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Abstract

We assemble a novel firm-level dataset to study the adoption and termination of suppliers over business cycles. We document that the aggregate number and rate of adoption of suppliers are procyclical. The rate of termination is acyclical at the aggregate level, and the cyclicality of termination encompasses large differences across producers. To account for these new facts, we develop a model with optimizing producers that incur separate costs for management, adoption, and termination of suppliers. These costs alter the incentives to scale up production and to replace existing with new suppliers. Both forces are critical to replicating the observed cyclicality in the adoption and termination rates at the producer and aggregate levels. Sufficiently high convexity in management relative to adjustment costs is required to replicate the observed decrease in the procyclicality of termination of suppliers with the size of producers. The optimal policy entails subsidies to management and adjustment costs.

Keywords: management and adjustment costs, adoption and termination of suppliers, business cycles.

JEL: E32, L14, L24.

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1. Introduction

Production of final output in modern economies requires inputs from multiple suppliers, so the adoption, termination, and management of suppliers are important decisions in the production of final goods. Despite abundant work dedicated to the adoption and termination of suppliers in models of international trade and in operation management textbooks, little is known about the cyclical regularities of these margins of adjustment at the producer level or their effects on the broader aggregate economy.[1] Consequently, several fundamental questions remain unanswered: What are the patterns of adoption and termination of suppliers at the producer level, and how are those linked with the business cycle? Are the adoption and termination of suppliers similar across different producers? What forces explain the empirical regularities? Are the levels of adoption and termination optimal? Can economic policy enhance welfare?

We study these questions, combining different datasets and providing novel facts regarding the adoption and termination of suppliers at the producer and aggregate levels. To account for our new evidence, we develop a model of optimizing producers that manufacture output using both new and existing suppliers. The model shows the central roles of the costs of managing and adjusting suppliers—particularly the convexity in the cost functions—in accounting for the empirical patterns. Inefficiencies associated with these costs—due to incomplete contracting and the gap between social and private costs—lead to *under*-adjustments in the number of suppliers by private producers, requiring the optimal policy to subsidize management and adjustment costs.

Our new evidence on the adoption and termination of suppliers is obtained via merging two datasets: the FactSet Revere Supply Chain Relationships data—which records producer-supplier relations, including adoption and termination of suppliers—and CompuStat Fundamentals—which provides information on producers' output, financial positions, and administrative costs. Our integrated data offer a comprehensive overview of producer-supplier relationships for U.S. producers between 2003 and 2020. Using this merged dataset, we establish three novel facts.

Facts 1 and 2 study the dynamics of adoption and termination of suppliers at the aggregate level over the business cycle. Fact 1 establishes that the aggregate number of suppliers is procyclical: it increases during economic expansions and declines during contractions. Fact 2 decomposes the changes in the aggregate number of suppliers into the rates of adoption and termination of suppliers. It establishes that the aggregate rate of adoption is procyclical and that the aggregate rate of termination is acyclical.

Fact 3 shows that the acyclical aggregate rate of termination conceals large heterogeneity in the cyclicality of the termination rate across producers having different numbers of suppliers and productivity levels. The termination rate is countercyclical for producers with a large number of suppliers and high productivity but procyclical for producers with a small number of suppliers and low productivity. The aggregate acyclicality in the rate of termination of suppliers results from the countervailing behavior of the termination rate

[1] See Feenstra, Heizer et al. (2016), and Stevenson (2018).

across different producers.

To account for Facts 1-3, we develop a model with producers that use a continuum of intermediate inputs supplied by two vintages of suppliers—the existing and new suppliers. Producers have different idiosyncratic productivities, and they incur separate costs for the management, adoption, and termination of suppliers.

These foregoing separate costs have different implications for changes in the adoption and termination of suppliers. *Management costs* constrain the scale of operation by decreasing the adoption of new suppliers and increasing the termination of existing suppliers. *Adjustment costs* discourage both the adoption of new suppliers and the termination of existing ones, which influence the vintage composition of suppliers. Accordingly, the two separate costs lead to two distinct effects of the aggregate TFP on the adoption and termination of suppliers. One is a *scaling effect*: the higher TFP decreases the relevance of management costs for the profits of the producer, leading to an optimal increase in the measure of suppliers for the production of the final goods. This effect fosters a rise in the adoption and a decline in the termination of suppliers. The second is a *switching effect*: the higher TFP reduces the relevance of adjustment costs for the producer's profits, engendering greater turnover of suppliers. The denouement is a rise in both the rates of adoption and termination of suppliers.

Scaling and switching effects jointly generate a positive correlation between the total measure of suppliers and the adoption of new suppliers with aggregate TFP; this finding is consistent with Facts 1-2. However, the two forces have countervailing effects on the correlation between the rate of termination and TFP. With higher TFP, the switching effect involves an increase in the termination of suppliers and enables producers to renew the vintages of suppliers. The scaling effect, though, decreases the termination of suppliers to enable producers to scale up production.

The model reveals that producers' different idiosyncratic productivity levels are critical to the heterogeneous responses of the termination rates across producers to aggregate TFP shocks, as well as to the overall acyclical response in the aggregate rate of termination. For an individual producer, its idiosyncratic productivity and the associated measure of suppliers are central to the relevance of adjustment costs for the adjustment in suppliers. The producer with high idiosyncratic productivity and a large measure of suppliers experiences low adjustment costs relative to its profit. This generates limited benefits from replacing existing with new suppliers when TFP increases (i.e., the scaling effect dominates). The producer with low idiosyncratic productivity and a small measure of suppliers, however, faces high adjustment costs relative to its profit, generating large benefits from replacing existing with new suppliers when TFP increases (i.e., the switching effect dominates). Thus, consistent with our Fact 3, producers with a large (vs. small) measure of suppliers display a negative (vs. positive) response of the termination rate to changes in aggregate TFP, which is driven by the dominating scaling (vs. switching) effect.[2]

[2]In particular, in Section 5.2.2 and Appendix E, we show that our assumption of *quadratic* (i.e., *strictly convex*) management

At the aggregate level, the cyclicality of the *aggregate* rate of termination depends on producers' distribution of idiosyncratic productivity and the size of management and adjustment costs that determine the relative strength of scaling and switching effects. We calibrate the model to U.S. data and show that it replicates the heterogeneous cyclicality in the termination rate across producers and the acyclical aggregate rate of termination, consistent with our Facts 2-3. Importantly, our calibration does not use the cyclicality of the observed aggregate rate of termination as a target.

In the context of producer-supplier relationships, two sources of inefficiency naturally emerge from management and adjustment costs, requiring policy interventions to retain market efficiency. First, because the producers earn a fraction (about 36% in the Bureau of Economic Analysis data) of output while bearing the entire costs of managing and adjusting suppliers, the private benefits of adjusting suppliers per producers' perceptions are lower than the social benefits; as such, producers under-adjust their portfolio of suppliers.[3] Second, because a fraction (about 60% in the American Productivity & Quality Center (APQC) data) of those private costs are the labor income of hired households rather than social costs, the private costs of adjusting suppliers are higher than the social costs, which also induces producers to under-adjust their portfolio of suppliers. Overall, the two inefficiencies result in under-adjustment in the total measure of suppliers and the adoption of new suppliers. Therefore, we show that the optimal policy of the government encompasses heavy subsidies (at the rate of 86%) on management and adjustment costs, which achieve the first-best allocation by eliminating the two sources of inefficiency.

Despite that the optimal policy requires subsidies on both management and adjustment costs to offset the distortions, those subsidies have different impacts on the cyclicality of the aggregate and producer-level rates of termination—which are central results of our empirical analysis. At the aggregate level, in response to negative aggregate TFP shocks, subsidies on management costs decrease the overall termination of suppliers by weakening the scaling effect. Subsidies on adjustment costs, though, increase the overall termination rate by weakening the switching effect. At the producer level, subsidies on management costs uniformly decrease termination across producers of different sizes because of the homogeneous scaling effect across producers, as discussed above. In contrast, subsidies on adjustment costs increase the termination more strongly for smaller producers, as the switching effect that attenuates the countercyclical termination is stronger for smaller producers.

Our analysis is related to several areas of research. It is linked to the literature on endogenous changes in producer-supplier relations over the business cycle. Previous work primarily focuses on the network structure of producer-supplier relations (Atalay, 2017; Grassi, 2017; Huneeus, 2018; Acemoglu and Tahbaz-

costs and *linear* adjustment costs—opposite to *linear* management costs as in the network literature (e.g., Lim, 2018; Huneeus, 2018) and *strictly convex* adjustment costs as in the labor literature (e.g., Zanetti, 2008)—is critical to replicating the procyclicality (vs. countercyclicality) of termination for small (vs. large) producers as in Fact 3. The key reason is that under our assumption, the scaling effect is homogeneous across producers, and the size of the switching effect decreases with the size of producers.

[3] The assumption that producers bear all management and adjustment costs arises in incomplete contracting for management and adjustment costs due to the asset specificity and appropriability problems, as discussed by Caballero and Hammour (1996).

Salehi, 2023) and the cyclical rate of relationship creation (Fernández-Villaverde et al., 2019, 2021). Instead, we document new empirical facts on the vintage structure of producer-supplier relations and the acyclical rate of relationship separation (i.e., termination of suppliers) and reveal the critical role of management and adjustment costs in replicating these facts.

Our study also relates to literature on cyclical fluctuations of intermediate input varieties (Jones, 2011; Gopinath and Neiman, 2014). Our work closely accords with Gopinath and Neiman (2014). They show that the variation in the number of imported goods and the incidence of management costs were central to the amplification of negative shocks during the economic crisis in Argentina in 2001-2002. We further reveal that both management and adjustment costs are critical in accounting for the observed empirical regularities, particularly the acyclical aggregate rate of termination and the cross-sectional distribution of cyclicality in the termination rate across producers.

Finally, we contribute to literature that documents cyclical reallocation of productive factors such as labor (Caballero and Hammour, 1994) and capital (Lanteri et al., 2023). Our management costs that generate the scaling effect are similar to fixed costs in the network literature (e.g., Lim, 2018; Huneeus, 2018). Our adjustment costs that generate the switching effect are similar to labor costs in the labor literature (e.g., Caballero and Hammour, 1994; Mumtaz and Zanetti, 2015; Zanetti, 2008). We show that the degrees of convexity in these two costs are critical to replicate the differences in the cyclicality of the rate of termination across producers with different suppliers. While Caballero and Hammour (1994) document countercyclical destruction of jobs (i.e., "the cleansing effect"), we document that the cleansing effect is absent for the termination of suppliers at the aggregate level, which is acyclical in the data.

The remainder of the paper is structured as follows. Section 2 outlines the construction of the data and defines the empirical variables. Section 3 describes the empirical results. Section 4 develops a simple model to study the empirical evidence. Section 5 presents the analytical results of the model. Section 6 discusses the quantitative results and compares them to the data. Section 7 provides policy analyses as applications to the model. Section 8 concludes.

2. Data and variables

We use the FactSet Revere Supply Chain Relationships data that records producer-supplier relations from several sources—including SEC 10-K annual filings, investor presentations, and press releases that producer and supplier firms report. The data comprise a record of 784,325 producer-supplier relationships that include the beginning and ending years of relationships for 152,119 producers and 95,932 suppliers collected between 2003 and 2021. We merge the FactSet Revere Relationships dataset with CompuStat Fundamentals to include income statements, balance sheets, and cash flows for each producer in the sample so that our dataset comprises producers' financial variables (i.e., sales, profits, and administrative costs). Described in Appendix A are the FactSet and Compustat datasets, the merging procedure, and the derivation of the variables used in the analysis. Our final panel data constitutes 3,609 producers with 28,461 producer-year observations, covering 78,193 producer-supplier relationships.

Using the above data, we first define our main variables of interest and provide an overview of the main statistics for the producer-supplier relations. The mean and median durations are 3.44 and 3.00 years, respectively, as shown in the histogram of the duration of each producer-supplier relationship in Panel (a) of Figure A.7 in Appendix A.

We denote by variable $v_{i,t}$ the number of suppliers that are in partnerships with the producer i in year t. The mean and the median numbers of suppliers for each producer are equal to 12.2 and 5.0, respectively, as shown in the histogram for the number of suppliers that each producer employs (Panel b of Figure A.7 in Appendix A). The right skewness of the distribution evinces that a non-trivial fraction of producers employ a large number of suppliers, averaging around 12, despite the majority of producers using five suppliers on average.

Our central interest is measuring the rates of adoption and termination of suppliers. We define the *rate of adoption* of each producer i in period t as $s_{i,N,t} \equiv v_{i,N,t}/v_{i,t-1}$, where $v_{i,N,t}$ is the number of new suppliers that producer i adopted in year t (the subscript N refers to new suppliers). Similarly, we define the *rate of termination* for each producer i in year t as $s_{i,T,t} \equiv v_{i,T,t}/v_{i,t-1}$, where $v_{i,T,t}$ is the number of existing suppliers that producer i terminated in year t (the subscript T refers to the termination of suppliers). In the data, the rate of termination is on average smaller, and less volatile than the rate of adoption, with means of 0.144 vs. 0.287 and standard deviations of 0.203 vs. 0.449. Shown in Table A.3 in Appendix A are the summary statistics of the rates of adoption and termination at the producer level.

To study the economy-wide changes in the total number and turnover of suppliers, we weight the growth rate of the number of suppliers ($\Delta v_{i,t}/v_{i,t-1}$), the adoption rate ($s_{i,N,t}$), and the termination rate ($s_{i,T,t}$) of each producer by their intermediate input expenditures to construct the aggregate indexes $\Delta v_t/v_{t-1}$, $s_{N,t}$, and $s_{T,t}$. These indexes track the growth rate of the aggregate number of suppliers, the aggregate rate of adoption, and the aggregate rate of termination in the economy, respectively.

3. Empirical results on adoption and termination of suppliers

In this section, we establish three novel facts on producer-supplier relations. Fact 1 shows that the aggregate number of suppliers is procyclical, motivating our study of the adoption and termination at business cycle frequencies. Fact 2 decomposes the aggregate number of suppliers into the number of adopted *new* suppliers and the number of terminated *existing* suppliers, documenting procyclical adoption and acyclical termination. Fact 3 studies the cross-sectional patterns of termination and shows the heterogeneous cyclicality in termination across producers with different sizes.

Fact 1: Procyclical total number of suppliers

Shown in Figure 1a are the growth rates of the aggregate number of suppliers (i.e., $\Delta \ln v_t$, solid green line with circles), the aggregate real intermediate inputs (i.e., $\Delta \ln X_t$, dash-dotted magenta line), and the real gross output (i.e., $\Delta \ln Y_t$, solid black line), respectively, for the period 2004-2020.[4] All variables strongly co-move with production: they sharply decline around the Great Recession of 2008, and rebound quickly in 2010, when the U.S. economy begin recovering. Similarly, the variables drop considerably in 2020 at the outset of the Covid-19 recession. The correlations of real output growth with the aggregate number of suppliers and the aggregate real intermediate inputs equal 0.65 and 0.98, respectively. These co-movements reveal strong synchronization between the aggregate number of suppliers, the aggregate use of intermediate inputs, and the aggregate output. To the best of our knowledge, this is the first study to document procyclicality in the aggregate number of suppliers in US data.[5]

Our new fact showing procyclicality in the aggregate number of suppliers is consistent with the positive correlation between a producer's sales and its number of suppliers at the firm level documented in previous studies (e.g., Lim 2018 for the US, Bernard et al. 2019 for Japan, and Arkolakis et al. 2023 for Chile). Those studies evince positive *returns from more relationships*, corroborating the central tenet of the "returns from more varieties." In Appendix B, we complement and extend the result in Lim (2018), using a comprehensive dataset of inter-firm relationships—the FactSet Revere—and verify a robust pattern of returns from having more suppliers for U.S. firms.[6]

Fact 2: Procyclical adoption and acyclical termination of suppliers

We now focus on aggregate adoption and termination rates that jointly determine the aggregate number of suppliers. We decompose the growth rate of the aggregate index of the number of suppliers (i.e., Δv_t, solid green line with circles) into the following metrics (Figure 1b): (i) the aggregate rate of adoption (i.e., $s_{N,t}$, solid red line with circles), and (ii) the aggregate rate of termination (i.e., $s_{T,t}$, dash-dotted blue line) of suppliers, according to $\Delta v_t = s_{N,t} - s_{T,t}$. The strong co-movement between the changes in the aggregate number of suppliers (Δv_t) and the aggregate rate of adoption ($s_{N,t}$) shows that fluctuations in the aggregate number of suppliers are primarily driven by the large fluctuations in the aggregate adoption rate; the aggregate termination rate ($s_{T,t}$), however, remains substantially unchanged over the sample period. The changes in the aggregate adoption rate are large and procyclical: the aggregate rate of adoption ranges from 10% in 2009 to 42% in 2014. In general, the aggregate adoption rate is higher than the aggregate

[4] We measure aggregate real intermediate inputs and output, X_t and Y_t, with the U.S. Bureau of Economic Analysis (BEA) chain-type quantity indices of intermediate inputs and gross output that cover the universe of the U.S. private firms, respectively.

[5] Our findings are consistent with the results in Gopinath and Neiman (2014). They document a strong procyclicality in the imported intermediate input varieties in Argentina, thus showing a similarly sharp contraction in the number of imported intermediate input varieties during the recession of 2001-2002.

[6] Lim (2018) uses Compustat Customer Segment database, which is limited to major customers that contribute to at least 10% of a supplier's revenue. In contrast, the FactSet Revere that we use provides a broader set of supply chain relationships that is about 30 times larger than those in Compustat. See Appendix A for a comparison of the two datasets on inter-firm relationships.

termination rate, generating an upward trend in the aggregate number of suppliers. This is consistent with the increasingly denser input-output networks (Acemoglu and Azar, 2020; Ghassibe, 2023).

To study the co-movements between aggregate rates of adoption and termination and aggregate economic activity, Figure 1b also shows the growth rate of real output (i.e., solid black line). The aggregate rate of adoption closely co-moves with the growth rate of real output and is highly procyclical. The two series have a pair-wise correlation of 0.67, which is significant at the 1% level. In contrast, the aggregate rate of termination is substantially acyclical, with a pair-wise correlation with the growth rate of output of -0.27, which is not significant at the 10% level.

