+1 minus t)	-0.0104	1												
3	ROA	-0.0596*	0.4273*	1	1										
4	Interconnectedness	0.0039	-0.0045	-0.0054	1										
5	PPE efficiency	-0.0021	0.0012	-0.0193*	-0.0013	1									
6	Inventory efficiency	-0.0092	0.007	-0.1110*	0.0038	0.0980*	1								
7	Marketing resource efficiency	-0.0163*	0.0294*	0.1739*	0.0025	0.2741*	0.1272*	1							
8	Eigenvector centrality in culture	-0.0082	0.0072	0.0109	-0.0832*	-0.0117*	-0.0116	-0.0234*	1						
9	Betweeness centrality in culture	0.0053	0.0003	0.0008	-0.0174*	-0.0031	-0.0022	-0.0057	0.1212*	1					
10	Log of sale	0.0093	0.0075	0.4014*	0.0089	-0.1391*	-0.2890*	-0.0462*	-0.0111	0.0039	1				
11	Cash flows	-0.0576*	0.3979*	0.9753*	-0.0042	-0.0315*	-0.1033*	0.1780*	0.0108	0.0006	0.4126*	1			
12	Debt ratio	0.0387*	-0.0667*	-0.2636*	0.0091	-0.0495*	-0.0573*	-0.0799*	-0.0212*	-0.0011	0.2649*	-0.2496*	1		
13	Tobin's Q (t+1 minus t)	-0.0226*	-0.0233*	-0.0415*	0.0031	-0.0272*	-0.0165*	0.002	0.0082	0.0018	0.0405*	-0.0338*	0.0794*	1	
14	Tobin's Q	-0.0129*	0.0513*	-0.1423*	0.0016	0.0506*	0.0991*	-0.0811*	-0.0028	0.0056	-0.1770*	-0.1603*	0.0726*	0.2678*	1
15	Firm age	-0.0004	-0.0055	0.1383*	0.0127*	-0.0997*	-0.1251*	-0.0153*	-0.0386*	-0.0088	0.3368*	0.1350*	0.0787*	0.0595*	-0.0861*

**p*<0.05 (two-tailed)

TABLE 2. Fixed effects estimates

	Hypothesis	Expected direction	Supported?	DV = ROA (t+2 minus t+1)				
				(1)	(2)	(3)	(4)	(5)
ROA (t+1 minus t)				0.0783***	0.0774***	0.0783***	0.0774***	0.0780***
				(0.0292)	(0.00952)	(0.00950)	(0.00952)	(0.00952)
ROA				-0.0500	-0.0508	-0.0495	-0.0504	-0.0520
				(0.0776)	(0.0364)	(0.0363)	(0.0364)	(0.0364)
PPE efficiency					0.0239***		0.0239***	0.0248***
					(0.00834)		(0.00834)	(0.00834)
Inventory efficiency					-0.00458		-0.00462	-0.00553
					(0.00702)		(0.00702)	(0.00702)
Marketing resource efficiency					-0.0152**		-0.0152**	-0.0157**
					(0.00767)		(0.00767)	(0.00767)
Interconnectedness						0.00107	0.00108	0.00485***
						(0.00141)	(0.00141)	(0.00166)
Interconnectedness × PPE efficiency	H1	+	Yes					0.00838**
								(0.00411)
Interconnectedness × Inventory efficiency	H2	+	Yes					0.0163***
								(0.00430)
Interconnectedness × Marketing resource efficiency	H3	+	No					-0.00213
								(0.00276)
Eigenvector centrality in culture				-0.000117	-0.000116	-3.70e-05	-3.54e-05	-2.99e-05
				(0.00135)	(0.00142)	(0.00142)	(0.00142)	(0.00142)
Betweeness centrality in culture				0.00107	0.00111	0.00108	0.00112	0.00116
				(0.00126)	(0.00141)	(0.00141)	(0.00141)	(0.00141)
Log of sale				-0.00757	-0.00787**	-0.00758*	-0.00788**	-0.00815**
				(0.00564)	(0.00398)	(0.00393)	(0.00398)	(0.00398)
Cash flows				-0.108	-0.102***	-0.109***	-0.103***	-0.102***
				(0.0855)	(0.0378)	(0.0377)	(0.0378)	(0.0378)
Debt ratio				0.00206	0.00327	0.00206	0.00327	0.00324
				(0.0290)	(0.0101)	(0.0101)	(0.0101)	(0.0101)
Tobin's Q (t+1 minus t)				-0.00239	-0.00227	-0.00239	-0.00227	-0.00234
				(0.00378)	(0.00160)	(0.00160)	(0.00160)	(0.00160)
Tobin's Q				-0.00614	-0.00630***	-0.00615***	-0.00631***	-0.00636***
				(0.00389)	(0.00182)	(0.00181)	(0.00182)	(0.00182)
Firm age				-0.0130	-0.0106	-0.0129	-0.0105	-0.00415
				(0.0188)	(0.0601)	(0.0601)	(0.0601)	(0.0602)
Constant				0.294	0.255	0.293	0.254	0.143
				(0.338)	(1.072)	(1.072)	(1.072)	(1.072)
Observations				28,461	28,461	28,461	28,461	28,461
R-squared				0.115	0.116	0.115	0.116	0.116

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

TABLE 3. Fixed-effects estimates -- Inclusion of controls for spatial autocorrelation, network-based endogeneity, and spillover adjustment

	DV = ROA (t+2 minus t+1)		
	(1)	(2)	(3)
ROA (t+1 minus t)	0.0783***	0.0774***	0.0780***
	(0.0291)	(0.00952)	(0.00952)
ROA	-0.0502	-0.0505	-0.0521
	(0.0775)	(0.0364)	(0.0364)
Interconnectedness		0.00111	0.00485***
		(0.00141)	(0.00166)
PPE efficiency		0.0237***	0.0246***
		(0.00834)	(0.00834)
Inventory efficiency		-0.00466	-0.00556
		(0.00702)	(0.00702)
Marketing resource efficiency		-0.0155**	-0.0160**
		(0.00767)	(0.00767)
Interconnectedness × PPE efficiency			0.00839**
			(0.00411)
Interconnectedness × Inventory efficiency			0.0161***
			(0.00430)
Interconnectedness × Marketing resource efficiency			-0.00215
			(0.00276)
Interconnectedness (spatial autocorrelation and endogeneity adjusted)	-0.00687	-0.00678	-0.00677
	(0.00784)	(0.00831)	(0.00830)
Eigenvector centrality in culture (spatial autocorrelation and endogeneity adjusted)	-0.00555	-0.00536	-0.00525
	(0.00964)	(0.00950)	(0.00950)
Betweeness centrality in culture (spatial autocorrelation and endogeneity adjusted)	0.0156*	0.0156*	0.0153*
	(0.00905)	(0.00801)	(0.00801)
Interconnectedness (spillover adjusted)	-0.00451	-0.00439	-0.00435
	(0.00770)	(0.00831)	(0.00830)
Eigenvector in culture (spillover adjusted)	-0.00845	-0.00825	-0.00811
	(0.00947)	(0.00932)	(0.00932)
Betweenness centrality in culture (spillover adjusted)	0.0170**	0.0169**	0.0166**
	(0.00853)	(0.00798)	(0.00798)
Eigenvector centrality in culture	-0.00127	-0.00118	-0.00114
	(0.00229)	(0.00226)	(0.00226)
Betweenness centrality in culture	0.00111	0.00116	0.00120
	(0.00126)	(0.00141)	(0.00141)
Log of sale	-0.00750	-0.00780*	-0.00807**
	(0.00565)	(0.00398)	(0.00398)
Cash flows	-0.108	-0.103***	-0.102***
	(0.0854)	(0.0378)	(0.0378)
Debt ratio	0.00197	0.00318	0.00316
	(0.0290)	(0.0101)	(0.0101)
Tobin's Q (t+1 minus t)	-0.00239	-0.00227	-0.00235
	(0.00377)	(0.00160)	(0.00160)
Tobin's Q	-0.00617	-0.00633***	-0.00638***
	(0.00390)	(0.00182)	(0.00182)
Firm age	-0.0136	-0.0111	-0.00478
	(0.0188)	(0.0601)	(0.0602)
Constant	0.304	0.264	0.154
	(0.338)	(1.072)	(1.073)
Observations	28,461	28,461	28,461
R-squared	0.115	0.116	0.117