We examine the separate contributions of aggregate adoption and termination rates to changes in the aggregate number of suppliers using the following variance decomposition:

$$\frac{Cov\big(\Delta\ln(v_t), s_{N,t}\big)}{Var\big(\Delta\ln(v_t)\big)} + \frac{Cov\big(\Delta\ln(v_t), -s_{T,t}\big)}{Var\big(\Delta\ln(v_t)\big)} = 1. \tag{1}$$

The derivation of equation (1) is described in Appendix A. The decomposition establishes that the contribution of the aggregate adoption rate to total changes in the number of suppliers (i.e., first term in the equation) equals 82%, but the contribution of the aggregate termination rate equals 18%. Together with the results shown in Figure 1b, the analysis consistently reveals that the aggregate adoption rate is the main driver of fluctuations in the aggregate number of suppliers, but the aggregate termination rate plays a subsidiary role.

In sum, our results show that the processes of adoption and termination of suppliers are notably different from the creation and destruction of jobs in the labor market, as discussed in the seminal study of Caballero and Hammour (1994). Although the labor market features the cleansing effect of recessions that leads to a countercyclical job destruction that cleanses the labor market from low-productivity jobs in recessions, the destruction margin remains inactive in producer-supplier relationships.

The procyclicality in the rate of aggregate adoption implies newer relationships in booms and older relationships in recessions. We show that this negative correlation between output and the age of relationships also holds at the cross-sectional level, to which we refer as the *returns from new relationships*. Specifically, we estimate the following regressions:

$$y_{i,t} = a\ln(age^{rel}_{i,t}) + b\ln(v_{i,t}) + c\ln(age^{pro}_{i,t}) + \alpha_i + \gamma_t + \epsilon_{i,t},\ y_{i,t} \in \{\ln(q_{i,t}),\ \ln(\pi_{i,t})\}\,,$$

where the dependent variables, $q_{i,t}$ and $\pi_{i,t}$, are a producer's real sales and profits, respectively. The key independent variable, $age^{rel}_{i,t}$, represents the average age of relationships for each producer i in year t. $v_{i,t}$ is the number of suppliers that we use to control for producer size. We also control for the producer's age, $age^{pro}_{i,t}$, which is positively correlated with both the profits and the age of relationships due to selection.

Shown in Table 2 are the estimation results. The average age of the relationships is negatively correlated with profits, evincing that relationships formed with new suppliers induce higher sales and profits. Conditional on the number of suppliers and the age of the producer, a 1% increase in the average age of the relationships is associated with a 0.048% and a 0.069% decline in the producer's sales and profits, respectively. The age of the producer is also positively correlated with the sales, consistent with the conventional finding (Haltiwanger et al., 1999; Coad et al., 2013). Our result of the positive return from new relationships echoes the positive effect of new vintages of capital on technological progress found in the vintage capital literature (Hulten, 1992; Sakellaris and Wilson, 2004).

Fact 3: Heterogeneous cyclicality in the termination rate among producers

Fact 2 established that procyclicality in the adoption of new suppliers at the aggregate level uniquely drives procyclicality in the aggregate number of suppliers, and the aggregate termination of suppliers is substantially insensitive to business cycle conditions. In Fact 3, we link acyclicality of aggregate termination to different cyclicalities in termination rates across producers with different numbers of suppliers.

Shown in Figure 2a is the bin scatter plot of the logarithm of the number of suppliers (x-axis) against the correlation between the termination rate and (log) real sales (y-axis) for the producers in our sample. As evinced, there is large heterogeneity in the correlation across producers with different numbers of suppliers. The correlation between termination and sales is *positive* for producers with a smaller number of suppliers. In particular, those producers terminate existing suppliers during economic expansions but retain them during economic downturns. In contrast, the correlation is *negative* for producers with a larger number of suppliers. Specifically, those producers retain existing suppliers during economic expansions but terminate them during economic downturns.

As shown in Figure 2a, the shares of producers having positive and negative correlations of the termination rate with sales are equally large, which generates a nearly zero correlation between the rate of termination and sales on average, consistent with the acyclical rate of termination at the aggregate level (documented in Figure 1b of Fact 2).

Productivity and the number of suppliers. Why is the correlation of the termination rate with sales linked to the number of suppliers? A logical conjecture is that the heterogeneous number of suppliers reflects different producer-specific productivity levels among producers, which could account for the heterogeneous dynamics of the termination rate. Shown in Figure 2b is the bin scatter plot of the logarithm of labor productivity (x-axis) against the logarithm of the number of suppliers (y-axis) for different producers. The strong positive correlation between the two variables suggests a systematic relationship between producers' numbers of suppliers and productivity. Overall, our results reveal that the differences in the number of suppliers and the productivity levels across different producers are important for the cyclicality in the rate of termination.

4. A model of adoption and termination of suppliers

We now develop a model with optimal choices for the costly adoption, termination, and management of suppliers, which allows us to replicate Facts 1-3 documented in the previous section.

4.1. Baseline environment and timing

The economy is static, and it is populated by a continuum of final-goods producers $i \in [0,1]$. Each producer i has an idiosyncratic productivity a_i drawn from a log-normal distribution with zero mean and standard deviation σ_a; this is the only source of heterogeneity in the model. We assume that there is no shock to idiosyncratic productivity (i.e., a_i is fixed for each producer). The final good market is perfectly competitive, with the price normalized to one. Each producer manufactures goods by assembling intermediate inputs that existing (E) and new (N) suppliers provide. Each vintage $k \in \{E, N\}$ is populated by a continuum of suppliers. Each supplier offers intermediate inputs to different producers.

At the beginning of the period, each producer i starts with the steady-state measure of total suppliers $\bar{V}_i^*$.[7] Each producer optimally sets the mix of existing and new suppliers to maximize profits. The adjustment in the measure of suppliers involves costs for termination (c^-) and adoption (c^+) of suppliers. Prices of intermediate inputs are determined by Nash bargaining between the producer and suppliers. Producer i manufactures the final good (Y_i) using the supplied inputs from new and existing suppliers at the established price. Summarized in Figure D.8 in Appendix D is the model's timeline.

4.2. Suppliers

Each supplier provides a distinct input to the producer. Suppliers of each vintage k are indexed by their match-specific efficiency z_k. Within the new vintage, match-specific efficiency is uniformly distributed over the interval $[0, 1]$ with unitary density. Within the existing vintage, match-specific efficiency is uniformly distributed over the interval $[1 - \bar{V}_i^*, 1]$ with unitary density.[8]

4.3. Producers and the bargained input price

Each producer i manages a continuum of production lines. Each line of production produces output using the input from one supplier z_k according to the following production technology:

$$y_{i,k}(z_k) = A a_i z_k, \quad \forall\, k \in \{E, N\}, \; \forall\, z_k,$$

[7] For each producer i, its measure of active suppliers in the production stage is a function $V_i^*(\bar{V}_i^*, A)$ of the measure of existing suppliers with which the producer starts $(\bar{V}_i^*)$ and the aggregate TFP (A). The steady-state measure of suppliers, $\bar{V}_i^*$, is the unique fixed point for the above mapping from $\bar{V}_i^*$ to V_i^* when the aggregate TFP is at the steady-state level $A = \bar{A}$, i.e., $V_i^*(\bar{V}_i^*, \bar{A}) = \bar{V}_i^*$.

[8] We assume that new and existing suppliers have the same maximum match-specific efficiency, which is normalized to one. Allowing different maximum efficiency for new and existing suppliers does not affect the results.

where A and a_i are aggregate TFP and idiosyncratic productivity, respectively. Aggregate TFP is random and follows a log-normal distribution with zero mean and standard deviation σ_A.

We assume that each supplier manufactures intermediate goods without cost. The total surplus $TS_{i,k}(z_k)$ from the producer-supplier relationship is the output produced by the corresponding production line, $y_{i,k}(z_k)$, which is split between the producer and the supplier by Nash bargaining over the price charged by the supplier ($p_{i,k}(z_k)$), according to the surplus-sharing condition:

$$p_{i,k}(z_k) = (1-\alpha) TS_{i,k}(z_k), \quad \forall\, i \in [0,1],\, \forall\, k \in \{E, N\},\, \forall\, z_k, \tag{2}$$

where $1-\alpha$ is the supplier's bargaining share.

4.4. *Measures of adoption and termination*

We denote by $z_{i,k}$ the marginal supplier of vintage k used by producer i. Specifically, producer i adopts the new suppliers whose idiosyncratic productivity levels are sufficiently high to generate profits and therefore adopts new suppliers with $z_N \in [z_{i,N}, 1]$. Similarly, producer i terminates existing suppliers whose idiosyncratic productivity levels are insufficient to generate profits and therefore terminates existing suppliers with $z_E \in [1-\bar{V}_i^*, z_{i,E})$. Measures of adopted new and terminated existing suppliers are equal to $1-z_{i,N}$ and $z_{i,E}-1+\bar{V}_i^*$, respectively. To retain consistent notation with Section 2, we denote by $s_{i,N}$ and $s_{i,T}$ the rate of adoption (of new suppliers) and the rate of termination (of existing suppliers), respectively, with $s_{i,N} = (1-z_{i,N})/\bar{V}_i^*$ and $s_{i,T} = \left(z_{i,E}-1+\bar{V}_i^*\right)/\bar{V}_i^*$.

4.5. *Costs of management, adoption, and termination of suppliers*

Costs of managing suppliers. Producers incur costs in managing suppliers, consistent with the *span of control* problem (Lucas Jr, 1978) and the "diminishing returns to management" (Coase, 1991). Following Gopinath and Neiman (2014), we assume a quadratic management cost that is a function of the total measure of production lines: $G(z_{i,N}, z_{i,E}) = \xi \cdot V_i^2/2$, where $V_i = 2 - z_{i,N} - z_{i,E}$ is the total measure of active suppliers for each producer i, or the total measure of suppliers whose idiosyncratic productivity levels are above the threshold for selection in each vintage.

Costs of adjusting suppliers. In addition to the costs of managing suppliers, the adoption and termination of suppliers are also costly, and they involve unitary costs of adoption c^+ and of termination c^-. We defer the discussion on the functional form of management and adjustment costs to Section 5.2.2.

Consistent with the seminal idea in Coase (1991) and subsequent studies, we assume that both management and adjustment costs are not contractable and, therefore, are paid entirely by producers—in consequence to asset specificity and appropriability problems, as studied in Caballero and Hammour (1996).[9]

[9] Specifically, if a complete contract cannot be written and enforced on sharing the management and adjustment costs that are specific assets for the producer, the quasi-rents from these specific assets are potentially appropriable, so the producer will incur the entire costs.

Inefficiencies associated with the costs. In our context of producer-supplier relationships, two sources of inefficiency naturally emerge from the producers' costs of managing and adjusting suppliers: first, since the producers earn a fraction of α of output while bearing the *entire* costs of managing and adjusting suppliers, the private benefits of managing and adjusting suppliers perceived by the producers are lower than the social benefits. Second, since a fraction of the producers' private costs is the labor income of hired households that contributes to consumption and welfare rather than social costs, the private costs of managing and adjusting suppliers are higher than the social costs.

Both sources of inefficiency lead producers to under-adjust the total measure of suppliers and the adoption of new suppliers, requiring the adoption of subsidies on the producers' management and adjustment costs to retain efficiency. This motivates us to conduct the policy analysis in Section 7, in which we show that the optimal subsidies achieve the first-best allocation by eliminating the two sources of inefficiency.

4.6. *Optimal choices of adoption and termination*

We now describe the optimization of each producer i that chooses the adoption and termination of suppliers to maximize profits. For a given set of marginal suppliers $z_{i,E}$ and $z_{i,N}$, each producer i manufactures final output with the linear production function:

$$Y_i = \int_{z_{i,E}}^{1} y_{i,E}(z_E)dz_E + \int_{z_{i,N}}^{1} y_{i,N}(z_N)dz_N, \tag{3}$$

where the marginal suppliers $z_{i,E}$ and $z_{i,N}$ are optimally chosen to maximize the profit function:

$$\begin{aligned}\Pi_i = \max_{\{z_{i,E}, z_{i,N}\}} & \underbrace{\int_{z_{i,E}}^{1} y_{i,E}(z_E)dz_E + \int_{z_{i,N}}^{1} y_{i,N}(z_N)dz_N}_{\text{Final output}} - \underbrace{\left(\int_{z_{i,E}}^{1} p_{i,E}(z_E)dz_E + \int_{z_{i,N}}^{1} p_{i,N}(z_N)dz_N\right)}_{\text{Input costs}} \\ & - \underbrace{\left[c^- \left(z_{i,E} - 1 + \bar{V}_i^*\right) + c^+ \left(1 - z_{i,N}\right)\right]}_{\text{Adjustment costs}} - \underbrace{\xi \cdot \left(2 - z_{i,N} - z_{i,E}\right)^2 /2}_{\text{Management cost}},\end{aligned} \tag{4}$$

where the final output from all production lines is diminished by input costs paid to suppliers, adjustment costs, and management costs. The adjustment costs comprise termination costs ($c^- \left(z_{i,E} - 1 + \bar{V}_i^*\right)$) and adoption costs ($c^+ \left(1 - z_{i,N}\right)$). The quadratic management cost encapsulates administrative costs for the management of suppliers.

Combining the bargained input price in equation (2) with equation (4) yields:

$$\begin{aligned}\Pi_i = \max_{\{z_{i,E}, z_{i,N}\}} & \alpha \left\{\int_{z_{i,E}}^{1} Aa_i z_E dz_E + \int_{z_{i,N}}^{1} Aa_i z_N dz_N\right\} - \left[c^- \left(z_{i,E} - 1 + \bar{V}_i^*\right) + c^+ \left(1 - z_{i,N}\right)\right] \\ & - \xi \cdot \left(2 - z_{i,N} - z_{i,E}\right)^2 /2.\end{aligned}$$

The solution to the above maximization problem yields the optimal conditions for the marginal suppliers $z^*_{i,E}$ and $z^*_{i,N}$:

$$z^*_{i,E} + \frac{c^-}{\alpha A a_i} = \frac{\xi V^*_i}{\alpha A a_i}, \tag{5}$$

$$z^*_{i,N} - \frac{c^+}{\alpha A a_i} = \frac{\xi V^*_i}{\alpha A a_i}, \tag{6}$$

where $V^*_i = 2 - z^*_{i,N} - z^*_{i,E}$ is the total measure of suppliers for producer i in equilibrium.

Equations (5) and (6) outline the distinct roles of the management and adjustment costs for the adoption and termination of suppliers. The management cost increases the marginal costs of using both new and existing suppliers and, therefore, deters expansion in the total measure of suppliers. The cost of adoption (c^+) decreases the marginal benefit of using new suppliers, and the cost of termination (c^-) increases the marginal benefit of retaining existing suppliers.

Combining equations (5) and (6) yields:

$$z^*_{i,N} - z^*_{i,E} = \frac{c^+ + c^-}{\alpha A a_i} > 0. \tag{7}$$

Equation (7) shows that the adjustment costs generate the differential in marginal productivity between new and existing suppliers, such that new suppliers have higher marginal productivity than existing ones in equilibrium. As we discuss in the next section, the productivity differential is critical to the incentive for producers to adopt new suppliers (Lemma 2), and for the different cyclicality in the rate of termination across producers with different idiosyncratic productivity (Proposition 1).

5. Analytical results

In this section, we show that our model based on optimizing producers, distinct management and adjustment costs, and idiosyncratic productivity of producers generates the empirical results in Facts 1-3. We begin by presenting the returns from more and new suppliers that directly result from the model (Section 5.1). We then present the scaling and switching effects (Section 5.2.1), which are the forces that determine the decisions of adoption, termination, and production by single producers. Then, we extend the analysis to the cross-sectional cyclicality of termination across different producers to study Fact 3 (Section 5.2.2). We conclude our analysis by extending it to the aggregate economy to focus on Facts 1 and 2 (Section 5.2.3).

5.1. Returns from more relationships and new relationships

Our model directly generates returns from more relationships and from new relationships, i.e., the profits and sales of producers increase with the number of suppliers, and the increase is magnified by relationships with new suppliers. These returns are the fundamental forces behind the cyclical movements in the total measure, the adoption, and the termination of suppliers and, therefore, are critical for replicating Facts 1-3.

We start by deriving analytical expressions for the returns from more and new relationships in our model. Combining equations (5) and (6), the next lemma holds.

Lemma 1. Returns from more relationships. *Conditional on the rate of adoption $s^*_{i,N}$, the final output increases in the total measure of suppliers, V^*_i.*

$$\frac{\partial \ln Y^*_i}{\partial \ln V^*_i} = \frac{A a_i V^*_i}{Y^*_i} z^*_{i,E} > 0.$$

Proof: In Appendix D.

Lemma 1 shows that the elasticity of output to the total measure of suppliers is always positive, which is consistent with *returns from more relationships* documented in Appendix B and in Lim (2018).

The model also generates the *returns from new relationships*, as formalized in the next lemma.

Lemma 2. Returns from new relationships. *When $c^+ > 0$ or $c^- > 0$, the semi-elasticity of final output (Y^*_i) to the adoption rate ($s^*_{i,N}$) is positive and equal to:*

$$\frac{\partial ln Y^*_i}{\partial s^*_{i,N}} = \frac{c^+ + c^-}{\alpha Y^*_i / \bar{V}^*_i} > 0.$$

Proof: In Appendix D.

Lemma 2 shows that the semi-elasticity of output to the rate of adoption is positive when the adjustment costs are positive, establishing the positive return from new relationships that is consistent with our empirical finding in Fact 2. Lemma 2 also reveals that this *return from new relationships* is proportional to the adjustment costs, which is a driving force behind the cyclical adjustments in the adoption and termination that we document in Facts 2 and 3.

5.2. Responses of adoption, termination, and output to changes in aggregate TFP (Facts 1-3)

In this section, we consider the responses of adoption, termination, and output to changes in aggregate TFP to replicate Facts 1-3. We first focus on the scaling and switching effects (Section 5.2.1) that determine the response of the single producer to changes in aggregate TFP—which jointly replicate the cross-sectional cyclicality of termination across different producers in Fact 3, particularly when the convexity of management costs is sufficiently high relative to that of adjustment costs (Section 5.2.2). Then, we extend the analysis to the aggregate economy to study Facts 1 and 2 (Section 5.2.3).