Robust standard errors in parentheses; year fixed effects and time-trends by two-digit SIC code (year × sic2 dummies) included.
*** p<0.01, ** p<0.05, * p<0.1

TABLE 4. LASSO regression

	DV = ROA (t+2 minus t+1)		
	Double selection model	Partialling out regression	cross-fit partialling out model
VARIABLES	(1)	(2)	(3)
ROA (t+1 minus t)	0.0326	0.0326	0.0330
	(0.0241)	(0.0241)	(0.0252)
ROA	-0.0841	-0.0841	-0.0803
	(0.0538)	(0.0538)	(0.0536)
Interconnectedness	0.00352*	0.00352*	0.00364*
	(0.00209)	(0.00208)	(0.00210)
PPE efficiency	0.00244	0.00244	0.000978
	(0.00425)	(0.00425)	(0.00432)
Inventory efficiency	-0.00432	-0.00432	-0.00504
	(0.00556)	(0.00556)	(0.00558)
Marketing resource efficiency	-0.000705	-0.000705	-3.36e-05
	(0.00359)	(0.00359)	(0.00365)
Interconnectedness × PPE efficiency	0.00807*	0.00807*	0.00764*
	(0.00432)	(0.00432)	(0.00441)
Interconnectedness × Inventory efficiency	0.0127**	0.0127**	0.0131**
	(0.00575)	(0.00573)	(0.00578)
Interconnectedness × Marketing resource efficiency	-0.000504	-0.000505	-0.000248
	(0.00383)	(0.00383)	(0.00385)
Controls	Included	Included	Included
Observations	28,461	28,461	28,461

Robust standard errors in parentheses; year fixed effects and time-trends by two-digit SIC code (year × sic2 dummies) included.
*** p<0.01, ** p<0.05, * p<0.1

FIGURE 1. Conceptual model

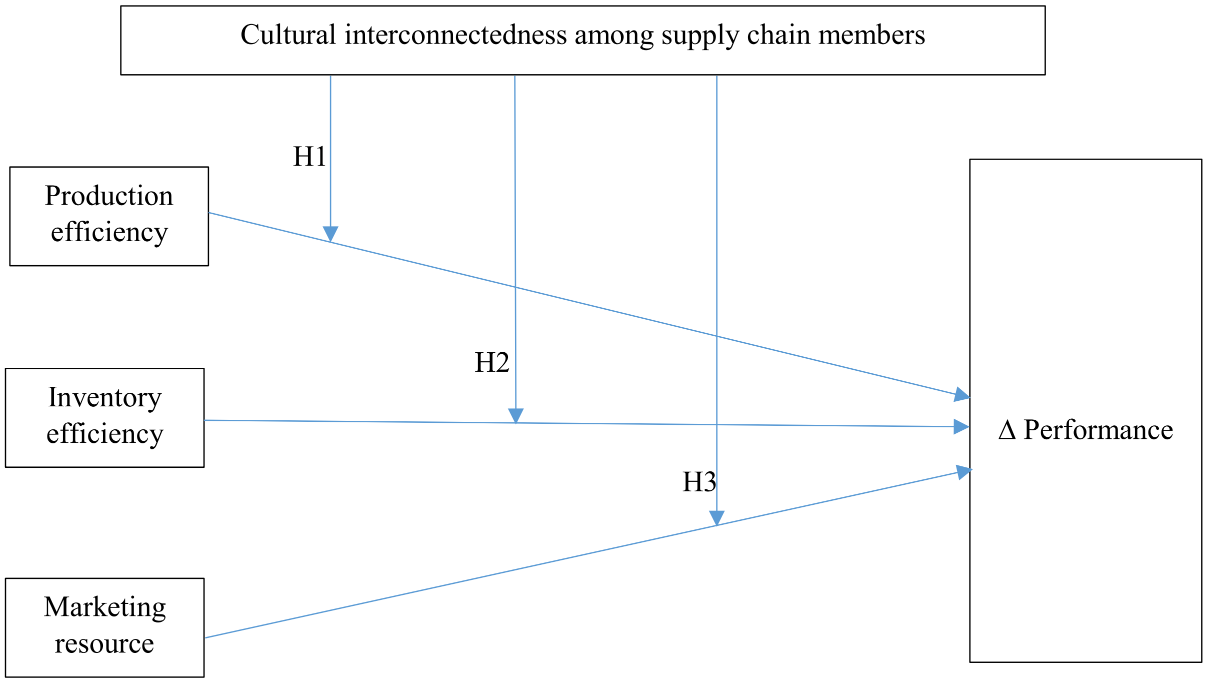
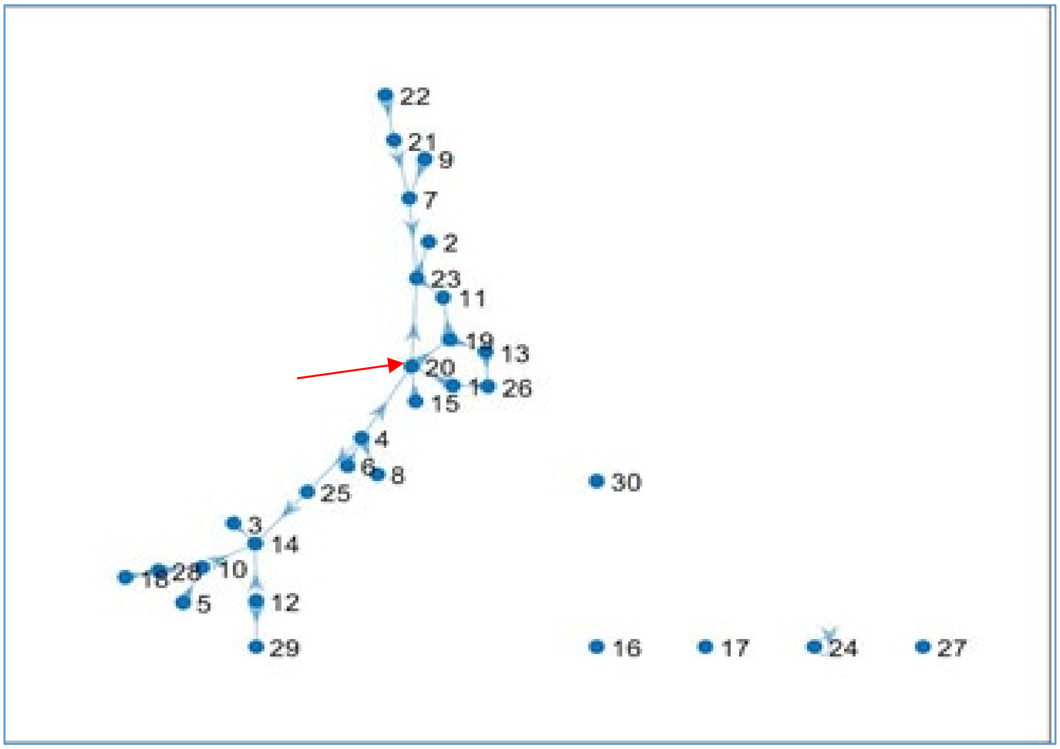


FIGURE 2. Illustration of cultural interconnectedness.