The response of the single producer to aggregate TFP shocks critically depends on the economic relevance of the costs of management, adoption, and termination of suppliers, which are measured by the costs of management, adoption, and termination of suppliers in units of the idiosyncratic productivity of the producer a_i, and are defined as $\widetilde{\xi}_i \equiv \xi / a_i$, $\widetilde{c}^+_i \equiv c^+ / a_i$, $\widetilde{c}^-_i \equiv c^- / a_i$, respectively. A higher $\widetilde{\xi}_i$ indicates that the producer faces a larger management cost relative to its idiosyncratic productivity; similarly, a higher $\widetilde{c}^+_i$ (vs.

$\widetilde{c}_i^-$) indicates that the producer faces a greater adoption (vs. termination) cost relative to its idiosyncratic productivity. For notational convenience, we define the total adjustment costs in units of the idiosyncratic productivity as: $\widetilde{c}_i = \widetilde{c}_i^+ + \widetilde{c}_i^-$, which measures the economic relevance of total adjustment costs.

To study the responses of variables to changes in aggregate TFP, we denote the steady state of a general variable x by $\bar{x}$, and the deviation of x from the steady state by $dx \equiv x - \bar{x}$.

5.2.1. Scaling and switching effects

Before focusing on Facts 1 to 3, we show that changes in aggregate TFP exert two distinct scaling and switching effects on the total measure and the composition of suppliers. These forces are critical for the responses of the adoption and termination rates of the single producer to aggregate TFP shocks.

The scaling effect. The higher aggregate TFP leads producers to increase the total measure of suppliers to benefit from the increased aggregate productivity (and profits) relative to the unchanged management costs. To take advantage of the higher productivity and resulting profits, producers increase their adoption of new suppliers and decrease their termination of existing suppliers, which we refer to as the *scaling effect*, as formalized in the next lemma.

Lemma 3. *The producer increases the total measure of new and existing suppliers to expand the scale of production in response to an increase in aggregate TFP. The size of the scaling effect is equal to:*

$$\textit{Scaling effect} \equiv \frac{d\ln V_i^*}{d\ln A} = \frac{2\widetilde{\xi}_i \bar{V}_i^* + \left(\widetilde{c}_i^+ - \widetilde{c}_i^-\right)}{\left(2\widetilde{\xi}_i + \alpha \bar{A}\right)\bar{V}_i^*} > 0, \tag{8}$$

which increases in $\widetilde{\xi}_i$ and decreases in a_i.

Proof: In Appendix D.

Lemma 3 shows that the magnitude of the scaling effect increases with the economic relevance of the management cost ($\widetilde{\xi}_i$), which governs the constraints on the producer's scale of production, when $\widetilde{c}_i^+ - \widetilde{c}_i^-$ is close to zero and $\bar{V}_i^*$ is positive. In particular, producers with higher $\widetilde{\xi}_i$ are more constrained by the burden of management costs and hence reduce the scale of production more strongly in response to a negative aggregate TFP shock. Because $\widetilde{\xi}_i$ is inversely related to idiosyncratic productivity, the scaling effect decreases with idiosyncratic productivity.

The scaling effect incentivizes producers to reduce the size of production by terminating existing suppliers in response to negative aggregate TFP shocks and, therefore, is critical to generate the countercyclical rate of termination among large producers established in Fact 3 (Figure 2a).

The switching effect. Adjustment costs generate a positive co-movement between rates of adoption and termination and aggregate TFP. For instance, the increase in aggregate TFP reduces the productivity differential between new and existing suppliers (see equation 7) and, therefore, incentivizes the producer to adjust the composition of suppliers by replacing existing with new suppliers. This incentive of switching suppliers enhances both rates of termination and adoption of suppliers. We refer to this phenomenon as the *switching effect*, as formalized in the next lemma.

Lemma 4. *For a given measure of suppliers, an increase in aggregate TFP generates the switching from existing to new suppliers. The size of the switching effect is equal to:*

$$\textit{Switching effect} \equiv \frac{\partial s^*_{i,N}}{\partial \ln A} = \frac{\partial s^*_{i,T}}{\partial \ln A} = \frac{\widetilde{c}_i}{2\alpha \bar{A} \bar{V}^*_i} > 0, \tag{9}$$

which increases in $\widetilde{c}_i$ and decreases in a_i.

Proof: In Appendix D.

Because replacing existing with new suppliers involves simultaneous adoption and termination of suppliers, the switching effect entails equal changes in the rates of adoption ($s^*_{i,N}$) and termination ($s^*_{i,T}$) of suppliers. Lemma 4 shows that the size of the switching effect increases with $\widetilde{c}_i$, which declines in idiosyncratic productivity a_i. In particular, smaller producers with lower a_i are more prone to a negative aggregate TFP shock than larger producers with higher a_i in their replacement of existing suppliers with new ones. This is because smaller producers endure larger increases in the relevance of the fixed adjustment costs in relation to their decreased profits. Therefore, they are more inclined to refrain from adjusting suppliers and hence display larger declines in adoption and termination rates (i.e., a larger switching effect).

5.2.2. *Effect of aggregate TFP on the producer's decisions*

Using the scaling and switching effects discussed above, we examine responses of the producer's rates of adoption, termination, and output to changes in aggregate TFP.

Response of the producer's adoption rate to changes in aggregate TFP. The response of the rate of adoption for the producer i ($s^*_{i,N}$) to changes in aggregate TFP (A) is a linear combination of the scaling and switching effects:

$$\frac{ds^*_{i,N}}{d\ln A} = \underbrace{\frac{1}{2}\frac{d\ln V^*_i}{d\ln A}}_{\text{Scaling effect on adoption} > 0} + \underbrace{\frac{\partial s^*_{i,N}}{\partial \ln A}}_{\text{Switching effect} > 0}. \tag{10}$$

Because the switching and scaling effects are both positive on the adoption rate, the response of the adoption rate to a positive aggregate TFP shock is always positive for the producer.[10]

[10] To derive equations (10) and (11), we combine equations (5) and (6), and the definitions of $s^*_{i,N}$ and $s^*_{i,T}$, which yields the producer's rates of adoption and termination: $s^*_{i,N} = \frac{V^*_i}{2\bar{V}^*_i} - \frac{\widetilde{c}_i}{2\alpha \bar{A} \bar{V}^*_i}$ and $s^*_{i,T} = 1 - \frac{V^*_i}{2\bar{V}^*_i} - \frac{\widetilde{c}_i}{2\alpha \bar{A} \bar{V}^*_i}$.

Response of the producer's termination rate to changes in aggregate TFP. The response of the rate of termination for producer i ($s^*_{i,T}$) to changes in aggregate TFP (A) is also a linear combination of the scaling and switching effects:

$$\frac{ds^*_{i,T}}{d\ln A} = \underbrace{-\frac{1}{2}\frac{d\ln V^*_i}{d\ln A}}_{\text{Scaling effect on termination}<0} + \underbrace{\frac{\partial s^*_{i,T}}{\partial \ln A}}_{\text{Switching effect}>0} . \tag{11}$$

The scaling effect implies a negative response of the termination rate to a positive aggregate TFP shock. This is because the producer achieves an increase in the scale of production by reducing the rate of termination of existing suppliers. In contrast, the switching effect implies a positive response of the rate of termination—consistent with the positive impact of the switching effect on the rate of termination to enact the replacement of existing suppliers with new ones. Equation (11) shows that the sign of the response of the termination rate to changes in aggregate TFP is determined by the relative strength of the switching and scaling effects.

Cross-sectional responses of the termination rate across different producers (Fact 3). To examine the countervailing forces of the scaling and switching effects in determining the response of the termination rate of the producer to changes in aggregate TFP, as well as how the forces vary across different producers, we show in Figure 3 the impacts of the scaling (i.e., solid red curve) and switching (i.e., dashed blue curve) effects on the responses of termination against the producer's idiosyncratic productivity, together with the combined total impact (i.e., solid black curve with circles) implied by the calibrated model.

Consistent with equation (11), the scaling (vs. switching) effect exerts a negative (vs. positive) impact on the response of termination to changes in aggregate TFP. Both curves converge towards zero, showing that the magnitudes of both effects decline with the producer's idiosyncratic productivity, as shown in Lemmas 3 and 4. Moreover, the scaling effect is less sensitive to changes in idiosyncratic productivity than the switching effect, as evinced by the steeper curve associated with the switching effect.[11] As a result, the total impact, shown by the solid-black curve with circle markers, follows the switching effect to decline with idiosyncratic productivity. Termination becomes acyclical when the total impact reaches zero at the idiosyncratic productivity of 0.04. When idiosyncratic productivity is lower than 0.04, the switching effect dominates, implying that the rate of termination increases with aggregate TFP (i.e., $ds^*_{i,T}/dlnA > 0$). In contrast, when idiosyncratic productivity is higher than 0.04, the scaling effect dominates, implying that the rate of termination decreases with aggregate TFP (i.e., $ds^*_{i,T}/dlnA < 0$).

Overall, our analysis shows that the different responses of the rate of termination to aggregate TFP shocks across producers are driven by the heterogeneous idiosyncratic productivity a_i, which determines

[11] The low sensitivity of the scaling effect to changes in idiosyncratic productivity relies on our assumption of quadratic management cost and linear adjustment cost functions, which we discuss below in the next paragraph of this subsection on the convexity of cost functions.

the economic relevance of the adjustment costs faced by each producer, as stated in the next proposition.

Proposition 1. Heterogeneous cyclicality in termination (Fact 3). *When both ξ and $c^{+} + c^{-}$ are sufficiently large, the rate of termination is countercyclical for producers with high idiosyncratic productivity while procyclical for producers with low idiosyncratic productivity.*
Proof: In Appendix D.

Note that the steady-state measure of suppliers ($\bar{V}_i^*$) increases with the idiosyncratic productivity. This is because the management cost is less relevant for the producers with higher idiosyncratic productivity, and these producers maintain a large scale of production with a large measure of suppliers. Therefore, Proposition 1 suggests that the rate of termination is countercyclical for producers with many suppliers, but procyclical for producers with a smaller measure of suppliers. This result is consistent with Fact 3 (Figure 2a), which shows that producers with a larger (vs. smaller) measure of suppliers display a countercyclical (vs. procyclical) rate of termination.

Convexity of the cost functions. The degrees of convexity of the management and adjustment cost functions are important for replicating the heterogeneous responses in the rate of termination across producers with a different number of suppliers, as in our Fact 3. More specifically, we show that the degree of convexity of the management cost function must be sufficiently high relative to that of the adjustment cost function for the model to be consistent with Fact 3 in Figure 2a, which displays a negative correlation between the procyclicality of termination and the size of the producer.

Our benchmark model assumes quadratic management costs and linear adjustment costs. This differs from the conventional formulation in the literature, which typically assumes linear management costs for suppliers (e.g., Lim, 2018; Huneeus, 2018) and strictly convex adjustment costs for labor inputs (e.g., Caballero and Hammour, 1994; Mumtaz and Zanetti, 2015; Zanetti, 2008). We show in Panel (b) of Figure E.9 in Appendix E that linear management costs and convex adjustment costs—the standard assumption in the literature—generate a positive correlation between the procyclicality of termination and producer size, inconsistent with our Fact 3.

As equation (11) shows, the management cost—similar to the fixed overhead cost in the network literature—generates the negative scaling effect and makes the rate of termination countercyclical, and the adjustment cost—similar to the adjustment cost in the labor literature—generates the switching effect and makes the rate of termination procyclical. Our analysis in Appendix E shows that the scaling effect is invariant to producer size, and the switching effect significantly decreases with producer size when the convexity of the management cost is sufficiently high relative to that of the adjustment cost (as in our baseline model). Thus, the (pro)cyclicality of termination—which equals the sum of the switching effect and the negative scaling effect, as shown in equation (11)—decreases with producer size, as evinced in Figure 2a of Fact 3. We illustrate this result quantitatively in Figure E.11 of Appendix E, where we extend our model to allow for flexible combinations of the degree of convexity in the management and adjustment costs (i.e., flexible combinations that nest linear and quadratic specifications for those costs).

5.2.3. Effect of aggregate TFP on the aggregate rates of adoption and termination

We now investigate the effect of aggregate TFP on the aggregate rates of adoption and termination of suppliers. Consistent with the empirical analysis, we define the aggregate measure of suppliers (V^*) and rates of adoption (s_N^*) and termination (s_T^*) as the weighted average of their counterparts at the producer level:

$$V^* = \sum_i V_i^* \frac{\bar{Y}_i^*}{\bar{Y}^*}, \; s_N^* = \sum_i s_{i,N}^* \frac{\bar{Y}_i^*}{\bar{Y}^*}, \; and \; s_T^* = \sum_i s_{i,T}^* \frac{\bar{Y}_i^*}{\bar{Y}^*},$$

respectively, where $Y^* = \sum_{i'} Y_{i'}^*$ is the aggregate output, and the steady-state share of output for the producer i, $\bar{Y}_i^*/\bar{Y}^*$, is used as the weight.

Effect of aggregate TFP on the aggregate measure of suppliers. A direct implication of the positive *scaling effect* established in Lemma 3 is the positive relationship between the total measure of suppliers for the producer and the aggregate TFP. Lemma 3 implies that the aggregate measure of suppliers is positively related to the aggregate TFP, as stated in the following proposition.

Proposition 2. Procyclical aggregate measure of suppliers (Fact 1). *The aggregate measure of suppliers, V^*, increases in A.*

Proof: In Appendix D.

Proposition 2 shows that our model replicates the procyclical aggregate measure of suppliers in Fact 1.

Effect of aggregate TFP on the aggregate rate of adoption. Because equation (10) implies a positive relationship between the rate of adoption of each producer and the aggregate TFP, the aggregate rate of adoption and the aggregate TFP are positively correlated, as summarized in the proposition below.

Proposition 3. Procyclical aggregate rate of adoption (Fact 2). *The aggregate rate of adoption of suppliers, s_N^*, increases in A.*

Proof: In Appendix D.

Proposition 3 shows that our model replicates the procyclical aggregate rate of adoption in Fact 2.

Effect of aggregate TFP on the aggregate rate of termination. The effect of aggregate TFP on the aggregate rate of termination is less definite and depends on several parameters. First, as shown in Proposition 1, the effect of aggregate TFP on the producer's rate of termination is heterogeneous across producers and decreases with the producer's idiosyncratic productivity. Thus, the cyclicality of the aggregate rate of termination depends on the distribution of producers' idiosyncratic productivity.

Second, as shown in equation (11), the effect of aggregate TFP on the rate of termination of each individual producer is determined by the sizes of the scaling and the switching effects, which depend on the magnitudes of the management and adjustment costs. Hence, the management and adjustment costs are both crucial determinants of the cyclicality of the aggregate rate of termination.

We will show in our quantitative analysis that the aggregate rate of termination is acyclical—consistent with Fact 2 (Figure 1b)—for a realistic calibration of the distribution of idiosyncratic productivity of the different producers and with the management and adjustment costs calibrated to the U.S. data.

Overall, our analysis reveals that our parsimonious model with optimizing producers and distinct costs for the management and adjustment of suppliers replicates the novel empirical findings on the adoption and termination of suppliers.

6. Quantitative analysis

In this section, we calibrate the model on U.S. data to explore the critical role of adjustment and management costs for the heterogeneity in the cyclicality of the rate of termination across producers with different measures of suppliers.

6.1. Calibration

We calibrate the standard deviation of the log idiosyncratic productivity of each producer, σ_a, equal to 0.2, which is the middle value between the estimates of 0.15 and 0.24 in Syverson (2004) and Fostera et al. (2015), respectively. The standard deviation of the log aggregate TFP, σ_A, is set to 0.024 to match the standard deviation of the cyclical (HP-filtered) annual log real gross output in the U.S. data for the period 2003-2019 (2.7%). We set the bargaining share of the producer (α) equal to 0.36 to match the ratio of the producers' operating surplus to intermediate input costs for the U.S. economy.

We assume symmetric costs of adoption and termination of suppliers, i.e., $c^+ = c^-$. Given the calibrated bargaining share and the average idiosyncratic productivity normalized to one, we jointly calibrate the parameters for the adjustment and management costs, c^+ (and equivalently, c^-) and ξ, to match two target moments. First, we match the ratio of the adjustment costs to the operating costs, set equal to 0.5 in Caballero and Hammour (1994) on the basis that the yearly adjustment costs in production amount to one-half of the operating costs (i.e., intermediate input costs in our model). The average observed duration of relationships is about 3.5 years, implying that the expected adoption and termination occur every 3.5 years. We calibrate c^+ and c^- to 0.076, so that the ratio of the total adjustment cost ($c^+ + c^-$) to the total operating cost over the expected duration of the relationship (i.e., 3.5×yearly operating cost) is equal to 0.14 (i.e., 0.5/3.5). Second, we calibrate ξ equal to 0.081 to match the ratio of the management costs to the sum of operating surplus and intermediate input costs for the producer, which is equal to approximately 9% (Gopinath and Neiman, 2014). Summarized in Table 1 is the calibration of the model.

We simulate 9,000 producers ($i \in \{1, 2, \cdots, 9000\}$) with i.i.d. idiosyncratic productivities drawn from the calibrated distribution. Then, we simulate 1,000 economies ($j \in \{1, 2, \cdots, 1000\}$) for the same 9,000 producers, and draw new i.i.d aggregate TFP shocks in each economy. We use the same set of producers for different economies to examine how the heterogeneity in producers affects the cyclicality of the aggregate rate of termination.

6.2. Heterogeneity in the cyclicality of the rate of termination across producers

Our empirical analysis in Section 3 shows that the rate of termination is countercyclical for larger producers and procyclical for smaller producers. In this subsection, we show that the model matches this important empirical regularity.