TGC Industries – mean cultural interconnectedness



Advanced energy industries – mean + 1 s.d. cultural interconnectedness

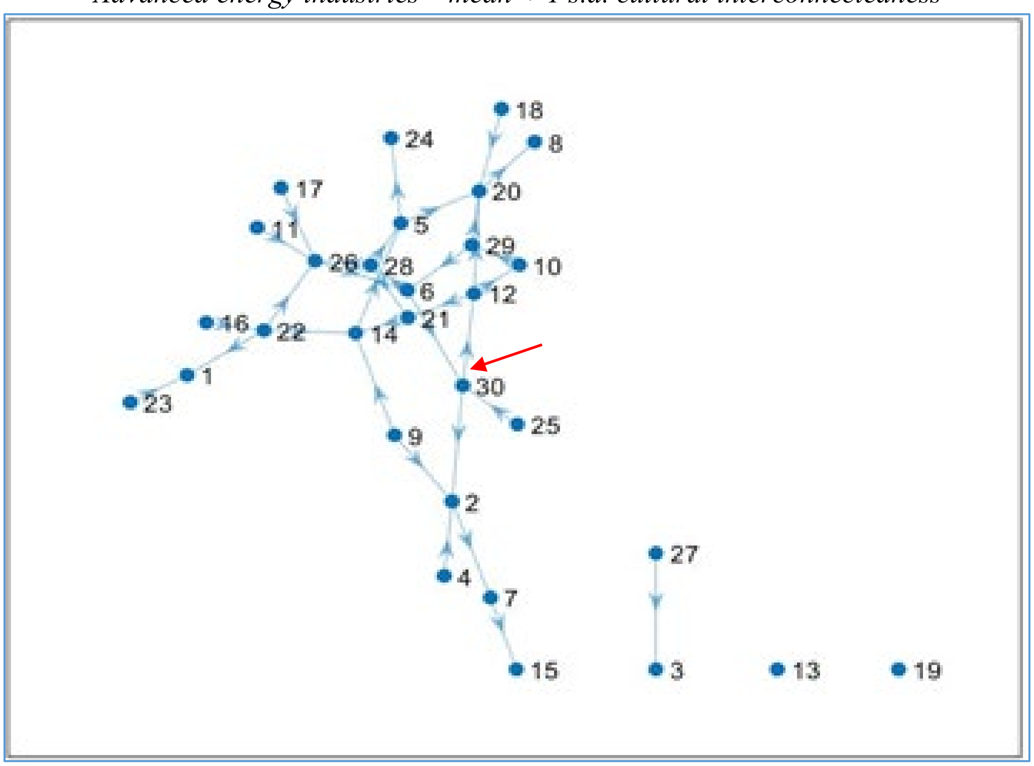


FIGURE 3. Moderation effects

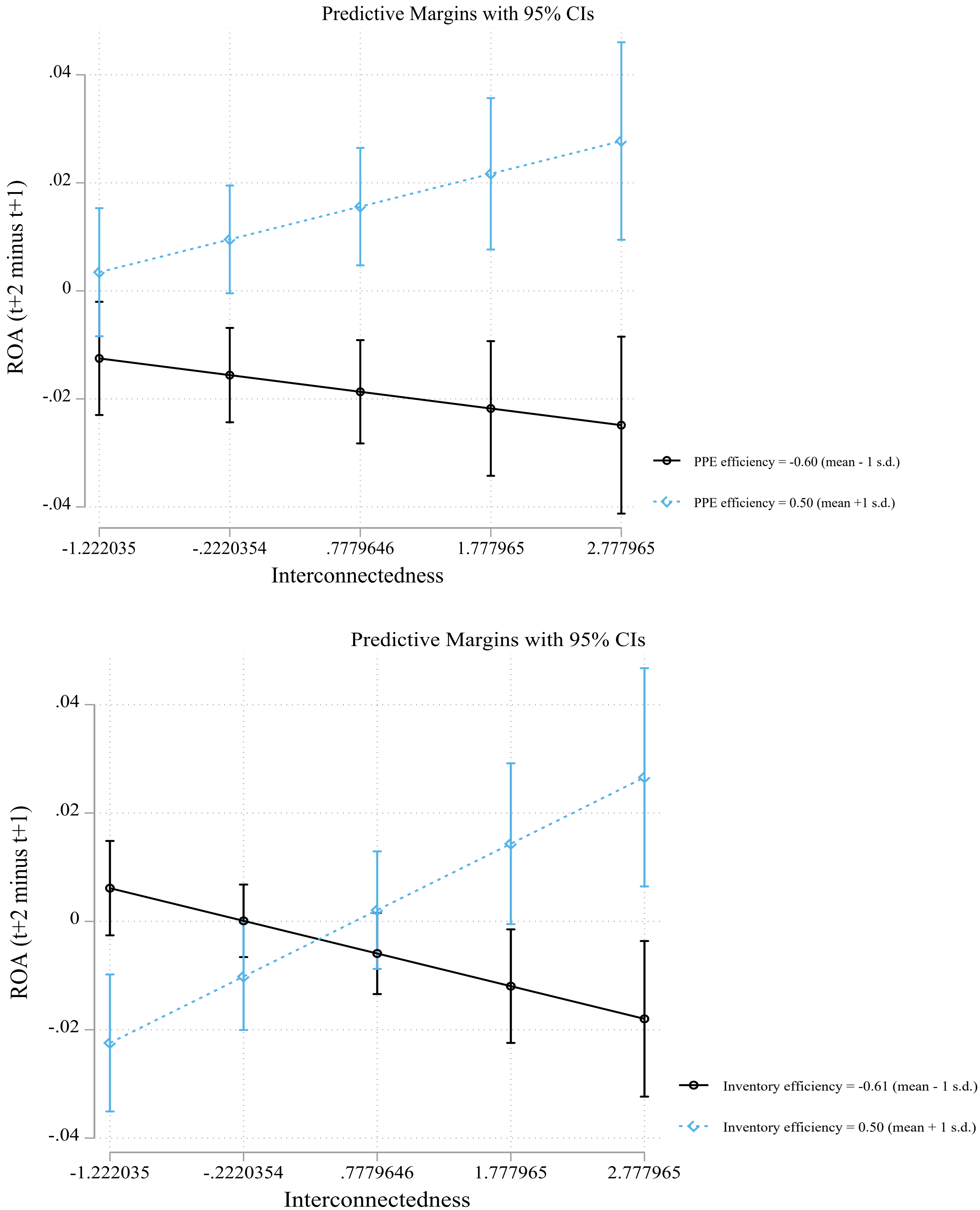
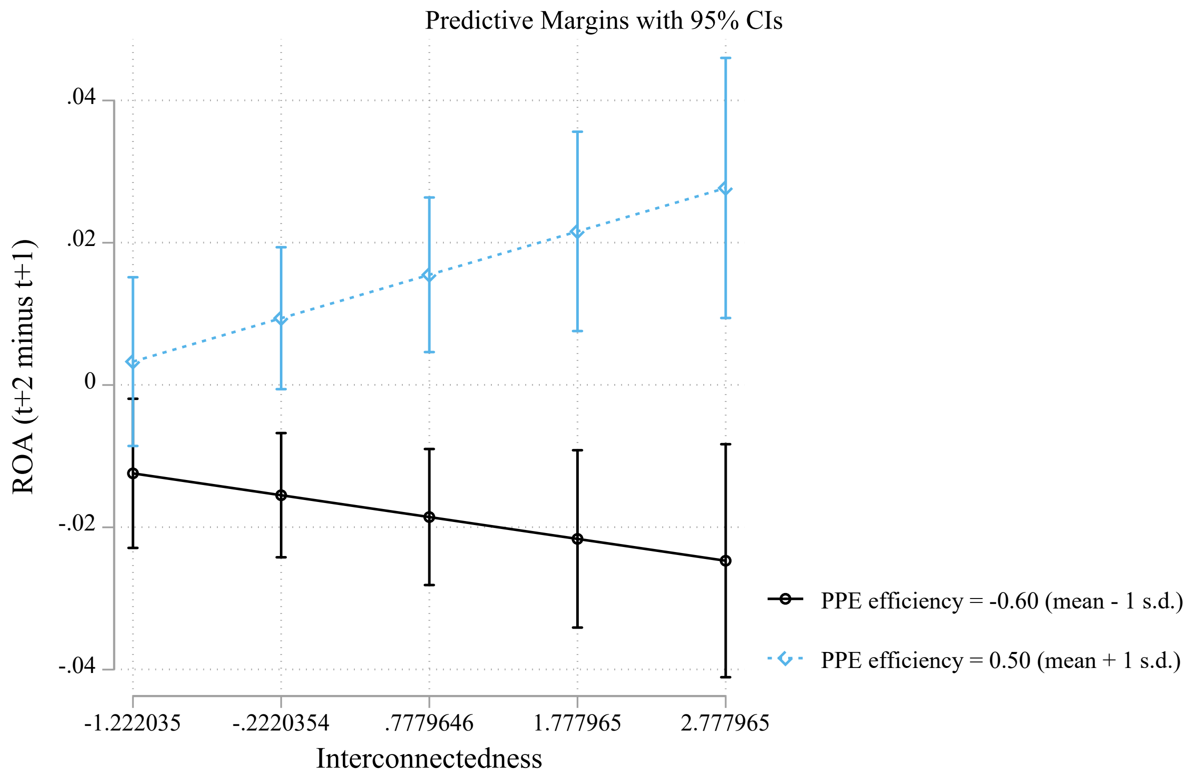
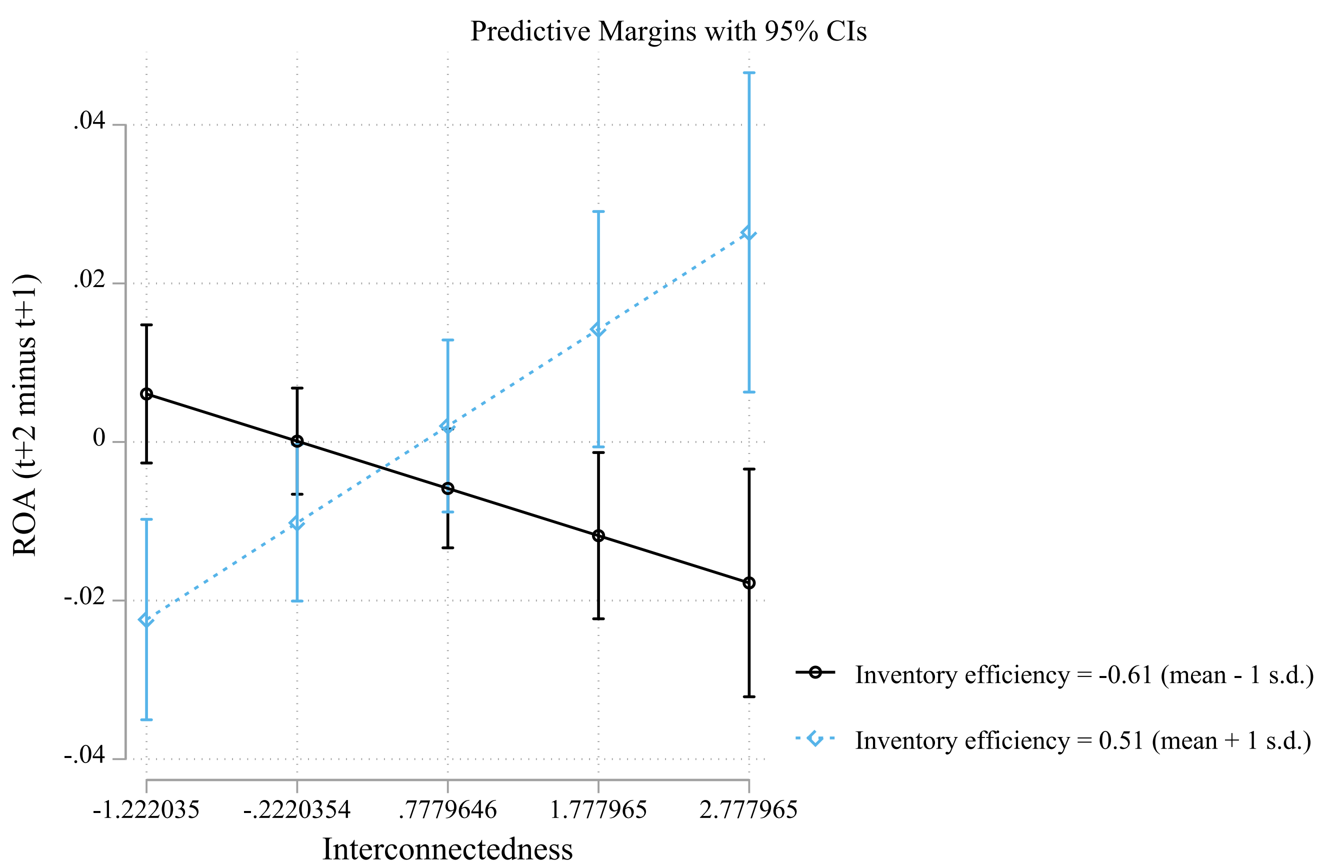