We group the 9,000 simulated producers by the measure of suppliers and divide them into 30 groups of equal size (i.e., each group contains 300 producers), with each group indexed by k. To investigate the heterogeneous responses of the termination rate to changes in the business condition across different groups of producers, we conduct the following panel regression for each k-group of producers separately using our simulated data:

$$s^k_{i,T,j} = a^k + b^k \cdot log(Y^k_{i,j}) + \chi^k_i + \epsilon^k_{i,j}, \tag{12}$$

where $s^k_{i,T,j}$ is the termination rate of producer i that belongs to group k in economy j, $Y^k_{i,j}$ is output, and χ^k_i is the producer fixed effect. The coefficient b^k measures the response of the rate of termination to output within the group k. It is the central focus of our analysis, as it captures the heterogenous cyclicality of the termination rate for different groups of producers. We then undertake a similar exercise using the observed data through performing the following regression:[12]

$$s^k_{i,T,t} = a^k + b^k \cdot log(Y^k_{i,t}) + \chi^k_i + \epsilon^k_{i,t}. \tag{13}$$

Panel (a) in Figure 4 shows the regression results from equation (13) estimated with the observed data. Blue dots show the point estimates of the different b^k coefficients (y-axis) against the log of the average number of suppliers $V^k \equiv \sum_i \sum_t V^k_{i,t}/N^k_{obs}$ (x-axis), where N^k_{obs} is the total number of observations in group k. The red line is the fitted curve estimated using OLS. Panel (b) shows the results from equation (12) estimated with the simulated data from the baseline model. In both panels, the correlation between the cyclicality of the termination rate (measured by b^k) and the size of producers (measured by V^k) is negative. This reveals that the model generates empirically congruous heterogeneity in the cyclicality of the termination rate across the producers with different measures of suppliers. This outcome is also consistent with the theoretical results in Proposition 1.

Another important similarity between the observed data and the simulated model that emerges from Figure 4 is the nearly zero cyclicality of the aggregate termination rate. To test formally that the correlation between termination and output is close to zero at the aggregate level, we estimate the following time-series

[12] Different from the estimation using the simulated data, the observed data have multiple periods t rather than the multiple economies j in the simulated data.

regressions with the simulated and the observed data separately:

$$s_{T,j} = a + b \cdot log(Y_j) + \epsilon_j, \tag{14}$$

$$s_{T,t} = a + b \cdot log(Y_t) + \epsilon_t, \tag{15}$$

where $s_{T,j}$ and $s_{T,t}$ are the aggregate termination rates in economy j (for the simulated data) and period t (for the observed data), and Y_j and Y_t are the aggregate output. The estimated values for the coefficient b are -0.006 and -0.012 for the simulated and the observed data, respectively. Both estimates are close to zero, evincing that the model is consistent with the observed acyclical aggregate rate of termination in Figure 1b.

To clarify the role of adjustment and management costs in the heterogeneous cyclicality of the termination rate across producers, we estimate the cyclicality of the termination rate for each group, b^k, using data simulated with two counterfactual models. One is a model without adjustment costs, and the other is a model without management costs, which are shown in Figures 4c and 4d, respectively.

When there are no adjustment costs (Panel c), the switching effect is absent (Lemma 4), and the cyclicality of termination is uniquely determined by the scaling effect. These results imply that producers reduce the size of production by terminating existing suppliers in response to a lower aggregate TFP. As a result, the rate of termination is countercyclical for all producers and highly countercyclical for smaller and lower-productivity suppliers, as the scaling effect is stronger for them. This is in stark contrast to the data where the rate of termination is procyclical for smaller producers and countercyclical for larger producers. Without adjustment costs, the aggregate rate of termination is countercyclical: the coefficient of log aggregate output in equation (14) is estimated as -0.11, which is also inconsistent with the data.

When management costs are absent (Panel d), the scaling effect is absent (Lemma 3), and the cyclicality of termination is uniquely determined by the switching effect. This effect induces producers to decelerate the turnover of suppliers in response to a low aggregate TFP. Thus, the rate of termination is procyclical for all producers and more so for smaller and less productive producers whose switching effect is stronger. Again, these findings are incompatible with the data. Without management costs, the aggregate rate of termination is procyclical: the coefficient of log aggregate output in equation (14) is estimated as 0.09, contradicting the data.

7. Policy analysis

In the previous Section 4.5, we point out that in the producer-supplier context, two sources of inefficiency associated with the management and adjustment costs naturally arise (i.e., due to incomplete contracting for the costs and due to the gap between social and private costs), requiring subsidies on the costs to retain efficiency. Therefore, in this section, we extend our model to study the optimal policy in the form of taxes or subsidies on management and adjustment costs and the role of these government policies for welfare (Section 7.1). We link these policies to the response of the aggregate rate of termination to aggregate TFP shocks and the heterogeneity in the response of termination rate across producers with different numbers of suppliers (Section 7.2).

To perform the analysis, we extend our model with a representative household whose utility provides a measure of welfare and introduce a government that may tax or subsidize the costs of managing and adjusting suppliers. Specifically, the economy comprises the production sector described in Section 4. It has a representative household with the log utility function $U(C) = log(C)$, where C is the aggregate consumption. The aggregate resource constraint is:

$$Y = C + \delta_m MC + \delta_a AC, \tag{16}$$

where $Y = \sum_i Y_i di$ is the aggregate output that assembles the output of the different final-goods producers $i \in [0, 1]$. MC is the aggregate management cost, and $\delta_m \in [0, 1]$ is the proportion of management costs that uses final goods (e.g., software used to manage suppliers). The remaining $(1-\delta_m)$ part of management costs comprises costs of labor (e.g., procurement clerks) and, therefore, contributes to consumption and welfare. AC is the aggregate adjustment cost, and δ_a is the proportion of adjustment costs that uses final goods (e.g., depreciated capital associated with the supplier adjustment supplemented with new capital goods). The remaining $(1 - \delta_a)$ part of the adjustment costs comprises costs of labor (e.g., managers who supervise supplier adjustment), and it contributes to consumption and welfare.[13] The terms $\delta_m MC$ and $\delta_a AC$ in equation (16) represent the part of *social costs* in the management and adjustment costs, respectively, since those costs subtract resources from consumption through using final goods and even the social planner cannot avoid by reallocating resources. The standard assumption in the literature on management and adjustment costs is either the special case of the costs entirely reliant on labor—such that $\delta_m = \delta_a = 0$ and the social costs are equal to zero (e.g., Lim, 2018)—or the special case of the costs entirely reliant on final goods, such that $\delta_m = \delta_a = 1$ and the management and adjustment costs are entirely social costs (e.g., Hayashi, 1982). Instead, we allow these values to cover the admissible range $[0, 1]$, and we show that the optimal government policy depends on the values for δ_m and δ_a. Finally, we follow the quantitative analysis in Section 6 to assume symmetric costs of adoption and termination of suppliers, i.e., $c^+ = c^-$.

First, we derive the efficient (i.e., first-best) allocation that can be achieved by the social planner, who sets the rates of adoption and termination of suppliers to maximize welfare subject to the production technology and the aggregate resource constraint. That is:

$$\text{Social planner:} \quad \max_{\{z_{i,N}, z_{i,E}\}_i} U(C) \quad \text{s.t.} \quad \text{equations (3) and (16).} \tag{17}$$

[13] Specifically, we have $MC \equiv \int_0^1 MC_i di \equiv \int_0^1 \xi(V_i^*)^2/2di$, where $MC_i \equiv \xi(V_i^*)^2/2$, and $AC \equiv \int_0^1 AC_i di \equiv \int_0^1 \left(c^- s_{i,T}^* + c^+ s_{i,N}^*\right) \bar{V}_i^* di$, where $AC_i \equiv \left(c^- s_{i,T}^* + c^+ s_{i,N}^*\right) \bar{V}_i^*$.

The first-order conditions (FOCs) for the social planner's problem can be written as:[14]

$$\text{Use of more suppliers:} \quad \underbrace{Aa_i \left(1 - V_i^*/2\right)}_{\text{Social marginal benefit}} = \underbrace{\delta_m \xi V_i^*}_{\text{Social marginal cost}}, \quad \forall\, i, \tag{18}$$

$$\text{Use of new suppliers:} \quad \underbrace{Aa_i \left(z_{i,N}^* - z_{i,E}^*\right)}_{\text{Social marginal benefit}} = \underbrace{\delta_a \left(c^+ + c^-\right)}_{\text{Social marginal cost}}, \quad \forall\, i, \tag{19}$$

where equation (18) shows that the *social* marginal benefit of having more suppliers for the producers (LHS) equals the *social* marginal cost (RHS), and equation (19) shows that the *social* marginal benefit of replacing existing suppliers with new suppliers (LHS) equals the *social* marginal cost (RHS). Equations (18) and (19) determine the social optimum.

7.1. Optimal government policy

The government can tax (or subsidize) the producers on their management and adjustment costs at the homogeneous rates τ_m and τ_a, respectively, where the tax income is transferred lump-sum to households. Negative values for τ_m and τ_a indicate subsidies financed by lump-sum taxes collected from the household.

We derive the market allocations in the decentralized economy from the first-order conditions for the producers in equations (5) and (6) that, with taxes, become:

$$z_{i,E}^* + \frac{(1+\tau_a)\, c^-}{\alpha A a_i} = \frac{(1+\tau_m)\, \xi V_i^*}{\alpha A a_i}, \quad z_{i,N}^* - \frac{(1+\tau_a)\, c^+}{\alpha A a_i} = \frac{(1+\tau_m)\, \xi V_i^*}{\alpha A a_i}.$$

They entail the following optimality conditions for the producers:

$$\text{Use of more suppliers:} \quad \underbrace{\alpha A a_i \left(1 - V_i^*/2\right)}_{\text{Private marginal benefit}} = \underbrace{(1+\tau_m)\, \xi V_i^*}_{\text{Private marginal cost}}, \quad \forall\, i, \tag{20}$$

$$\text{Use of new suppliers:} \quad \underbrace{\alpha A a_i \left(z_{i,N}^* - z_{i,E}^*\right)}_{\text{Private marginal benefit}} = \underbrace{(1+\tau_a)\left(c^+ + c^-\right)}_{\text{Private marginal cost}}, \quad \forall\, i, \tag{21}$$

where equation (20) shows that the producers' marginal benefit (LHS) and cost (RHS) of having more suppliers must be equal, and equation (21) shows that producers' marginal benefit of replacing existing suppliers with new suppliers (LHS) must also equal the corresponding marginal cost (RHS).

The comparison between equation (18) (vs. equation 19) and equation (20) (vs. equation 21) reveals two inefficiencies in the decentralized economy arising from the discrepancy between private and social benefits and costs. First, the private benefits of adjusting suppliers perceived by the producers are lower than the social benefits of those adjustments. This is because producers only reap the α share of output, as

[14] Combining the social planner's FOCs $Aa_i z_{i,E}^* + \delta_a c^- = \delta_m \xi V_i^*$, $Aa_i z_{i,N}^* - \delta_a c^+ = \delta_m \xi V_i^*$ yields equations (18) and (19).

evinced by the α term on the LHS of equations (20) and (21), but they bear the entire costs of managing and adjusting suppliers. Therefore, the individual producers under-adjust the portfolio of suppliers in the competitive equilibrium compared to the social optimum. Our result critically depends on the assumption that management and adjustment costs are incurred entirely by the producers rather than being bargained and shared between the producers and suppliers, which is justified in Section 4.5.

Second, the private costs of adjusting suppliers to the producers are higher than the social costs in the absence of subsidies. This is because the shares $1 - \delta_m$ and $1 - \delta_a$ of those private costs do not crowd out consumption and are not social costs, as evinced by the δ_m and δ_a in the social marginal costs of the RHS of equations (18) and (19). This force also induces producers to under-adjust the portfolio of suppliers. Thus, these two inefficiencies are the key ones that a benevolent government offsets by choosing τ_m and τ_a to maximize welfare in the competitive equilibrium.

The optimal subsidies to management and adjustment costs. The benevolent government solves the Ramsey problem, in which it chooses the tax rates τ_m and τ_a to maximize the utility of the household subject to the production technology, the economic resource constraint, and the producers' optimality conditions, such that:

$$\text{Government:} \quad \max_{\tau_m, \tau_a} U(C) \quad \text{s.t.} \quad \text{equations (3), (16), (20) and (21).} \tag{22}$$

There is a salient difference between the benevolent government and the social planner: the social planner chooses the rates of adoption and termination of suppliers; the government, though, is subject to the optimality conditions of producers. However, the government achieves the first-best allocations through subsidizing the management and adjustment costs to counteract the under-adjustment in the total measure of suppliers and the adoption of new suppliers. These subsidies reduce the marginal costs of scaling up the number of suppliers and adopting new suppliers for the private producers until the producers choose the same (optimal) allocations of the social planner (i.e., equations (20) and (18) yield the same solution for the use of more suppliers, and equations (21) and (19) yield the same solution for the adoption of new suppliers). Therefore, the optimal subsidies by the government in our model can achieve efficient allocation (i.e., be the solution to the social planner's problem in equation (17)), as stated in the next proposition that defines the optimal tax (or subsidy) rates.

Proposition 4. *The optimal rates of taxes on management and adjustment costs that solve the Ramsey problem of the benevolent government in equation (22) are:*

$$\tau_m = \alpha\delta_m - 1 \ \textit{and} \ \tau_a = \alpha\delta_a - 1, \tag{23}$$

which achieve the efficient allocation that solves the social planner's problem in equation (17).

Proof: In Appendix D.

Because the effective ratios of the private marginal benefit to the social marginal benefit for managing more suppliers (i.e., $\alpha\delta_m$) and for switching suppliers (i.e., $\alpha\delta_a$) are less than one, Proposition 4 implies that subsidies (instead of taxes) on management and adjustment costs are required to maximize welfare. Lower α (vs. δ_m and δ_a) results in a large discrepancy between the social benefits (vs. costs) and the producers' private benefits (vs. costs), leading to greater inefficiencies and requiring larger subsidies, as shown in Proposition 4. In our model, the optimal subsidies by the benevolent government achieve the efficient allocation for two reasons. First, there are exactly *two* decision margins (i.e., the total measure of suppliers and the adoption of new suppliers) for both the social planner and private producers, which coincide with the number of (*two*) policy instruments (i.e., the subsidy rates on management costs and on adjustment costs). Second, the inefficiencies influence all producers homogeneously, as in equations (20) and (21), which can be eliminated by subsidy rates τ_m and τ_a that are homogeneous across producers.

To study the quantitative relevance of Proposition 4, we confront our extended model with the data through calibrating the shares of social costs in management and adjustment costs (i.e., δ_m and δ_a, respectively) to 0.4 to match the fractions of non-personnel cost in the total cost for the management and adjustment of the supply chain from the APQC dataset. Specifically, APQC surveyed 640 firms from a wide range of industries, such as Pharmaceutical, Health Care, and Automotive, about their supply chain practices and found that about 40% of their procurement costs—a major component of supply chain management and adjustment costs—accrues to the non-personnel category. These non-personnel costs include system, overhead, and other costs that are equivalent to the social costs in our model. The remaining 60% of the procurement costs are personnel costs and contribute to the labor income and, in turn, are counted in consumption and, therefore, are not social costs in our model. We calibrate the other parameters to the baseline values described in Section 6.1. In accordance with Proposition 4, the optimal tax rates on management and adjustment costs, τ_m and τ_a, are set equal to -0.86 ($\alpha * \delta_m - 1 = \alpha * \delta_a - 1 = 0.36 * 0.4 - 1$).

Shown in Figure 5 is the log aggregate consumption (y-axes) against the tax rates on management and adjustment costs (x-axes). Panel (a) considers the case of subsidies to management costs. The dashed-black, dash-dotted blue, and dashed-green lines display log consumption as a function of τ_m for the alternative cases of δ_m equal to 1, 0, and the baseline level of 0.4, respectively. τ_a is set at the optimal level. In all cases, the optimal tax rates on management costs (red circles) are negative, indicating that subsidies to management costs are the optimal policy. Moreover, the optimal subsidy to the management costs increases with the size of the inefficiency, which is inversely related to δ_m.

Similarly, Panel (b) considers the case of subsidies to adjustment costs. The three lines display log consumption as a function of τ_a for the alternative cases of δ_a equal to 1, 0, and the baseline level of 0.4, respectively. τ_m is set at the optimal level. In all cases, the optimal tax rates on adjustment costs (red circles) are negative, indicating that the optimal policy is to subsidize adjustment costs. Moreover, the optimal subsidy to adjustment costs increases with the size of the inefficiency, which is inversely related to δ_a.

7.2. The effect of government policy on the aggregate and cross-sectional rates of termination

The previous subsection has shown that subsidies to management and adjustment costs in the competitive equilibrium can achieve efficient allocation. The current subsection shows that the two policies have distinct effects on the cyclicality of the aggregate rate of termination and on the heterogeneity in the cyclicality of termination of suppliers across producers—which are central focuses of our empirical analysis.

Subsidy on the management cost. Panel (a) of Figure 6 shows the semi-elasticity of the termination rate to aggregate TFP shocks across producers of different sizes for the optimal level of *subsidy rate on management costs* of 86% (blue-dashed curve) and zero (black-solid curve), respectively. For both curves, we fix the subsidy rate on adjustment costs to zero. The semi-elasticity of the termination rate to aggregate TFP shocks when the subsidy is optimal (blue-dashed line) is higher in the absence of subsidies (black-solid line). Thus, the subsidy increases the procyclicality of the termination rate, reducing the rate of termination of suppliers during economic contractions, which is opposite to the Schumpeterian-cleansing effect. The intuition for our result is straightforward: the subsidy on the management costs weakens the scaling effect, as shown by equation (20), incentivizing producers to reduce the rate of termination of suppliers (to preserve scale) during economic contractions. Because the optimal subsidy is sufficiently large, it induces all producers to refrain from terminating suppliers in economic contractions. As a result, both aggregate and producer-level termination rates become procyclical, and the Schumpeterian-cleansing effect is absent. Moreover, the two curves are almost parallel, showing that the effects of the subsidy on the countercyclicality of termination are approximately uniform across different producers.

Subsidy on the adjustment cost. Panel (b) of Figure 6 shows the semi-elasticity of termination rate to aggregate TFP shocks across different sizes of producers for the optimal *subsidy rate on adjustment costs* of 86% (blue-dashed curve) and zero (black-solid curve), respectively. For both curves, we fix the subsidy rate on management costs to zero. The semi-elasticity of the termination rate to aggregate TFP shocks under the optimal subsidy (blue-dashed curve) is more negative than the rate in the absence of subsidy (black-solid curve). Thus, the subsidy enhances the countercyclicality in the rate of termination, thereby supporting the Schumpeterian-cleansing effect. The intuition for our result is straightforward: the subsidy on the adjustment costs weakens the switching effects, as implied by equation (21), and thus enhances the dominance of the scaling effects, inducing producers to replace existing with new suppliers during economic contractions (i.e., countercyclical termination or Schumpeterian cleansing). Because the optimal subsidy is sufficiently large for the entire set of producers, the termination rate of all producers becomes countercyclical, which enhances the Schumpeterian-cleansing effect. Interestingly, the difference between the cyclicalities of the termination rate of the two considered cases (i.e., absent subsidies vs. optimal) decreases with the size of producers, suggesting that the effect of the subsidy on the degree of countercyclicality of termination is stronger for smaller producers.[15]

8. Conclusion

Our analysis—using newly assembled firm-level data—establishes several novel facts concerning the adoption and termination of suppliers. At the producer level, producer sales and profits positively co-move with the adoption of new suppliers and the expansion in the total number of suppliers. At the aggregate level, the rate of adoption of new suppliers and the total number of suppliers are procyclical, while the termination of existing suppliers is acyclical. The acyclical rate of termination at the aggregate level arises from the different cyclicality in the rate of termination across producers with different numbers of suppliers.

To account for this new evidence, we develop a simple model of producers that optimally adjust the total measure and the composition of new and existing suppliers subject to distinct management and adjustment costs. The model shows the central and separate roles of the costs of managing, adopting, and terminating suppliers in altering the incentives to scale up the measure of suppliers (i.e., scaling effect) and to replace existing with new suppliers (i.e., switching effect) in response to aggregate TFP shocks. The scaling and switching effects are critical to replicate the observed procyclicality in the adoption of new suppliers and the total measure of suppliers. They generate the observed differences in the cyclicality of the rate of termination across producers that result in the acyclical rate of termination at the aggregate level. We find that sufficiently high convexity in management costs relative to adjustment costs is required to replicate the observed decrease in the procyclicality of termination with the size of the producers.

We extend our model to study optimal policy and find that subsidies to management and adjustment costs are required for the competitive equilibrium to attain efficient allocations. Moreover, subsidies to management and adjustment costs have distinct effects on the cyclicality of termination both at the aggregate level and across producers of different sizes.

Our study suggests several interesting avenues for future research. First, there is limited empirical evidence that distinguishes between management and adjustment costs, whose differences we find critical to the optimizing decision of producers and the resulting movements in the aggregate rates of adoption and termination of suppliers. Second, the analysis could be extended to consider the intertemporal dimension in the adoption and termination of suppliers, which will link the optimal choices of producers to the discount rate, asset prices, and the expected benefits of the producer-supplier relationship. Third, we find that the heterogeneity in the productivity of producers is important for the adoption and termination of suppliers. Future work could focus on the optimal sorting between producers and suppliers with different productivity

[15] While our model assumes fixed idiosyncratic productivity and, therefore, abstracts from growth, smaller firms typically have a higher potential growth rate of output in the data (e.g., Dunne et al., 1989; Santarelli et al., 2006). As shown in Figure 6, subsidies on adjustment (as opposed to management) costs promote Schumpeterian cleansing *more* for the smaller-sized yet higher-growth firms, and therefore, may bring additional productivity and welfare improvement that are not accounted in our current model.

levels, which may enhance the cooperation between firms and improve productivity, as shown in Fernández-Villaverde et al. (2023). Finally, though we center on the relationship between a single producer and several suppliers, the analysis could be extended to explore the linkages between producers and suppliers in the context of a network economy, and the endogenous changes in the structure of the network, as documented in Ghassibe (2023). We plan to investigate some of these issues in future work.

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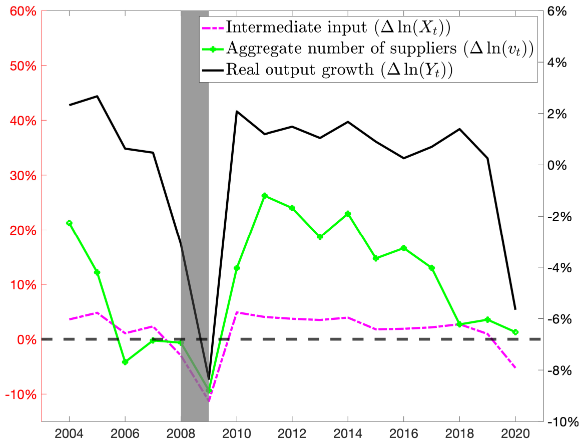
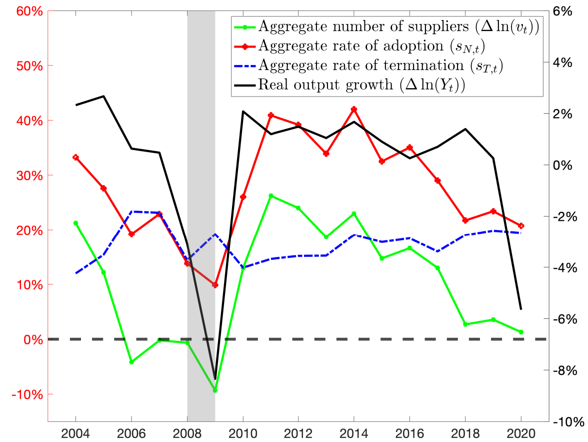
Figure 1: Procyclical total number, procyclical adoption, and acyclical termination of suppliers



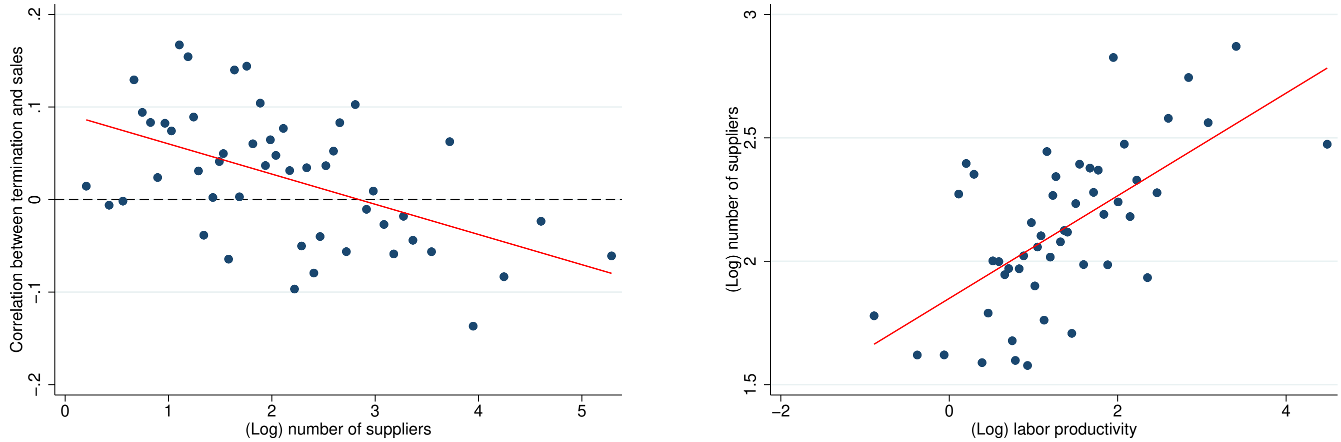
(a) Aggregate number of suppliers



(b) Aggregate adoption and termination

Notes: Panel (a) of the figure shows the growth rates of the aggregate real intermediate inputs (i.e., dash-dotted magenta line), the aggregate number of suppliers (i.e., solid green line with circles), and real output (i.e., solid black line). Panel (b) shows the growth rate of the aggregate number of suppliers (i.e., solid green line with circles), the aggregate rates of adoption (i.e., solid red line with circles) and termination (i.e., dash-dotted blue line), and the growth rate of real output (i.e., solid black line). The aggregate index of the number of suppliers is the weighted average of the number of suppliers across all producers, with the costs of goods sold by each producer as the weight. The growth rates of the aggregate real intermediate inputs and the real output are the growth rates of the BEA chain-type quantity indices of intermediate inputs and gross output of private industries, respectively. Aggregate number of suppliers is the aggregate index of the number of suppliers. Aggregate rate of adoption ($s_{N,t}$) and Aggregate rate of termination ($s_{T,t}$) are the weighted averages of $s_{i,N,t}$ and $s_{i,T,t}$ across all producers, respectively, with the costs of goods sold of each producer as the weight. Real output growth is demeaned. Shaded areas indicate NBER-defined recession years. We restrict our sample to producers whose maximum numbers of suppliers over time exceed one.

Figure 2: Termination rate vis-à-vis sales and productivity for producers with different numbers of suppliers



(a) Termination rate vis-à-vis sales

(b) Labor productivity

Notes: The bin scatter plot in Panel (a) shows the (log) number of suppliers (x-axis) against the correlation between the termination rate and the (log) real sales (y-axis) for the producers in our sample. Producers are divided into 50 bins according to their (log) number of suppliers. For the y-axis, we first compute the correlation between the rate of termination and (log) real sales over years for each producer, then average this correlation across producers within the same bin. Similarly, for the x-axis, we first compute the average number of suppliers over years for each producer, then average it across producers within the same bin. The solid red line is a linear fit of the correlation (between the termination rate and the log sales) on the (log) number of suppliers. Our sample excludes producers with no more than ten observation years for both the termination rate and the log sales for the calculation of their correlation. The bin scatter plot in Panel (b) shows the (log) labor productivity (x-axis) against the (log) number of suppliers (y-axis) for the producers in our sample. We use Compustat “Sales/Turnover,” deflated by the GDP deflator, as the producer’s real sales. The labor productivity is computed as the ratio of real sales to employment. Producers are divided into 50 bins according to their (log) labor productivity, and each dot represents a bin. For the y-axis, we first compute the average number of suppliers over years for each producer, then average it across producers within the same bin. Similarly, for the x-axis, we first compute the average labor productivity over years for each producer, then average it across producers within the same bin. The solid red line is a linear fit of the log number of suppliers on the log labor productivity.

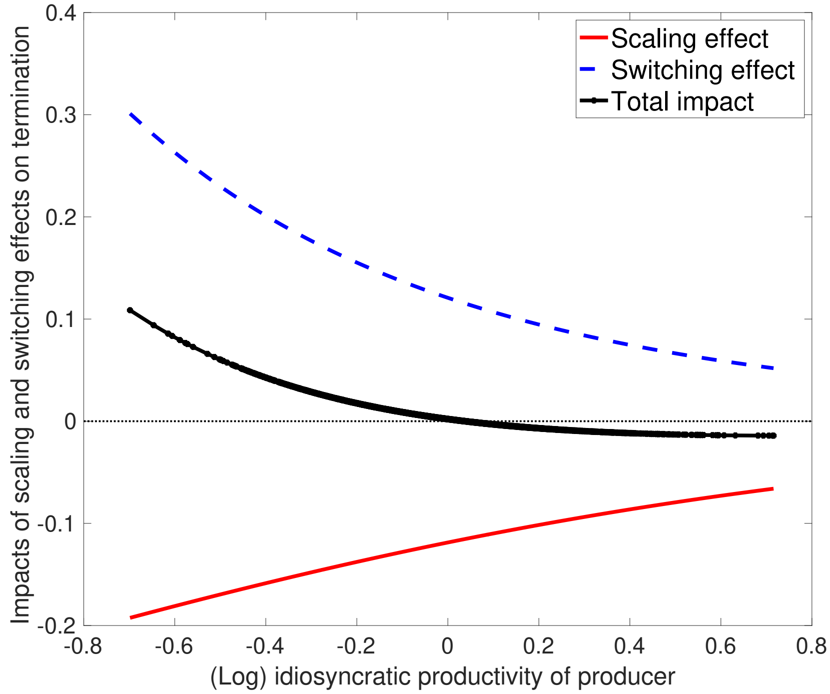
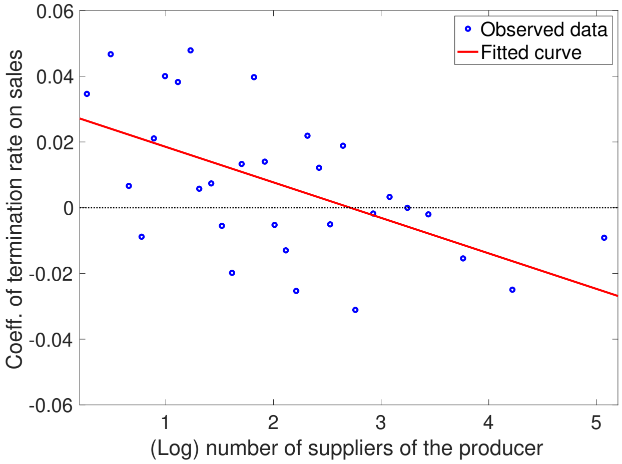


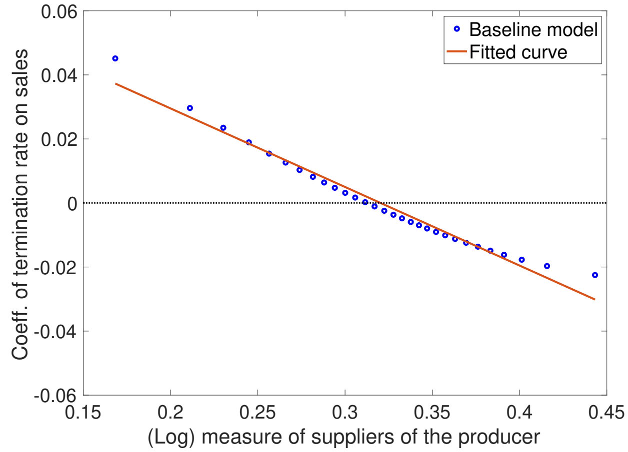
Figure 3: Impacts of scaling and switching effects on termination as functions of a_i

Notes: The figure plots the impacts of scaling (solid red curve) and the switching (dashed blue curve) effects on the response of termination rate to changes in aggregate TFP as functions of the (log) idiosyncratic productivity of the producer, respectively. The solid black curve with circles is the total impact of the two effects.

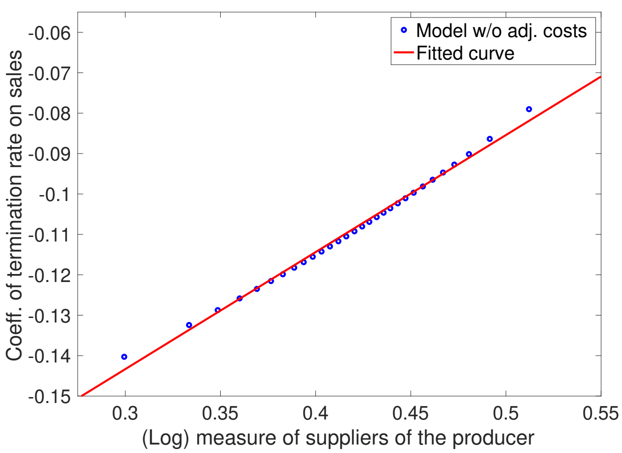
Figure 4: Coefficient of regressing the rate of termination on sales: Data vs. baseline vs. counterfactual models



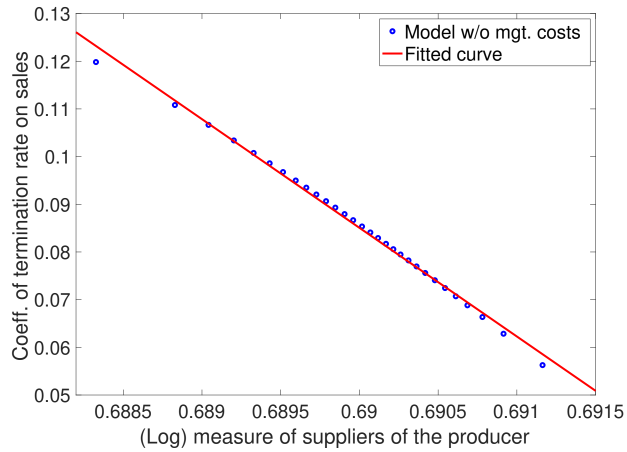
(a) Data



(b) Baseline model



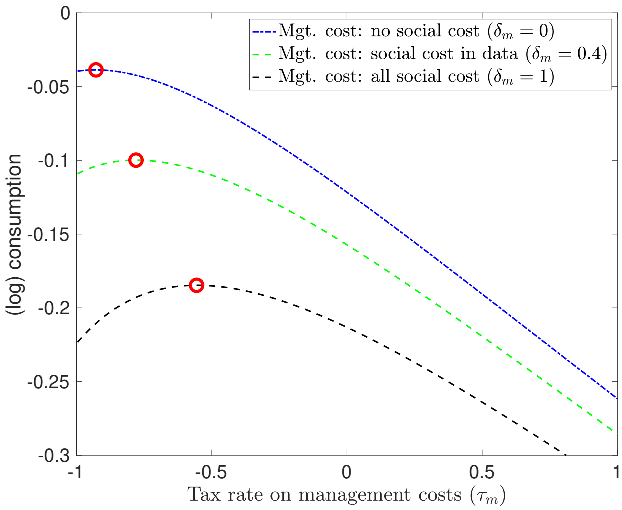
(c) Counterfactual model without adjustment costs



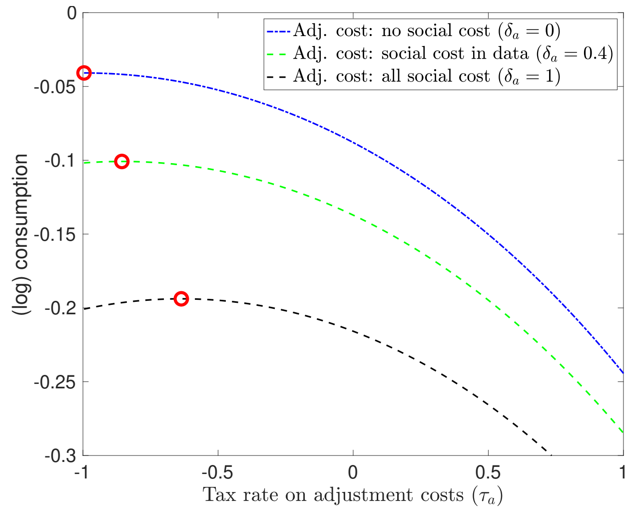
(d) Counterfactual model without management costs

Note: Panels (a), (b), (c), and (d) plot the coefficients of regressing the termination rate on (log) sales for different producer groups using the observed data (Panel a), the simulated data from the baseline model (Panel b), the simulated data from the counterfactual model with zero adjustment costs (Panel c), and the simulated data from the counterfactual model with zero management costs (Panel d), respectively. In Panel (a) (vs. Panels b, c, and d), we group the 900 (9,000) observed (simulated) producers by the number (measure) of suppliers and then divide them into 30 groups of equal size. Within each group, we run panel regressions of the termination rate on log sales, controlling for the producer fixed effect. For the x-axis, we compute the average number (measure) of suppliers across years (economies) for each producer, which is then averaged across the producers within each group. In Panel (a), our data sample excludes producers with no more than ten observation years for both the termination rate and the log sales for the panel regression.