FIGURE 4. Moderation effects with controls for endogeneity and spillovers





Appendix A

TABLE A1. Descriptive by year

fyear	ROA (t+2 minus t+1)	ROA (t+1 minus t)	ROA	Interconnectedness	PPE efficiency	Inventory efficiency	SGA efficency	Eigenvector centrality	Betweeness centrality
2001	0.068	-0.074	-0.063	-0.053	-0.096	-0.173	-0.085	0.221	0.247
	[0.291]	[0.230]	[0.281]	[1.015]	[0.372]	[0.470]	[0.602]	[1.156]	[1.080]
2002	0.019	-0.015	-0.047	-0.062	-0.136	-0.21	-0.052	0.357	0.05
	[0.130]	[0.271]	[0.239]	[0.970]	[0.250]	[0.291]	[0.463]	[1.162]	[1.048]
2003	0	0.053	-0.002	-0.113	-0.124	-0.214	-0.036	0.318	0.036
	[0.154]	[0.237]	[0.178]	[0.910]	[0.252]	[0.299]	[0.470]	[1.149]	[1.020]
2004	-0.004	0.015	0.011	-0.09	-0.134	-0.199	-0.022	0.332	0.043
	[0.217]	[0.172]	[0.204]	[0.973]	[0.253]	[0.267]	[0.452]	[1.126]	[1.054]
2005	-0.014	0	0.011	-0.031	-0.137	-0.186	-0.002	0.351	0.058
	[0.245]	[0.158]	[0.204]	[0.981]	[0.274]	[0.300]	[0.478]	[1.241]	[1.059]
2006	-0.056	0.006	0.019	-0.017	-0.123	-0.176	0.013	0.227	0.061
	[0.287]	[0.156]	[0.186]	[0.973]	[0.298]	[0.291]	[0.505]	[1.151]	[0.983]
2007	0.019	-0.012	0.013	-0.054	-0.073	-0.175	0.018	0.076	0.027
	[0.245]	[0.148]	[0.202]	[0.969]	[0.384]	[0.353]	[0.517]	[1.082]	[1.016]
2008	0.037	-0.054	-0.045	0.054	-0.075	-0.148	0.025	-0.24	-0.041
	[0.201]	[0.231]	[0.271]	[1.016]	[0.344]	[0.366]	[0.525]	[0.762]	[0.962]
2009	-0.006	0.014	-0.023	-0.029	-0.087	-0.146	0.011	0.024	-0.008
	[0.165]	[0.233]	[0.222]	[0.987]	[0.371]	[0.363]	[0.495]	[1.000]	[1.011]
2010	-0.02	0.033	0.009	-0.012	-0.074	-0.15	0.05	0.106	0.013
	[0.175]	[0.195]	[0.248]	[1.017]	[0.398]	[0.353]	[0.508]	[1.099]	[1.016]
2011	-0.006	-0.005	0.012	-0.008	-0.075	-0.151	0.103	0.019	-0.047
	[0.219]	[0.144]	[0.216]	[1.014]	[0.397]	[0.366]	[0.575]	[1.010]	[0.966]
2012	-0.002	-0.016	-0.002	-0.001	-0.055	-0.186	0.153	-0.077	-0.036
	[0.213]	[0.184]	[0.232]	[1.019]	[0.393]	[0.394]	[0.586]	[0.917]	[0.989]
2013	-0.031	-0.003	0.012	-0.029	-0.069	-0.189	0.176	-0.034	-0.013
	[0.266]	[0.142]	[0.199]	[0.981]	[0.384]	[0.313]	[0.560]	[0.911]	[0.991]
2014	0.011	-0.003	-0.001	0.038	-0.059	-0.168	0.153	-0.134	0.015
	[0.288]	[0.153]	[0.227]	[1.027]	[0.391]	[0.374]	[0.586]	[0.857]	[1.009]
2015	0.009	-0.029	-0.027	-0.003	-0.054	-0.149	0.165	-0.131	-0.022
	[0.200]	[0.244]	[0.280]	[0.994]	[0.428]	[0.359]	[0.599]	[0.894]	[0.964]
2016	-0.006	0.008	-0.004	0.071	-0.07	-0.171	0.173	-0.268	-0.06
	[0.194]	[0.181]	[0.205]	[1.032]	[0.371]	[0.378]	[0.600]	[0.717]	[0.951]
2017	-0.009	0.006	-0.001	0.064	-0.084	-0.171	0.183	-0.296	-0.057
	[0.204]	[0.159]	[0.207]	[1.023]	[0.354]	[0.357]	[0.599]	[0.687]	[0.971]
Total	-0.004	-0.001	-0.004	-0.012	-0.087	-0.172	0.072	0.027	0
	[0.220]	[0.192]	[0.224]	[0.996]	[0.357]	[0.345]	[0.543]	[1.015]	[1.000]