Figure 5: Consumption under different tax rates and social costs



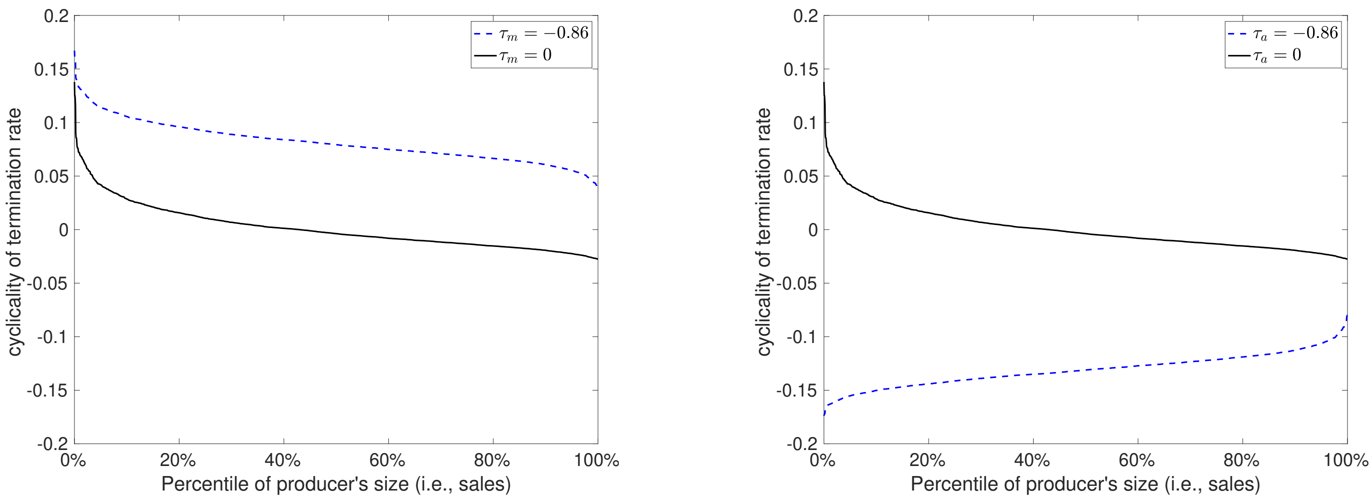
(a) Subsizing management costs



(b) Subsizing adjustment costs

Notes: Panels (a) and (b) show the (log) aggregate consumption under different rates of tax on management and adjustment costs, respectively. A negative tax rate means subsidies. In Panel a (vs. Panel b), the dashed black curve, the dashed green curve, and the dash-dotted blue curve plot the log consumption where all of, 40% of (i.e., baseline level), and none of the management (vs. adjustment) costs are social costs, respectively. In particular, Panel (a) assumes that 40% of adjustment costs are social costs with the optimal subsidies on adjustment costs, and Panel (b) assumes 40% of management costs are social costs with the optimal subsidies on management costs. The red circles indicate the optimal rates of tax (or subsidy) to maximize welfare under different levels of social costs.

Figure 6: Cyclicality of termination under different subsidies to management and adjustment costs



(a) Subsidizing management costs

(b) Subsidizing adjustment costs

Notes: Panels (a) and (b) show the semi-elasticity of the rate of termination to aggregate TFP shocks under different levels of subsidies to management and adjustment costs, respectively. The dashed blue curve and the solid black curve in Panel a (vs. Panel b) correspond to optimal level of 86% subsidy and zero subsidy on the management (vs. adjustment) costs, respectively. The rates of subsidies on adjustment and management costs in Panels (a) and (b) are set to zero, respectively.

Table 1: Calibration of the model

Parameter	Value	Target moment
α	0.36	The ratio of producers' surplus to intermediate input costs.
ξ	0.081	Steady-state share of management costs (Gopinath and Neiman, 2014).
$c^{+}(c^{-})$	0.076	Steady-state share of adjustment costs in operating costs (Caballero and Hammour, 1994).
σ_a	0.2	Middle estimate between Syverson (2004) and Fostera et al. (2015).
σ_A	0.024	The standard deviation of the HP-filtered log real gross output.

Notes: α is the bargaining share of the producer, ξ is the management cost parameter, c^{+} (c^{-}) is the cost of adoption (termination), and σ_a and σ_A are the standard deviations of $log(a_i)$ and $log(A)$, respectively.

Table 2: Sales, profits, and the average age of relationships

	(a)	(b)
VARIABLES	Sales	Profits
Number of suppliers	0.085***	0.027
	(0.016)	(0.018)
Relationship age	-0.048**	-0.069**
	(0.024)	(0.028)
Producer age	0.401***	0.174
	(0.105)	(0.135)
Observations	18,227	16,077
Number of producers	2,607	2,364
Producer fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
R^2	0.250	0.0802

Notes: Data are annual. Sales, Profits, and Number of suppliers are the log of the producer's real sales, real earnings before interest, taxes, depreciation, and amortization (EBITDA), and its total number of suppliers, respectively. Relationship age is the log of the average age of producer i's producer-supplier relationships in year t. Producer age is the log age of producer i in year t since the establishment of the producer. Producer and year fixed effects are controlled. We restrict our sample to producers whose maximum numbers of suppliers exceed one over time and the adoption rate is below one. Standard errors are clustered at the producer level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Online Appendix

The Adoption and Termination of Suppliers over the Business Cycle

(Le Xu, Yang Yu, and Francesco Zanetti)

Appendix A. Data

Our data combine two datasets: the FactSet Revere Supply Chain Relationships data that allows tracking the adoption and termination of suppliers, and the Compustat Fundamentals data that provides the financial statement variables and administrative costs of each producer.

The FactSet Revere Supply Chain Relationships data consists of 784,325 producer-supplier relationship records between 152,119 producers and 95,932 suppliers from 2003 to 2021. Each record includes the start and end dates of the relationship. The database systematically collects producer-supplier relationship information from public sources such as SEC 10-K annual filings, investor presentations, and press releases reported by either the producer or the supplier. Compared to the commonly used Compustat Customer Segment database (e.g., the dataset used by Lim, 2018)—which only includes major customers who contribute to more than 10% of a supplier's revenue—FactSet Revere provides a much less truncated set of suppliers.[16] The broader coverage results in more accurate measures of producer-supplier relationships, the number of suppliers, and their adoption and termination. As a result, FactSet Revere captures many supply-chain linkages that would be otherwise missing if the Compustat data were used instead.

To measure the extensive margin, we use the starting and ending years of each producer-supplier relationship. Based on this information, we calculate the total number of suppliers of producer i in year t and denote it by $v_{i,t}$. We also calculate the number of suppliers adopted and terminated by the producer i in year t and denote them by $v_{i,N,t}$ and $v_{i,T,t}$, respectively, which we employ to construct the rates of adoption and termination.

Then, we further merge the FactSet data with Compustat data using the first six digits of the producer's CUSIP numbers, which uniquely identify a company. With the above merger, we obtain a sample of 3,609 producers with 28,461 producer-year observations spanning from 2003 to 2021, covering 78,193 producer-supplier relationships.

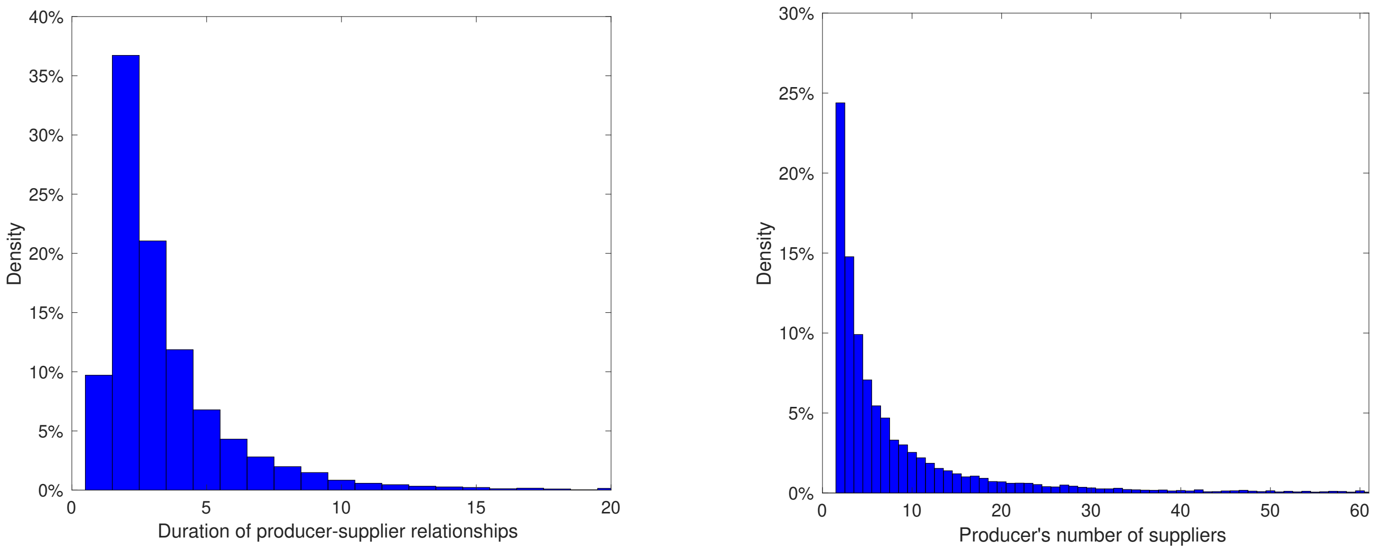
Summary statistics of the supply-chain relationship data.

Table A.3: Summary statistics of the rates of adoption and termination

VARIABLES	Mean	Standard deviation	Median	Min	Max
Rate of adoption ($s_{i,N,t}$)	0.287	0.449	0.053	0	2
Rate of termination ($s_{i,T,t}$)	0.144	0.203	0	0	0.75

Notes: Rate of adoption ($s_{i,N,t}$) and Rate of termination ($s_{i,T,t}$) are the numbers of new and existing suppliers adopted and terminated by producer i in year t divided by its total number of suppliers in year $t-1$, respectively. The top and bottom 2.5% of the samples for each rate are winsorized.

Figure A.7: Distributions of producer-supplier relationship durations and the number of suppliers



(a) Distribution of duration of relationships

(b) Distribution of the number of suppliers

Notes: Panels (a) and (b) show the distribution of the duration of producer-supplier relationships and the distribution of the producer's number of suppliers, respectively. The height of each bar equals the percentage of samples within the bin in all samples.

Derivation of number of suppliers and rates of adoption and termination. We describe how we derive the number of suppliers and the rates of adoption and termination at both the producer and the aggregate levels.

To compute the aggregate series, we need the share of each producer's intermediate input expenditure in the total intermediate input expenditure of all producers. We denote the share of producer i's intermediate input expenditure in the total intermediate input expenditure as $COGS\_share_{i,t}$, which is computed as

$$COGS\_share_{i,t} = \frac{cogs_{i,t}}{\sum_{i'} cogs_{i',t}},$$

where $cogs_{i,t}$ is the *cost of goods sold* (COGS) of producer i documented in Compustat.[17]

With the producers' intermediate input shares defined above, we define the aggregate growth rate of the number of suppliers as

$$\frac{\Delta v_t}{v_{t-1}} \equiv \sum_i \left(COGS\_share_{i,t} \cdot \frac{\Delta v_{i,t}}{v_{i,t-1}} \right). \tag{A.1}$$

[16]Publicly-traded companies are required to report their major customers in accordance with Financial Accounting Standards No. 131, which is the source of Compustat Customer Segments.

[17]COGS in Compustat is a commonly used measure of the variable cost. According to the Compustat data manual, it "represents all expenses that are directly related to the cost of merchandise purchased or the cost of goods manufactured that are withdrawn from finished goods inventory and sold to customers."

The producer-level decomposition of the growth rate of the number of suppliers is

$$\frac{\Delta v_{i,t}}{v_{i,t-1}} = s_{i,N,t} - s_{i,T,t},$$

where $s_{i,N,t} \equiv v_{i,N,t}/v_{i,t-1}$ and $s_{i,T,t} \equiv v_{i,T,t}/v_{i,t-1}$ are the producer-level rates of adoption and termination, which are defined as the numbers of new suppliers adopted and existing suppliers terminated by producer i in year t divided by the producer's total number of suppliers in year $t-1$, respectively. Similar to the aggregation of the number of suppliers in equation (A.1), we use the weighted averages of adoption and termination rates as the aggregate rates of adoption and termination, i.e.,

$$\text{aggregate rate of adoption}: \quad s_{N,t} \equiv \sum_i \Big(COGS\_share_{i,t} \cdot s_{i,N,t} \Big),$$
$$\text{aggregate rate of termination}: \quad s_{T,t} \equiv \sum_i \Big(COGS\_share_{i,t} \cdot s_{i,T,t} \Big).$$

It follows that the growth rate of the aggregate number of suppliers can be decomposed into the aggregate rates of adoption and termination:

$$\frac{\Delta v_t}{v_{t-1}} = s_{N,t} - s_{T,t}. \tag{A.2}$$

Based on equation (A.2), we compute the variation of the growth rate of the aggregate number of suppliers as

$$Var\big(\frac{\Delta v_t}{v_{t-1}}\big) = Cov\big(\frac{\Delta v_t}{v_{t-1}}, s_{N,t} - s_{T,t}\big) = Cov\big(\frac{\Delta v_t}{v_{t-1}}, s_{N,t}\big) + Cov\big(\frac{\Delta v_t}{v_{t-1}}, -s_{T,t}\big),$$

which indicates the following equation showing the percentage contributions of the aggregate rates of adoption and termination to the growth rate of the aggregate number of suppliers

$$\frac{Cov\big(\frac{\Delta v_t}{v_{t-1}}, s_{N,t}\big)}{Var\big(\frac{\Delta v_t}{v_{t-1}}\big)} + \frac{Cov\big(\frac{\Delta v_t}{v_{t-1}}, -s_{T,t}\big)}{Var\big(\frac{\Delta v_t}{v_{t-1}}\big)} = 1,$$

where the first and second terms are the contributions of the aggregate rates of adoption and termination, respectively.

Appendix B. Positive returns from more relationships

We study the relationship between market returns and the total number of suppliers using the following regression:

$$y_{i,t} = \beta \ln(v_{i,t}) + \alpha_i + \gamma_t + \epsilon_{i,t},$$

where $y_{i,t} \in \{\ln(q_{i,t}),\ \ln(\pi_{i,t})\}$ and $q_{i,t}$ and $\pi_{i,t}$ are the real sales and the real "earnings before interest, taxes, depreciation, and amortization" (EBITDA) for producer i, respectively. α_i and γ_t are producer and year fixed effects.

Table B.4: Number of suppliers is positively correlated with sales and profits

	(a)	(b)
VARIABLES	*Sales*	*Profits*
Number of suppliers	0.093***	0.041***
	(0.014)	(0.015)
Observations	22,994	20,110
Number of producers	2,751	2,493
Producer fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
R^2	0.214	0.078

Notes: Sales, Profits, and Number of suppliers are the log of the producer's real sales, real earnings before interest, taxes, depreciation, and amortization (EBITDA), and its total number of suppliers, respectively. Data are annual and at the producer level. We restrict our sample to producers whose maximum numbers of suppliers over time exceed one. Producer and year fixed effects are controlled. Standard errors are clustered at the producer level. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

As shown in column (a) of Table B.4, the real sales of the producer is positively correlated with the number of suppliers, and a 1% increase in the number of suppliers is associated with approximately a 0.1% increase in the real sales of the producer. Shown in column (b) are findings for the same regression for the profits of the producer. A 1% increase in the number of suppliers is associated with about a 0.04% rise in the real profits of the producer, consistent with the result in column (a). Note that we control for year fixed effects in the regressions. Therefore, the positive correlation between the sales and the number of suppliers indicates more of a positive return from more relationships than the procyclicality in the aggregate number of suppliers.

These findings concerning the positive returns of the producer from having more suppliers are consistent with the positive correlation between the producer's sales and the number of suppliers at the firm level documented in previous studies (e.g., Lim 2018 for the US, Bernard et al. 2019 for Japan, and Arkolakis et al. 2023 for Chile), which evinces *returns from more relationships*, corroborating the central tenet of the "returns from more varieties" in models of product varieties (see Ethier, 1982; Feenstra et al., 1999; Halpern et al., 2015; Gopinath and Neiman, 2014; Goldberg et al., 2010; Bilbiie et al., 2012; Hamano and Zanetti, 2017, 2022).[18] Notably, we complement and extend the result in Lim (2018) through using a comprehensive dataset of inter-firm relationships, the FactSet Revere, and verify a robust pattern of returns

[18] The return from more relationships is also important in models with producer-supplier relationships to generate amplification of TFP shocks á la Baqaee (2018). Xu (2021) documents a positive relationship between the number of suppliers and the TFP of the producer.

from having more suppliers for the US firms.

Appendix C. A brief literature review of switching costs

This section of the Appendix reviews literature on the switching cost and categorizes its various dimensions into adoption and termination costs. Switching costs are mainly incurred in two types of situations—when consumers/households switch suppliers or retailers and when producers switch suppliers/vendors. Our adoption and termination costs correspond to the switching costs in the second situation.[19]

Most theoretical work on switching costs builds on the switching costs for consumer/household purchasing. However, most of their analyses on the switching costs apply to our situation of producers switching suppliers as well. Among these works, Klemperer (1987, 1995) first provided a taxonomy of switching costs. He classified switching costs into the compatibility of equipment, transaction costs of switching suppliers, learning costs in the use of new brands, uncertainty about the quality of untested brands, loyalty costs for the issuance of discount coupons and similar marketing strategies to adopt producers, contractual costs, and psychological costs. Among these types of switching costs, compatibility of equipment, learning costs in the use of new brands, and uncertainty about the quality of untested brands are purely adoption costs; transaction, contractual, and psychological costs of switching suppliers involve both adoption and termination costs; and loyalty costs are purely termination costs. With the taxonomy of switching costs, Klemperer (1995) used a model to show that switching costs reduce competition and increase prices.