Standard deviations in brackets

TABLE A2. Descriptives by industry

sic2	ROA (t+2 minus t+1)	ROA (t+1 minus t)	ROA	Interconnectedness	PPE efficiency	Inventory efficiency	SGA efficency	Eigenvector centrality	Betweeness centrality
1	-0.008	0.002	0.03	-0.067	0.318	-0.264	-0.341	-0.012	0.124
	[0.073]	[0.081]	[0.070]	[1.009]	[0.491]	[0.434]	[0.303]	[0.978]	[1.185]
7	-0.002	0.001	0.072	-0.096	-0.217	-0.33	0.042	0.305	0.351
	[0.022]	[0.023]	[0.023]	[1.045]	[0.399]	[0.332]	[0.550]	[1.364]	[1.270]
10	-0.002	-0.006	0.007	0.008	1.237	-0.118	1.747	-0.06	-0.002
	[0.428]	[0.211]	[0.179]	[0.953]	[0.475]	[0.297]	[0.514]	[0.961]	[1.012]
11	-0.002	-0.003	-0.018	0.004	0.94	-0.14	1.213	-0.011	-0.024
	[0.212]	[0.167]	[0.151]	[1.042]	[0.556]	[0.309]	[0.445]	[0.959]	[1.018]
13	-0.019	-0.009	0.017	-0.054	0.253	-0.319	0.226	0.149	0.173
	[0.177]	[0.126]	[0.107]	[0.970]	[0.330]	[0.255]	[0.371]	[1.053]	[1.102]
14	-0.01	-0.017	-0.007	-0.054	0.153	-0.225	0.161	0.015	0.01
	[0.336]	[0.274]	[0.250]	[0.977]	[0.170]	[0.248]	[0.348]	[1.022]	[1.033]
16	-0.015	-0.007	0.003	0.103	-0.07	-0.166	-0.119	0.02	-0.028
	[0.121]	[0.097]	[0.115]	[0.976]	[0.508]	[0.602]	[0.438]	[1.029]	[1.024]
17	0.001	0.003	0.013	-0.023	-0.102	-0.273	-0.203	-0.162	-0.081
	[0.076]	[0.116]	[0.090]	[0.958]	[0.551]	[0.583]	[0.296]	[0.791]	[0.966]
18	-0.009	-0.015	-0.012	-0.036	-0.385	-0.24	-0.044	0.279	-0.095
	[0.124]	[0.157]	[0.165]	[0.913]	[0.500]	[0.657]	[0.684]	[1.271]	[1.063]
20	-0.001	-0.002	0.056	0.226	-0.403	-0.39	-0.251	-0.004	0.173
	[0.057]	[0.055]	[0.050]	[1.026]	[0.254]	[0.113]	[0.641]	[1.033]	[0.935]
21	-0.001	-0.005	0.047	-0.05	-0.127	-0.241	-0.048	0.018	0.008
	[0.158]	[0.132]	[0.201]	[0.995]	[0.118]	[0.200]	[0.462]	[1.040]	[1.044]
22	0	0.007	0.097	-0.07	-0.018	-0.137	-0.08	0.007	-0.042
	[0.049]	[0.065]	[0.097]	[0.933]	[0.483]	[0.467]	[0.710]	[0.981]	[0.984]
23	-0.001	0	0.052	-0.04	-0.19	-0.239	-0.135	0.038	-0.005
	[0.120]	[0.136]	[0.128]	[0.963]	[0.356]	[0.420]	[0.420]	[1.042]	[0.963]
24	-0.016	0.001	0.037	-0.023	-0.227	-0.214	-0.038	0.004	0.053
	[0.208]	[0.109]	[0.115]	[1.000]	[0.282]	[0.427]	[0.730]	[0.944]	[0.937]
25	-0.011	0.002	0.019	-0.054	-0.183	-0.28	-0.347	0.115	0.009
	[0.132]	[0.096]	[0.100]	[0.927]	[0.515]	[0.243]	[0.617]	[1.038]	[0.964]
26	-0.001	0	0.046	-0.017	-0.086	-0.198	-0.301	-0.006	-0.024
	[0.095]	[0.096]	[0.085]	[1.028]	[0.438]	[0.616]	[0.537]	[1.024]	[1.051]
27	-0.002	0	0.024	-0.002	-0.133	-0.223	-0.141	0.028	0.002
	[0.130]	[0.121]	[0.101]	[0.984]	[0.404]	[0.312]	[0.582]	[0.998]	[0.989]
28	-0.006	-0.004	0.022	-0.032	-0.195	-0.186	-0.066	0.101	0.051
	[0.159]	[0.105]	[0.114]	[1.017]	[0.187]	[0.399]	[0.335]	[1.036]	[1.029]
29	-0.003	0.008	-0.044	-0.004	-0.041	-0.159	0.464	0.016	-0.014
	[0.274]	[0.252]	[0.332]	[1.018]	[0.192]	[0.202]	[0.474]	[0.978]	[0.975]
30	-0.007	-0.01	0.051	0.043	-0.007	-0.202	0.248	-0.034	-0.059
	[0.101]	[0.079]	[0.094]	[1.052]	[0.274]	[0.323]	[0.444]	[1.013]	[0.930]
31	0	-0.002	0.065	-0.031	-0.135	-0.34	-0.337	0.066	0.042
	[0.079]	[0.118]	[0.117]	[0.935]	[0.325]	[0.318]	[0.410]	[1.103]	[0.979]
32	-0.005	-0.022	0.047	0.066	-0.351	-0.417	-0.387	0.233	0.126
	[0.098]	[0.097]	[0.116]	[0.987]	[0.658]	[0.342]	[0.388]	[1.151]	[1.089]
33	-0.009	-0.003	0.01	-0.03	-0.002	-0.273	-0.297	0.041	0.053
	[0.132]	[0.117]	[0.123]	[0.939]	[0.718]	[0.378]	[0.380]	[1.060]	[1.012]
34	-0.001	-0.003	0.025	0.044	-0.123	-0.25	-0.169	0.003	0.032
	[0.142]	[0.091]	[0.085]	[0.972]	[0.242]	[0.226]	[0.390]	[0.981]	[1.059]
35	-0.001	-0.004	0.038	0.033	-0.098	-0.255	-0.288	0.016	0.106
	[0.123]	[0.128]	[0.109]	[0.979]	[0.551]	[0.327]	[0.338]	[0.967]	[1.049]
36	-0.003	0.001	-0.001	-0.014	-0.147	-0.106	0.034	0.051	0.036
	[0.177]	[0.153]	[0.182]	[0.990]	[0.249]	[0.282]	[0.359]	[1.024]	[1.030]
37	-0.004	0.001	-0.043	-0.017	-0.162	-0.113	-0.013	0.041	-0.027
	[0.229]	[0.219]	[0.255]	[1.017]	[0.230]	[0.201]	[0.450]	[1.002]	[0.978]
38	0.001	-0.001	0.024	-0.016	-0.147	-0.16	0.052	-0.012	0.011
	[0.124]	[0.109]	[0.148]	[0.974]	[0.176]	[0.239]	[0.466]	[1.012]	[1.012]
39	0	-0.001	-0.061	-0.012	-0.104	-0.13	0.211	0.012	-0.024
	[0.283]	[0.246]	[0.332]	[1.009]	[0.195]	[0.249]	[0.402]	[1.020]	[0.994]
40	-0.009	-0.023	-0.032	-0.038	-0.133	-0.141	-0.056	0.028	-0.052
	[0.281]	[0.287]	[0.325]	[0.948]	[0.420]	[0.652]	[0.294]	[1.073]	[1.009]
41	0.026	-0.022	0.01	0.111	0.084	0.142	-0.657	0.273	-0.198
	[0.107]	[0.101]	[0.104]	[0.919]	[0.795]	[1.071]	[0.308]	[1.253]	[0.774]
43	-0.008	-0.019	0.071	0.243	-0.146	0.65	0.109	-0.042	0.038
	[0.097]	[0.067]	[0.096]	[1.077]	[0.314]	[1.399]	[0.298]	[1.026]	[1.048]
44	-0.009	-0.013	0.019	-0.08	0.302	-0.176	-0.015	0.095	-0.075
	[0.138]	[0.092]	[0.114]	[0.902]	[0.523]	[0.825]	[0.606]	[1.087]	[0.997]
45	-0.03	-0.028	-0.004	-0.025	0.079	-0.208	-0.103	0.069	0.167
	[0.529]	[0.302]	[0.297]	[0.988]	[0.491]	[0.590]	[0.631]	[0.986]	[1.040]
46	0	0	0.033	0.037	-0.183	-0.118	-0.042	-0.025	0.04
	[0.073]	[0.068]	[0.068]	[0.979]	[0.371]	[0.446]	[0.490]	[0.996]	[1.014]
47	-0.001	-0.001	0.052	0.009	-0.202	-0.273	0.141	0.21	0.002
	[0.035]	[0.044]	[0.068]	[1.031]	[0.537]	[0.609]	[0.537]	[1.137]	[1.039]
48	-0.001	0.005	0.061	-0.379	-0.629	-0.636	-0.021	1.031	0.088
	[0.116]	[0.059]	[0.038]	[0.718]	[0.046]	[0.151]	[0.097]	[1.325]	[0.986]
49	0.001	0.007	0.017	0	-0.104	-0.155	-0.06	-0.01	-0.023
	[0.121]	[0.180]	[0.127]	[0.969]	[0.279]	[0.198]	[0.428]	[0.995]	[0.955]

50	-0.003	0	0.019	0.062	0.063	0.022	0.267	-0.015	0.015
	[0.072]	[0.075]	[0.086]	[1.038]	[0.358]	[0.427]	[0.485]	[1.021]	[0.967]
51	-0.003	-0.003	0.033	-0.021	-0.205	-0.188	-0.107	0.028	0.025
	[0.101]	[0.102]	[0.106]	[0.973]	[0.183]	[0.256]	[0.363]	[1.038]	[1.015]
52	-0.001	-0.002	0.035	-0.025	-0.177	-0.208	-0.093	-0.032	0.048
	[0.138]	[0.124]	[0.120]	[0.984]	[0.280]	[0.282]	[0.430]	[0.947]	[1.017]
53	-0.008	0.001	0.078	-0.208	-0.199	-0.17	-0.208	-0.13	-0.002
	[0.070]	[0.040]	[0.061]	[0.840]	[0.885]	[0.802]	[0.857]	[0.936]	[1.045]
54	-0.005	-0.003	0.055	-0.05	-0.109	-0.156	-0.036	0.089	-0.041
	[0.079]	[0.064]	[0.083]	[0.933]	[0.424]	[0.493]	[0.728]	[1.086]	[0.933]
55	0	-0.002	0.03	-0.001	-0.053	-0.231	-0.115	0.087	0.04
	[0.066]	[0.069]	[0.065]	[1.006]	[0.553]	[0.567]	[0.460]	[1.091]	[1.075]
56	-0.009	-0.002	0.075	0.085	-0.302	-0.187	-0.079	-0.03	0.046
	[0.084]	[0.069]	[0.077]	[0.989]	[0.425]	[0.558]	[0.839]	[0.957]	[0.987]
57	-0.012	-0.008	0.056	-0.022	-0.256	-0.032	-0.062	0.18	-0.001
	[0.123]	[0.111]	[0.123]	[0.966]	[0.293]	[0.814]	[0.803]	[1.133]	[1.041]
58	-0.017	-0.002	0.041	0.009	-0.157	-0.261	-0.269	0.014	-0.017
	[0.065]	[0.052]	[0.057]	[1.032]	[0.618]	[0.586]	[0.649]	[0.982]	[0.946]
59	-0.003	0	0.051	-0.04	-0.172	-0.3	-0.214	0.004	-0.066
	[0.101]	[0.089]	[0.096]	[0.972]	[0.128]	[0.218]	[0.291]	[1.001]	[0.945]
60	-0.005	0.011	0.027	0.079	-0.231	-0.208	-0.022	0.038	-0.099
	[0.223]	[0.179]	[0.137]	[1.047]	[0.180]	[0.309]	[0.592]	[1.021]	[0.953]
61	-0.122	-0.001	-0.008	-0.663	-0.719	0.681	0.399	-0.625	-0.179
	[0.243]	[0.151]	[0.111]	[0.462]	[0.166]	[0.515]	[0.419]	[0.246]	[0.705]
62	0	0.001	0.017	0.017	-0.365	-0.318	-0.126	-0.08	0.065
	[0.006]	[0.006]	[0.008]	[1.021]	[0.093]	[0.095]	[0.176]	[0.890]	[0.845]
63	-0.018	0.019	-0.121	0.133	-0.311	-0.299	-0.33	0.342	0.32
	[0.496]	[0.473]	[0.296]	[0.980]	[0.076]	[0.068]	[0.347]	[1.306]	[1.060]
66	-0.009	-0.004	0.03	-0.148	0.062	-0.203	-0.246	-0.143	0.107
	[0.310]	[0.070]	[0.058]	[0.904]	[0.300]	[0.279]	[0.158]	[0.773]	[0.998]
68	-0.017	-0.011	-0.038	0.027	-0.237	-0.23	-0.244	-0.13	-0.051
	[0.580]	[0.163]	[0.220]	[1.058]	[0.090]	[0.542]	[0.270]	[0.904]	[0.914]
71	-0.003	0.006	0.049	-0.111	0.306	-0.358	-0.245	0.06	-0.136
	[0.043]	[0.041]	[0.063]	[1.002]	[0.442]	[0.199]	[0.213]	[0.964]	[1.094]
72	-0.01	0	0.055	-0.006	-0.066	-0.245	-0.048	0.105	0.033
	[0.086]	[0.066]	[0.078]	[0.976]	[0.831]	[0.571]	[0.824]	[0.986]	[0.976]
74	-0.004	0.013	-0.021	-0.036	-0.131	-0.158	0.15	0.04	0.009
	[0.278]	[0.289]	[0.274]	[0.991]	[0.113]	[0.283]	[0.464]	[1.045]	[0.983]
75	0.008	-0.005	0.031	-0.085	-0.267	-0.272	-0.343	0.341	0.43
	[0.062]	[0.075]	[0.071]	[0.803]	[0.409]	[0.594]	[0.357]	[1.371]	[1.399]
76	0.007	0.005	0.013	-0.107	0.1	0.399	-0.346	-0.039	-0.096
	[0.028]	[0.032]	[0.029]	[1.041]	[0.387]	[0.529]	[0.246]	[1.203]	[0.964]
79	-0.007	0.003	0.012	0.063	-0.243	-0.301	0.046	-0.002	-0.063
	[0.074]	[0.077]	[0.082]	[1.108]	[0.104]	[0.385]	[0.297]	[0.993]	[0.962]
80	-0.002	0	0.013	-0.058	-0.158	-0.381	0.02	0.05	0.056
	[0.094]	[0.137]	[0.119]	[1.038]	[0.137]	[0.368]	[0.540]	[1.048]	[1.064]
81	0.014	-0.02	-0.092	-0.034	-0.185	-0.23	-0.05	-0.095	-0.042
	[0.255]	[0.271]	[0.324]	[1.026]	[0.299]	[0.314]	[0.519]	[0.934]	[0.971]
82	-0.001	-0.01	0.024	-0.029	-0.223	-0.26	-0.168	-0.016	-0.077
	[0.113]	[0.109]	[0.114]	[0.935]	[0.370]	[0.536]	[0.652]	[0.916]	[0.915]
83	0.052	0.008	-0.069	-0.09	-0.416	0	0.613	0.36	-0.741
	[0.063]	[0.113]	[0.063]	[1.270]	[0.016]	[1.000]	[0.256]	[0.161]	[0.611]
87	-0.014	0.014	0.142	0.038	-0.227	-0.284	0.154	0.339	0.224
	[0.062]	[0.097]	[0.099]	[1.097]	[0.129]	[0.580]	[0.122]	[1.261]	[1.083]
88	0.003	-0.002	-0.028	-0.012	-0.209	-0.25	-0.055	0.038	-0.013
	[0.195]	[0.177]	[0.272]	[0.986]	[0.353]	[0.447]	[0.372]	[0.974]	[1.019]
100	-0.043	-0.017	-0.095	0.03	-0.108	-0.257	0.963	0.228	-0.075
	[0.501]	[0.273]	[0.271]	[1.017]	[0.116]	[0.323]	[0.691]	[1.138]	[1.031]
Total	-0.004	-0.001	-0.004	-0.012	-0.087	-0.172	0.072	0.027	0
	[0.220]	[0.192]	[0.224]	[0.996]	[0.357]	[0.345]	[0.543]	[1.015]	[1.000]