Compared to the theoretical work, empirical studies on switching costs are more recent. Scholars have examined the costs for producers to switch suppliers in an array of vendor industries, such as hardware, computer purchasing, chemical, insurance, and IT outsourcing, with IT outsourcing as the most studied industry. (Ping, 1993; Heide and Weiss, 1995; Nielson, 1996; Whitten and Wakefield, 2006; Whitten, 2010; Whitten et al., 2010; Barroso and Picón, 2012) The focus of their efforts was to identify various dimensions of switching costs. Most of the dimensions uncovered were similar to those in Klemperer (1987, 1995); however, some additional dimensions specific to the producer-supplier relationship environment were revealed. For example, Nielson (1996), Whitten and Wakefield (2006), Whitten (2010), and Whitten et al. (2010) explored the costs of hiring and retaining skilled workers during switching, which belong to the adoption costs. Whitten and Wakefield (2006), Whitten (2010), and Whitten et al. (2010) investigated the costs of upgrading the management system along vendor switching, which entail both adoption and termination costs. Whitten and Wakefield (2006) and Whitten (2010) explored the sunk costs attendant with vendor switching (i.e., the non-recoverable time/money/effort associated with the existing vendor). The sunk costs are psychological but greatly influence the switching decision. The sunk costs belong to termination costs.

Empiricism on switching costs has also documented the important role of the costs in vendor switching. Whitten and Wakefield (2006) found that switching costs prevented producers from switching from

[19] Whitten and Wakefield (2006) and Van Deventer (2016) provide comprehensive reviews on the research of switching costs.

unsatisfactory vendors. Whitten (2010) discerned that high switching costs promoted the continuation of producer-supplier relationships.

Insufficient data concerning the size of switching costs exists. However, Van Deventer (2016) collected recent examples of discontinued IT outsourcing contracts, which provided an approximate size of costs for switching vendors. The share of switching costs in the values of the organizations had a median of 6.6% and were as high as 15%.

Appendix D. Model timeline and proofs for propositions

Timeline of the model.

Figure D.8: Timeline

Notes: At the beginning of the period, the final goods producer is endowed with a continuum of existing suppliers. Then, it terminates a subset of the existing suppliers and adopts a subset of the new suppliers. Next, it bargains with each of its input suppliers on the price of the intermediate input that splits the surplus of each production line. At the end of the period, the producer manufactures the final output using the inputs from the selected new and existing suppliers.

Proofs for propositions.

Using equations (5) and (6), we have

$$\begin{aligned} 1 - \left(V_i^* - \bar{V}_i^* s_{i,N}^*\right) &= \frac{\xi V_i^* - c^-}{\alpha A a_i} \\ \iff \left(1 + \bar{V}_i^* s_{i,N}^*\right) &= V_i^* + \frac{\xi V_i^* - c^-}{\alpha A a_i}, \end{aligned} \tag{D.1}$$

and

$$\left(1 - \bar{V}_i^* s_{i,N}^*\right) = \frac{\xi V_i^* + c^+}{\alpha A a_i}. \tag{D.2}$$

Summing equations (5) and (6), we have

$$\begin{aligned} 2 &= V_i^* + \frac{2\xi V_i^* + c^+ - c^-}{\alpha A a_i} \\ \iff V_i^* &= \frac{2\alpha A a_i - c^+ + c^-}{\alpha A a_i + 2\xi}. \end{aligned}$$

Taking the difference between equations (D.1) and (D.2), we have

$$
\begin{aligned}
2\bar{V}_i^* s_{i,N}^* &= -\frac{c^- + c^+}{\alpha A a_i} + V_i^* \\
\Longrightarrow s_{i,N}^* &= \frac{1}{2}\left(\frac{V_i^*}{\bar{V}_i^*} - \frac{c^- + c^+}{\alpha A a_i \bar{V}_i^*}\right) < \frac{1}{2}\frac{V_i^*}{\bar{V}_i^*},
\end{aligned} \tag{D.3}
$$

and

$$
\begin{aligned}
s_{i,T}^* &= \left[\bar{V}_i^* - \left(V_i^* - \bar{V}_i^* s_{i,N}^*\right)\right] / \bar{V}_i^* \\
&= -\frac{1}{2}\left(\frac{V_i^*}{\bar{V}_i^*} + \frac{c^- + c^+}{\alpha A a_i \bar{V}_i^*}\right) + 1,
\end{aligned} \tag{D.4}
$$

and

$$
\begin{aligned}
s_{i,E}^* &= \frac{V_i^*}{\bar{V}_i^*} - \frac{1}{2}\left(\frac{V_i^*}{\bar{V}_i^*} - \frac{c^- + c^+}{\alpha A a_i \bar{V}_i^*}\right) \\
&= \frac{1}{2}\left(\frac{V_i^*}{\bar{V}_i^*} + \frac{c^- + c^+}{\alpha A a_i \bar{V}_i^*}\right).
\end{aligned} \tag{D.5}
$$

In equilibrium, the output of producer i satisfies:

$$
\begin{aligned}
Y_i^* =& a_i A \frac{\left(2 - \bar{V}_i^* s_{i,E}^*\right) \bar{V}_i^* s_{i,E}^* + \left(2 - \bar{V}_i^* s_{i,N}^*\right) \bar{V}_i^* s_{i,N}^*}{2} \\
\Longleftrightarrow lnY_i^* =& lna_i + lnA + ln\left[\frac{\left(2 - \bar{V}_i^* s_{i,N}^*\right) \bar{V}_i^* s_{i,N}^* + \left(2 - \bar{V}_i^* s_{i,E}^*\right) \bar{V}_i^* s_{i,E}^*}{2}\right] \\
=& lna_i + lnA + ln\left[\frac{\left(2 - \bar{V}_i^* s_{i,N}^*\right) \bar{V}_i^* s_{i,N}^* + \left(2 - V_i^* + \bar{V}_i^* s_{i,N}^*\right)\left(V_i^* - \bar{V}_i^* s_{i,N}^*\right)}{2}\right].
\end{aligned} \tag{D.6}
$$

Lemma 1

Proof. Taking the partial derivative of equation (D.6) wrt. lnV_i^*, we have

$$
\frac{\partial lnY_i^*}{\partial lnV_i^*} = \frac{Aa_i V_i^*}{Y_i^*} z_{i,E}^* > 0.
$$

□

Lemma 2

Proof. Taking the partial derivative of equation (D.6) wrt. $s_{i,N}^*$, we have

$$
\begin{aligned}
\frac{\partial lnY_i^*}{\partial s_{i,N}^*} =& \frac{\left(V_i^* - 2s_{i,N}^*\bar{V}_i^*\right)\bar{V}_i^*}{\frac{\left(2-\bar{V}_i^* s_{i,N}^*\right)\bar{V}_i^* s_{i,N}^* + \left(2-V_i^*+\bar{V}_i^* s_{i,N}^*\right)\left(V_i^*-\bar{V}_i^* s_{i,N}^*\right)}{2}} \\
=& \frac{a_i A V_i^*\left(1-2\frac{\bar{V}_i^* s_{i,N}^*}{V_i^*}\right)\bar{V}_i^*}{Y_i^*} \\
=& \frac{\left(c^- + c^+\right)}{\alpha Y_i^*/\bar{V}_i^*} > 0,
\end{aligned}
$$

where the last equality comes from equation (D.3).

□

Lemma 3

Proof. Combining equations (D.1) and (D.2), we have

$$
2 = V_i^* + \frac{\xi V_i^* - c^-}{\alpha A a_i} + \frac{\xi V_i^* + c^+}{\alpha A a_i}. \tag{D.7}
$$

Applying the implicit function theorem to equation (D.7), we have

$$
\begin{aligned}
\frac{dV_i^*}{dlnA} =& \frac{2\xi\bar{V}_i^* + \left(c^+ - c^-\right)}{2\xi + \alpha\bar{A}a_i} \\
=& \frac{\alpha\bar{A}a_i\left(z_{i,E}^* + z_{i,N}^*\right)}{2\xi + \alpha\bar{A}a_i} > 0.
\end{aligned}
$$

Therefore,

$$
\begin{aligned}
\frac{d\ln V_i^*}{d\ln A} &= \frac{2\widetilde{\xi}_i\bar{V}_i^* + \left(\widetilde{c}_i^+ - \widetilde{c}_i^-\right)}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)\bar{V}_i^*} \\
&= \frac{2\alpha\bar{A}/\bar{V}_i^* - \alpha\bar{A}}{2\widetilde{\xi}_i + \alpha\bar{A}}.
\end{aligned} \tag{D.8}
$$

When $c^+ = c^-$,

$$
\frac{d\ln V_i^*}{d\ln A} = \frac{2\widetilde{\xi}_i}{2\widetilde{\xi}_i + \alpha\bar{A}}. \tag{D.9}
$$

□

Lemma 4

Proof. Taking the partial derivatives of equations (D.3) and (D.4) wrt. $\ln A$, we have

$$
\frac{\partial s_{i,N}^*}{\partial\ln A} = \frac{\partial s_{i,T}^*}{\partial\ln A} = \frac{\widetilde{c}_i}{2\alpha\bar{A}\bar{V}_i^*} > 0. \tag{D.10}
$$

□

Proposition 1

Proof. Taking the total derivative of equation (D.4) wrt. $\ln A$, we have

$$\frac{ds^*_{i,T}}{d\ln A} = \underbrace{-\frac{1}{2}\frac{d\ln V^*_i}{d\ln A}}_{\text{Scaling effect} < 0} + \underbrace{\frac{\widetilde{c}_i}{2\alpha\bar{A}\bar{V}^*_i}}_{\text{Switching effect} > 0}$$
$$= -\frac{1}{2}\frac{2\alpha\bar{A}/\bar{V}^*_i - \alpha\bar{A}}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)} + \frac{\widetilde{c}_i/\bar{V}^*_i}{2\alpha\bar{A}}.$$

Therefore,

$$\frac{\partial\left(\frac{ds^*_{i,T}}{d\ln A}\right)}{\partial a_i} = \frac{1}{2}\frac{2\left(2\alpha\bar{A}/\bar{V}^*_i - \alpha\bar{A}\right)}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)^2}\left(-\frac{\widetilde{\xi}_i}{a_i}\right) - \frac{\widetilde{c}_i}{2a_i\alpha\bar{A}\bar{V}^*_i}$$
$$-\frac{1}{2}\left[\frac{\widetilde{c}_i}{\alpha\bar{A}} - \frac{2\alpha\bar{A}}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)}\right]\frac{1}{\left(\bar{V}^*_i\right)^2}\frac{\partial\bar{V}^*_i}{\partial a_i}$$
$$= -\frac{1}{2a_i}\left[\frac{2\left(2\widetilde{\xi}_i + \left(\widetilde{c}^+_i - \widetilde{c}^-_i\right)/\bar{V}^*_i\right)\widetilde{\xi}_i}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)^2} + \frac{\widetilde{c}_i}{\alpha\bar{A}\bar{V}^*_i}\right]$$
$$-\frac{1}{2a_i}\left[\frac{\widetilde{c}_i}{\alpha\bar{A}} - \frac{2\alpha\bar{A}}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)}\right]\frac{1}{\left(\bar{V}^*_i\right)^2}\frac{\partial\bar{V}^*_i}{\partial a_i},$$

where the first term is always negative while the second term is negative for small a_i and positive for large a_i. Note that applying the implicit function theorem to equation (D.7) in the steady state, we have

$$\frac{\partial\bar{V}^*_i}{\partial a_i} = \frac{2\xi\bar{V}^*_i + \left(c^+ - c^-\right)}{a_i\left(2\xi + \alpha\bar{A}a_i\right)}$$
$$= \frac{\alpha\bar{A}\left(z^*_{i,E} + z^*_{i,N}\right)}{2\xi + \alpha\bar{A}a_i} > 0.$$

Thus, when a_i increases from zero, $ds^*_{i,T}/d\ln A$ first declines and then increases.

Note that

$$\frac{ds^*_{i,T}}{d\ln A} = -\frac{1}{2}\frac{2\alpha\bar{A}/\bar{V}^*_i - \alpha\bar{A}}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)} + \frac{\widetilde{c}_i/\bar{V}^*_i}{2\alpha\bar{A}}$$
$$= \frac{1}{2\bar{V}^*_i}\left(\frac{\widetilde{c}_i}{\alpha\bar{A}} - \frac{2\alpha\bar{A}}{2\widetilde{\xi}_i + \alpha\bar{A}}\right) + \frac{1}{2}\frac{\alpha\bar{A}}{\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)}.$$

Assume both ξ and $c^+ + c^-$ are sufficiently large. When a_i approaches zero, $2\alpha\bar{A}/\left(2\widetilde{\xi}_i + \alpha\bar{A}\right)$ goes to zero and $\widetilde{c}_i/\left(\alpha\bar{A}\right)$ becomes extremely positive. Therefore, $ds^*_{i,T}/d\ln A$ is positive. When a_i approaches positive infinite, $\widetilde{\xi}_i$ and $\widetilde{c}_i$ both go to zero, and

$$\frac{ds^*_{i,T}}{d\ln A} = -\frac{2}{2\bar{V}^*_i} + \frac{1}{2} = -\frac{2-\bar{V}^*_i}{2\bar{V}^*_i} < 0.$$

Given that $ds^*_{i,T}/d\ln A$ is continuous in a_i, $ds^*_{i,T}/d\ln A$ is positive when a_i is small, and negative when a_i is large. In other words, the rate of termination is countercyclical for producers with high idiosyncratic productivity, but procyclical for producers with low idiosyncratic productivity.

When $c^- = c^+ = 0$, we have

$$\frac{ds^*_{i,N}}{d\ln A} = \frac{1}{2}\frac{d\ln V^*_i}{d\ln A} > 0,$$
$$\frac{ds^*_{i,T}}{d\ln A} = -\frac{1}{2}\frac{d\ln V^*_i}{d\ln A} < 0,$$

i.e., procyclical adoption and countercyclical termination (i.e., Schumpeterian cleansing) for all producers.

□

Proposition 2

Proof. Immediately following Lemma 3, we have

$$\frac{dV^*}{d\ln A} = \sum_i \frac{dV^*_i}{d\ln A}\frac{\bar{Y}^*_i}{\bar{Y}^*} > 0.$$

□

Proposition 3

Proof.

$$\frac{ds^*_{i,N}}{d\ln A} = \frac{1}{2}\frac{d\ln V^*_i}{d\ln A} + \frac{1}{2}\frac{\widetilde{c}_i}{\alpha\bar{A}\bar{V}^*_i} > 0.$$

Therefore,

$$\frac{ds^*_N}{d\ln A} = \sum_i \frac{ds^*_{i,N}}{d\ln A}\frac{\bar{Y}^*_i}{\bar{Y}^*} > 0.$$

□

Proposition 4

Proof. Following the primal approach to the Ramsey problem in Lucas Jr and Stokey (1983), the solution to the Ramsey problem of the benevolent government in equation (22) is equivalent to finding the *Ramsey* allocation that maximizes the aggregate consumption subject to the resource constraints (3) and (16), and the first-order conditions by the producers (20) and (21). Compared to the social planner's problem in equation (17), the Ramsey problem is subject to two more constraints—first-order conditions by the producers(20) and (21). Therefore, the *Ramsey* allocation is weakly dominated by the efficient allocation (i.e., the solution to the social planner's problem), and the maximum welfare of the Ramsey problem *cannot* exceed the maximum welfare that can be obtained by the social planner.

Now, we show that the optimal subsidies can achieve the efficient allocation. When the rates of subsidies on management and adjustment costs are $\tau_m = \alpha\delta_m - 1$ and $\tau_a = \alpha\delta_a - 1$, the first-order conditions of the private producers are exactly the same as those of the social planner (i.e., equations (20) and (21) are exactly the same as equations (18) and (19)), which, therefore, lead to the exactly same solution. As a result, under the subsidies $\tau_m = \alpha\delta_m - 1$ and $\tau_a = \alpha\delta_a - 1$, the allocation of the measures of total and new suppliers in the competitive equilibrium coincides with the efficient allocation that solves the social planner's problem. Thus, the above subsidies, through achieving the efficient allocation, are optimal subsidies because they achieve the maximum welfare that can be obtained by the benevolent government in the Ramsey problem in equation (22). And the *Ramsey allocation* under these optimal subsidies are exactly the efficient allocation. □

Appendix E. Extended model with flexible convexity in management and adjustment costs

Appendix E.1. Flexible combination of convexity in management and adjustment costs

We extend our model to allow for flexible combinations of the degree of convexity in the management and adjustment costs (i.e., flexible combinations that nest linear and quadratic specifications for those costs). The management cost becomes

$$G\left(z_{i,N}, z_{i,E}\right) = \xi_0 V_i + \xi_1 \cdot V_i^2/2, \tag{E.1}$$

where parameter ξ_0 governs the size of the linear component and ξ_1 governs the size of the quadratic (i.e., strictly convex) component. The share of the quadratic component in the entire management cost, denoted by $\hat{\xi}_1 \equiv \xi_1/(\xi_0 + \xi_1)$, captures the degree of convexity in the management cost function.