Standard deviations in brackets

TABLE A3. Fixed-effects estimates -- Alternate outcome variables

	ROS (t+2 minus t+1)	ROE (t+2 minus t+1)
	(2)	(3)
Interconnectedness	-0.00240	0.00217
	(0.00171)	(0.00372)
PPE efficiency	-0.00220	0.0377**
	(0.00861)	(0.0187)
Inventory efficiency	0.0107	-0.0253
	(0.00725)	(0.0157)
Marketing resource efficiency	0.00183	0.000805
	(0.00797)	(0.0171)
Interconnectedness × PPE efficiency	-0.00531	-0.00916
	(0.00424)	(0.00920)
Interconnectedness × Inventory efficiency	-0.000859	0.00567
	(0.00444)	(0.00964)
Interconnectedness × Marketing resource efficiency	0.00398	-0.000957
	(0.00285)	(0.00619)
Difference in DV	Included	Included
DV	Included	Included
Controls	Included	Included
Constant	0.633	0.656
	(1.106)	(2.397)
Observations	28,461	28,378
R-squared	0.193	0.136

Robust standard errors in parentheses; year fixed effects and time-trends by two-digit SIC code (year × sic2 dummies) included.
*** p<0.01, ** p<0.05, * p<0.1

TABLE A4. Fixed-effects estimates -- Squared term estimates

	DV = ROA (t+2 minus t+1)	
	(1)	(2)
ROA (t+1 minus t)	0.0780***	0.0779***
	(0.00952)	(0.00952)
ROA	-0.0520	-0.0500
	(0.0364)	(0.0364)
Interconnectedness	0.00639***	0.00741***
	(0.00197)	(0.00228)
Interconnectedness--square	-0.00181	
	(0.00132)	
Interconnectedness--square × PPE efficiency	-0.00448	
	(0.00306)	
Interconnectedness--square × Inventory efficiency	-0.00368	
	(0.00338)	
Interconnectedness--square × Marketing resource efficiency	-0.000285	
	(0.00220)	
PPE efficiency	0.0299***	0.0166
	(0.00902)	(0.0106)
Interconnectedness × PPE efficiency	0.0123**	0.0139**
	(0.00488)	(0.00564)
PPE efficiency--square		0.00761
		(0.00661)
PPE efficiency--square × Interconnectedness		-0.00690
		(0.00440)
Inventory efficiency	-0.00218	0.00583
	(0.00772)	(0.00994)
Interconnectedness × Inventory efficiency	0.0194***	0.0221***
	(0.00515)	(0.00585)
Inventory efficiency--square		-0.00788
		(0.00499)
Inventory efficiency--square × Interconnectedness		-0.00515
		(0.00354)
Marketing resource efficiency	-0.0158**	-0.0179**
	(0.00795)	(0.00799)
Interconnectedness × Marketing resource efficiency	-0.00205	-0.00457
	(0.00321)	(0.00320)
Marketing resource efficiency--square		0.00424
		(0.00477)
Marketing resource efficiency--square × Interconnectedness		0.00283
		(0.00264)
Eigenvector centrality	-2.26e-05	7.45e-06
	(0.00142)	(0.00142)
Betweeness centrality	0.00118	0.00115
	(0.00141)	(0.00141)
Log of sale	-0.00817**	-0.00722*
	(0.00398)	(0.00401)
Cash flows	-0.102***	-0.102***
	(0.0378)	(0.0378)
Debt ratio	0.00326	0.00372
	(0.0101)	(0.0101)
Tobin's Q (t+1 minus t)	-0.00239	-0.00231
	(0.00160)	(0.00160)
Tobin's Q	-0.00632***	-0.00635***
	(0.00182)	(0.00182)
Firm age	-0.00344	-0.00305
	(0.0602)	(0.0602)
Constant	0.132	0.117
	(1.073)	(1.074)
Observations	28,461	28,461
R-squared	0.116	0.117

Robust standard errors in parentheses; year fixed effects and time-trends by two-digit SIC code (year × sic2 dummies) included.
*** p<0.01, ** p<0.05, * p<0.1

Appendix B

Spatial-autoregressive model and Network-based endogeneity estimates

In this Appendix we describe how endogeneity and spatially adjusted measures were computed as alternatives to (2)—(4). The relevant measures are denoted u_t and we provide details for a single equation corresponding to the specifications of (2)—(4). These equations (for PPE, inventory and marketing resources) can be thought of as production frontiers where the dependent variable is PPE, inventory or marketing expenses. Inefficciency, estuimated by Bayesian stochastic frontier methods, in turn, represents an adjusted measure relative to (2)—(4). As we explicitly account for network properties via matrix W and regressor endogeneity these measures are likely to act as control functions that account for important network characteristics additional to theose in (2)—(4).

B.1 Spatial-autoregressive model for supply chain networks

Suppose $y_t = [y_{1t}, \dots, y_{nt}]$ is the $n \times 1$ vector that includes all time observations for unit i, $X_t = [x_{it}, i = 1, \dots, n]$ is the $n \times k$ matrix containing observations on the explanatory variables[6], and similarly $v_t = [v_{1t}, \dots, v_{nt}]$ and $u_t = [u_{1t}, \dots, u_{nt}]$. The spatial $n \times n$ weight matrix is defined so that $W_t = [w_{ij,t}, i, j = 1, \dots, n]$ where $w_{ij,t}$ is proximity between units i and j for period t, and $w_{ii,t} = 0$. The Spatial Autoregressive (SAR) model (Glass et al. 2013; Glass and Kenjegalieva 2019; Glass et al. 2016; Kutlu 2018; Tsukamoto 2019) has the form:

$$y_{it} = \rho \sum_{j \neq i} w_{ij,t}\, y_{jt} + x'_{it}\beta + v_{it} - u_{it}, \forall (i,t) \in \mathbb{J}, \tag{1}$$

where ρ is the unknown spatial autoregressive parameter. We have:

$$y_t = \rho W_t y_t + X_t \beta + v_t - u_t, \forall t \in \mathbb{T}. \tag{2}$$

In turn, we have:

$$y_t = (I_n - \rho W_t)^{-1}(X_t \beta + v_t - u_t), \tag{3}$$

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[6] These include cash flow, debt ratio, Tobin's Q, the time difference of Tobin's Q, fitm age and fixed effects.

where I_n is the $n \times n$ identity matrix. W incorporates the connections between firms based on the cost of goods sold used to weigh the supply chain relationship and the relative culture weights.

If we assume that the maximum absolute eigenvalue of ρW_t is less than unity[7], then we have (provided $W_t = W$ for all t):

$$(I_n - \rho W)^{-1} = I_n + \rho W + \rho^2 W^2 + \cdots, \tag{4}$$

where $W^2 = WW$, etc. In turn, we can write (3) as follows:

$$y_t = \sum_{l=0}^{\infty} \rho^l W^l (X_t \beta + v_t - u_t). \tag{5}$$

Therefore, y_{it} depends not only on (its own) x_{it} and z_{it} but also on all other x_{jt}, z_{it}, and inefficiencies u_{jt} ($j \neq i \in \mathbb{I}$), given our network is time-varying, (5) does not hold.

The model can be also written as

$$(I_n - \rho W) y_t = X_t \beta + v_t - u_t, \tag{6}$$

where $v_t \sim \mathcal{N}_n(0, \sigma_v^2 I_n)$, and $u_t \sim \mathcal{N}_n^+(Z_t \gamma, \sigma_v^2 I_n)$ $\forall t \in \mathbb{T}$, where $\mathcal{N}_n$ denotes the n-variate normal distribution, $\mathcal{N}_n^+$ denotes the n-variate truncated normal distribution, and $Z_t = [z_{it}, i \in \mathbb{I}]$ is an $n \times m$ matrix containing observations on $z_{it}, i \in \mathbb{I}$. Suppose $\zeta \sim \mathcal{N}_n^+(\mu, \sigma_u^2 I_n)$. Then, its density is given by $p(\zeta) = \pi \sigma_u^2)^{-n/2} \Phi_n(\zeta^*)^{-1} e^{-(1/2\sigma_u^2)(\zeta - \mu)'(\zeta - \mu)}$, where $\zeta^* = -\sigma_u^{-1} \mu$ and $\Phi_n(\zeta^*)$ denotes the n-variate normal probability that ζ exceeds ζ^*, viz. $\Phi_n(\zeta^*) = (2\pi)^{-d/2} |\Sigma|^{-1/2} \int_{\{\zeta \geq \zeta^*\}} e^{-(1/2)\zeta'\zeta} \, d\zeta$. In turn, we have the density of u_t:

$$\begin{aligned} & p(u_t | Z_t, \gamma, \sigma_u) \\ & = (2\pi\sigma_u^2)^{-n/2} \Phi \quad (-\sigma_u^{-1} Z_t \gamma)^{-1} e^{-(1/2\sigma_u^2)(u_t - Z_t\gamma)'(u_t - Z_t\gamma)}. \end{aligned} \tag{7}$$

From (6) the likelihood function is

[7]If the eigenvalues of W_t are denoted by $\lambda_{i,t}$ ($\forall i \in \mathbb{I}$), equivalent we have: $\rho \in \left(\frac{1}{\lambda_{t,max}}, \frac{1}{\lambda_{t,min}}\right)$ where $\lambda_{t,min} = \min_{1 \leq i \leq n} \lambda_{t,i}$ and $\lambda_{t,max} = \max_{1 \leq i \leq n} \lambda_{t,i}$.

$$L(\theta;Y) \propto ||I_n - \rho W||^{n/2} \cdot$$
$$\int_{\mathbb{R}_+^n} \sigma_v^{-n/2} \exp\left\{-\frac{1}{2\sigma_v^2}[(I_n - \rho W)y_t - X_t\beta + u_t]'[(I_n - \rho W)y_t - X_t\beta + u_t]\right\} p(u_t|Z_t,\gamma,\sigma_u)\mathrm{d}u_t, \quad (8)$$

where $\theta \in \Theta \subset \mathbb{R}^d$ are the parameter vector (dimensionality denoted by d) and the available data are denoted by Y. If we have a prior $p(\theta)$ then the augmented posterior is given as follows.

$$p(\theta,\{u_t\}_{t=1}^T|Y) \propto p(\theta) \cdot ||I_n - \rho W||^{n/2} \cdot$$
$$\sigma_v^{-n/2} \exp\left\{-\frac{1}{2\sigma_v^2}\sum_{t=1}^T [(I_n - \rho W)y_t - X_t\beta + u_t]'\,[(I_n - \rho W)y_t - X_t\beta + u_t]\right\} \quad (9)$$
$$\sigma_u^{-n/2}\prod_{t=1}^T \Phi \quad (-\sigma_u^{-1}Z_t\gamma)^{-1} e^{-\frac{1}{2\sigma_u^2}\sum_{t=1}^T (u_t - Z_t\gamma)'(u_t - Z_t\gamma)}.$$

Our prior is as follows:

$$p(\theta) \propto \sigma_v^{-1}\sigma_u^{-1}\mathbb{I}_\Lambda(\rho) \quad (10)$$

where $\mathbb{I}_{(0,1)}(\rho) = 1$ if $\rho \in (0,1)$ and zero otherwise[8]. Therefore, the prior in (10) is a flat for β . Since $\int_{\mathbb{R}_+^n} p\,(\theta,\{u_t\}_{t=1}^T|Y)\mathrm{d}\{u_t\}_{t=1}^T = p(\theta|Y)$ it follows that we have the correct posterior corresponding to (8) multiplied by the prior, $p(\theta)$. The augmented posterior in (9) can be analyzed using standard MCMC methods.

B.2 Network-based endogeneity in supply chain networks

Rarely, if ever, inputs are exogenous in a production function as they may be correlated with the error term. The point has been made forcefully since Marschak and Andrews (1944) and, more recently, it has been taken up in Ackerberg et al. (2015), Blundell and Bond (2000), Gandhi et al. (2020), Levinsohn and Petrin (2003), and Olley and Pakes (1996).

To account for input network-based endogeneity we proposed the model as follows.

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[8]If we standardize a raw spatial weighting matrix by dividing all of its elements by its largest eigenvalue in absolute value, then we need the restriction $\rho \in (0,1)$, see Kelejian, H.H., Prucha, I.R. (2010) Specification and estimation of spatial autoregressive models with autoregressive and heteroskedastic disturbances. *Journal of econometrics* 157(1): 53-67..

$$y_{it} = \rho \sum_{j \neq i} w_{ij,t}\, y_{jt} + x'_{it}\beta + v_{it} - u_{it}, \forall (i,t) \in \mathbb{J}, \qquad (11)$$
$$x_{it} = \Pi z_{it} + v_{it,*},$$

where Π is a $k \times m$ matrix that includes unknown (reduced form) parameters, v_{it}^{*} is an error term supported in $\mathbb{R}^k$ and we assume:

$$V_{it} = [v_{it}, v'_{it,*}]' \sim \mathcal{N}_{k+1}(0, \Sigma). \qquad (12)$$

The assumption that the errors in the production function or a stochastic frontier (Olley and Pakes 1996) of the reduced form are correlated is essential in modeling network-based endogeneity. To access the posterior we use a Gibbs sampler with data augmentation (Geweke 1999; Tanner and Wong 1987; Tierney 1994) using 150,000 passes omitting the first 50,000 to mitigate the impact of potential startup effects. Convergence is monitored using the standard Geweke (1992) diagnostics.