We allow for similar flexible combinations in the degree of convexity in adjustment costs. Particularly, we assume symmetric functions of the adoption and termination costs, which are written as

$$c^{+}\left(V_{i,N}\right) * V_{i,N} = c_0 V_{i,N} + c_1 V_{i,N}^2/2, \tag{E.2}$$

$$c^{-}\left(V_{i,T}\right) * V_{i,T} = c_0 V_{i,T} + c_1 V_{i,T}^2/2, \tag{E.3}$$

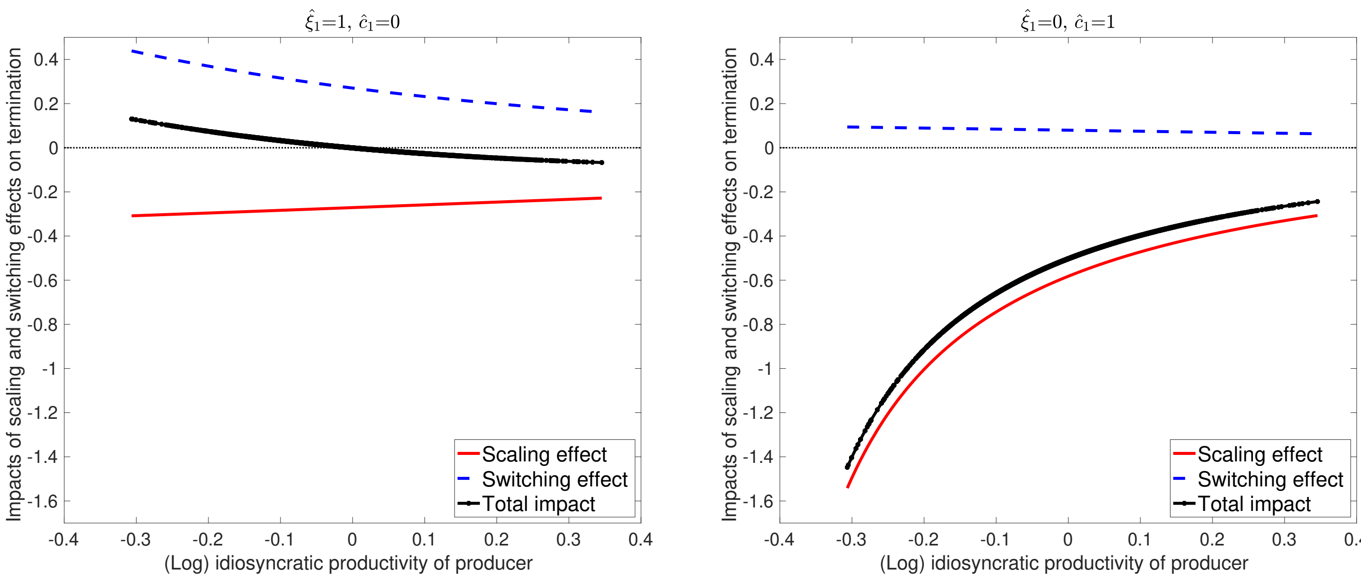
where $V_{i,N} \equiv \bar{V}_i^* s_{i,N} = 1 - z_{i,N}$ and $V_{i,T} \equiv \bar{V}_i^* s_{i,T} = z_{i,E} - 1 + \bar{V}_i^*$ are the measures of adopted new suppliers and terminated existing suppliers, respectively. Parameter c_0 governs the size of the linear component, and c_1 governs the size of the quadratic (i.e., strictly convex) component. The share of the quadratic component in the entire adoption (vs. termination) cost, denoted by $\hat{c}_1 \equiv c_1/(c_0 + c_1)$, captures the degree of convexity in the adoption (vs. termination) cost function.

In our baseline model of Sections 4 and 5, we have $\hat{\xi}_1 = 1$ and $\hat{c}_1 = 0$ such that the management cost is quadratic and the adoption and termination costs are linear (i.e., $G(z_{i,N}, z_{i,E}) = \xi_1 \cdot V_i^2/2$ and $c^+(V_{i,N}) = c^-(V_{i,T}) = c_0$).

Appendix E.2. Convexity of costs and cross-sectional scaling and switching effects for the termination rate

In this section, we experiment with different degrees of convexity in the management and adjustment costs. We fix $\xi_0 + \xi_1$ and $c_0 + c_1$ to the baseline values that are consistent with the acyclical aggregate termination rate. Then, we change the degree of convexity of the management cost by varying the share of the quadratic component in the management cost (i.e., $\hat{\xi}_1$). Similarly, we change the degree of convexity of the adjustment cost by varying the share of the quadratic component in the adoption and termination costs (i.e., $\hat{c}_1$).

Figure E.9: Convexity in management and adjustment costs and the scaling and switching effects



(a) Baseline model

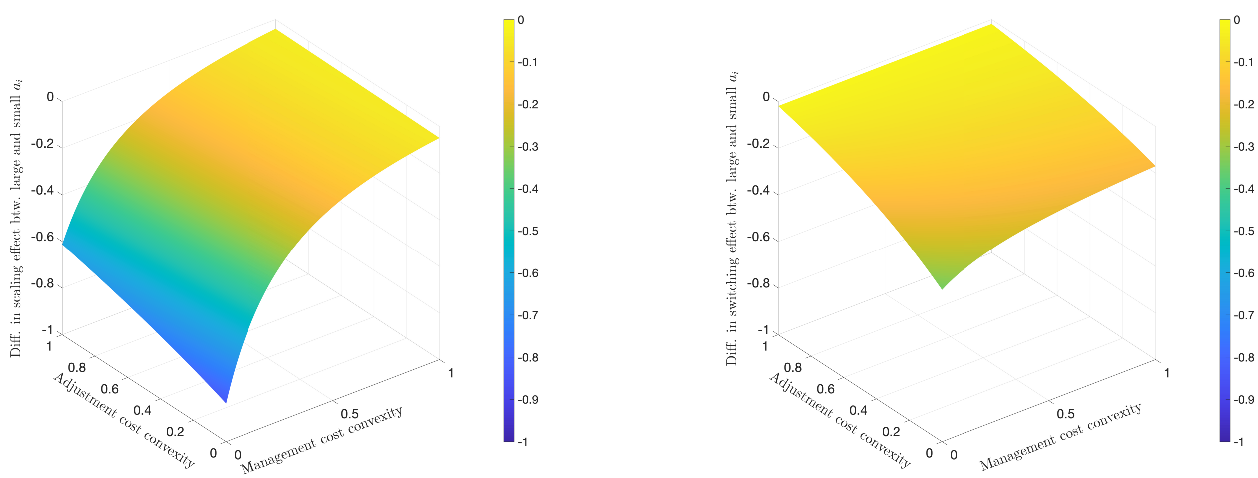
(b) Counterfactual model

Notes: The figure plots the impacts of scaling (solid red curve) and the switching (dashed blue curve) effects on the response of termination rate to changes in aggregate TFP as functions of the (log) idiosyncratic productivity of the producer, respectively. The solid black curve with circles is the total impact of the two effects, which indicates the (pro)cyclicality of the rate of termination. Panel (a) is the baseline model with quadratic management cost and linear adjustment costs (i.e., $\hat{\xi}_1 = 1$ and $\hat{c}_1 = 0$), and Panel (b) is the counterfactual model with linear management cost and quadratic adjustment costs (i.e., $\hat{\xi}_1 = 0$ and $\hat{c}_1 = 1$).

Panel (a) of Figure E.9 shows our baseline model that has quadratic management costs (i.e., $\hat{\xi}_1 = 1$) and linear adoption and termination costs (i.e., $\hat{c}_1 = 0$). In the baseline model, the switching effect significantly declines with the idiosyncratic productivity of the producer, while the size (i.e., the absolute value) of the scaling effect is insensitive to the idiosyncratic productivity. Thus, the total impact (i.e., the procyclicality of termination)—which equals the sum of the switching effect and the negative scaling effect, as shown in equation (11)—decreases with the producer's idiosyncratic productivity, generating countercyclical termination for large producers and procyclical termination for small producers that are consistent with Figure 2a of Fact 3.

Panel (b) of Figure E.9 shows the counterfactual specification of the model where the management cost is linear as in the network literature (i.e., $\hat{\xi}_1 = 0$ and therefore less convex than in the baseline model, e.g., Lim, 2018; Huneeus, 2018), and the adjustment cost is quadratic as in the labor literature (i.e., $\hat{c}_1 = 1$ and more convex than in the baseline model, e.g., Caballero and Hammour, 1994; Bloom, 2009; Zanetti, 2008). In this counterfactual specification of the model, the switching effect hardly changes with the idiosyncratic productivity of the producer, while the size (i.e., the absolute value) of the scaling effect significantly diminishes with the idiosyncratic productivity. Thus, the total impact (i.e., the procyclicality of termination)—which equals the sum of the switching effect and the negative scaling effect, as shown in equation (11)—is negative for all producers and increases with the producer's idiosyncratic productivity, generating countercyclical termination for small producers as well as *less* countercyclical termination for large producers, against the empirical results in Figure 2a of Fact 3.

Figure E.10: Diff. in the size of scaling/switching effect btw. large and small producers vis-à-vis convexity of costs



(a) Diff. in the size of scaling effect

(b) Diff. in the size of switching effect

Notes: Panel (a) plots the difference in the size (i.e., the absolute value) of the scaling effect (for the termination rate) between the two producers with (log) idiosyncratic productivity equal to 0.2 and -0.2 (vertical axis) *vis-à-vis* the convexity in the management and the adjustment costs (horizontal axes). The size of the scaling effect equals the minus of the scaling effect because the scaling effect is negative for the termination rate. Panel (b) plots the difference in the size of the switching effect (for the termination rate) between the two producers with (log) idiosyncratic productivity equal to 0.2 and -0.2 (vertical axis) *vis-à-vis* the convexity in the management and the adjustment costs (horizontal axes). The convexity in the management and adjustment costs are measured by $\hat{\xi}_1$ and $\hat{c}_1$, respectively.

Comparing Panels (a) and (b) in Figure E.9, we can conclude that the *sensitivity* of the scaling (vs. switching) effect to the producer's idiosyncratic productivity—defined as the *semi-elasticity* of the size (i.e., the absolute value) of the scaling (vs. switching) effect to a_i—declines with the degree of convexity of the management (vs. adjustment) costs. This pattern is verified by Figure E.10, where the difference in the size of the scaling (vs. switching) effect between the larger and the smaller producers—measuring the *sensitivity* of the scaling (vs. switching) effect to a_i—is plotted against broader combinations of the degree of convexity in management (vs. adjustment) costs.[20] Panel a (vs. Panel b) in Figure E.10 shows that the difference in the size of the scaling (vs. switching) effect between the larger and the smaller producers is always negative, evincing that the size of the scaling (vs. switching) effect diminishes with the idiosyncratic productivity of the producer, consistent with Lemmas 3 and 4, and Figure E.9. Moreover, for the scaling (vs. switching) effect, the difference (between large and small producers) is more negative when the management (vs. adjustment) cost is closer to linear and less convex, indicating that the sensitivity of the scaling (vs. switching) effect to a_i declines with the convexity of the management (vs. adjustment) cost, again consistent with Figure E.9.[21]

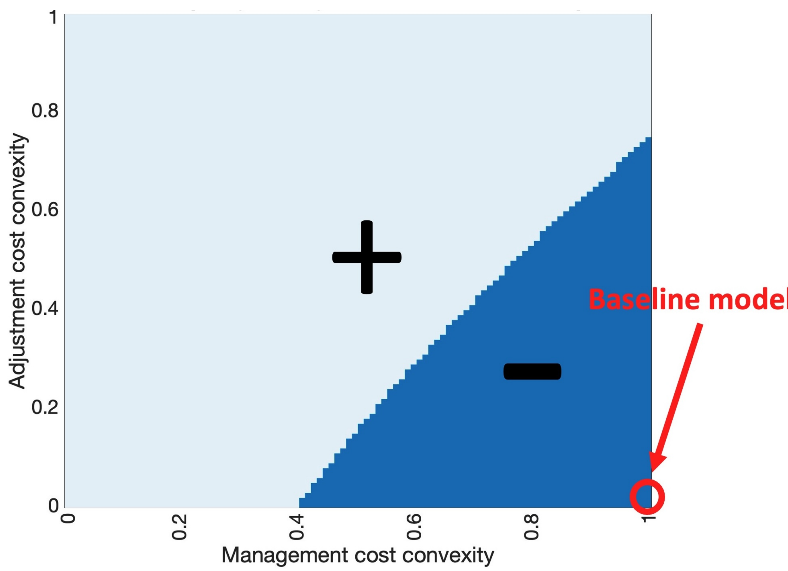


Figure E.11: Difference in (pro)cyclicality of termination btw. small and large producers *vis-à-vis* convexity of costs

Notes: The figure plots the difference in the total impacts of scaling and switching effects (for the termination rate) between a large and a small producer with (log) idiosyncratic productivity equal to 0.2 and -0.2 (measured by the darkness of color) *vis-à-vis* the convexity in the management (x-axis) and the adjustment costs (y-axis). The convexity in the management and adjustment costs are measured by $\hat{\xi}_1$ and $\hat{c}_1$, respectively. Our baseline model with quadratic (i.e., maximum degree of convexity) management and linear (i.e., minimum degree of convexity) adjustment costs is indicated by the red circle in the bottom right of the figure.

Similar to Figure E.10, Figure E.11 plots the difference in the procyclicality of termination between the larger and the smaller producers *against* various combinations of the degree of convexity in management and adjustment costs, where the procyclicality of termination is measured by the total impact of scaling and switching effects. The difference in the total impact between the large and small producers is indicated by the color, where the light (vs. dark) blue area indicates a more positive (vs. negative) total impact and,

[20]The larger and the smaller producers have log idiosyncratic productivity of 0.2 and -0.2, respectively.

[21]In Figure E.10, for the scaling (vs. switching) effect, the difference (between the larger and smaller producers) is also more negative when the adjustment (vs. management) cost is closer to linear and less convex. However, the sensitivity of the scaling (vs. switching) effect to a_i declines more with the convexity of the management (vs. adjustment) cost than with the convexity of the adjustment (vs. management) cost.

in turn, more procyclical (vs. countercyclical) rate of termination for the larger producer than the smaller producer. The convexity in the management (x-axis) and the adjustment costs (y-axis) are measured by $\hat{\xi}_1$ and $\hat{c}_1$, respectively. Our baseline model with quadratic (i.e., maximum degree of convexity) management and linear (i.e., minimum degree of convexity) adjustment costs is represented by the red circle in the bottom right of the figure.

Figure E.11 shows that when the management cost has a sufficiently large degree of convexity and the adjustment cost has a sufficiently small degree of convexity (i.e., sufficiently close to linear), the procyclicality of termination is more negative (i.e., more countercyclical termination) for the large producer than for the small producer, evinced by the dark-blue area towards the bottom right of the figure that includes the red circle representing the quadratic management cost and linear adjustment cost in our baseline model. As Figure E.10 shows, the large convexity in the management cost and the small convexity in the adjustment cost make the scaling effect insensitive to a_i and the switching effect more sensitive to a_i. Therefore, the switching effect dominates in the sensitivity of the cyclicality of termination to a_i, making the termination less procyclical (i.e., more countercyclical) for large producers than for small producers.[22]

In contrast, when the management cost becomes more linear (i.e., towards the left of Figure E.11), and/or adjustment cost becomes more convex (i.e., towards the top of Figure E.11), the switching effect is insensitive to a_i while the scaling effect is more sensitive to a_i. Therefore, the scaling effect dominates in the sensitivity of the cyclicality of termination to a_i, making the termination less countercyclical for large producers than for small producers.[23] This result is consistent with the counterfactual model in Panel (b) of Figure E.9 but contradicts Figure 2a of Fact 3.

To understand why the sensitivity of the scaling (vs. switching) effect to the idiosyncratic productivity declines with the convexity of the management (vs. adjustment) costs, we study equations (E.4) and (E.5). In these two equations, the sizes of the scaling and switching effects are functions of the convexity of the management and adjustment costs (i.e., $\hat{\xi}_1$ and $\hat{c}_1$), the size of the producer (i.e., $\bar{V}_i^*$), and other parameters.[24]

$$\text{Scaling effect} = -\frac{1}{2}\frac{d\ln V_i^*}{d\ln A} = -\frac{1}{2}\left[\left(\alpha\bar{A}a_i\right)^2/2 + \xi_1\alpha\bar{A}a_i + \left(\alpha\bar{A}a_i + \xi_1\right)c_1 + c_1^2/2\right]^{-1} \tag{E.4}$$
$$(\xi_0+\xi_1)\left[(1-\hat{\xi}_1) + \hat{\xi}_1\bar{V}_i^*\right]/\bar{V}_i^* * \left(\alpha\bar{A}a_i + c_1\right).$$
$$\text{Switching effect} = \frac{\left[(1-\hat{c}_1) + \hat{c}_1\bar{V}_i^*\bar{s}_{i,N}^*\right]/\bar{V}_i^*}{(\alpha\bar{A}a_i + c_1)(c_0+c_1)}. \tag{E.5}$$

Equations (E.4) and (E.5) show that sizes of the scaling effect (i.e., $\frac{1}{2}d\ln V_i^*/d\ln A$) and the switching effect are mainly affected by two opposite forces that are functions of the size of the producer: (1) the scaling (vs. switching) effect is positively correlated to the marginal management (vs. adjustment) cost

[22]Recall that the size of the switching effect diminishes with the size of the producer in Lemma 4, evinced by Figure E.9.

[23]Recall that the size of the scaling effect diminishes with the size of the producer in Lemma 3, evinced by Figure E.9.

[24]Recall that the producer's size in terms of total measure of suppliers (i.e., $\bar{V}_i^*$) increases with its idiosyncratic productivity, i.e., more (vs. less) productive producers correspond to larger (vs. smaller) producers.

(i.e., $\left[(1-\hat{\xi}_1)+\hat{\xi}_1\bar{V}_i^*\right]$ vs. $\left[(1-\hat{c}_1)+\hat{c}_1\bar{V}_i^*\bar{s}_{i,N}^*\right]$), which increases with the size of the producer $\bar{V}_i^*$ when the management (vs. adjustment) cost is strictly convex (i.e., $\hat{\xi}_1 > 0$ vs. $\hat{c}_1 > 0$); (2) the scaling (vs. switching) effect is inversely related to the steady-state measure of suppliers of the producer (i.e., $\bar{V}_i^*$) because the ratio of the management (vs. adjustment) cost to the profit—which determines the size of the scaling (vs. switching) effect—is smaller for larger producers with higher profits than for smaller producers. Consequently, the relationship between the scaling (vs. switching) effect and the idiosyncratic productivity (or size) of the producer and, in turn, the sensitivity of the scaling (vs. switching) effect to a_i, depends on the degree of convexity in the management (vs. adjustment) cost. When the management (vs. adjustment) cost is more convex, the marginal cost increases with $\bar{V}_i^*$ by a larger extent, making the ratio of the marginal cost (i.e., the first force) to the size of the producer (i.e., the second force) less variant to changes in the size of the producer and leading to a smaller sensitivity of the scaling (vs. switching) effect to a_i that is consistent with Panel a (vs. Panel b) in Figure E.10.

In our baseline model, the management cost is at the maximum convexity (i.e., quadratic with $\hat{\xi}_1 = 1$) and the adjustment cost is at the minimum convexity (i.e., linear with $\tilde{c}_0 = 0$). Therefore, the scaling effect is insensitive to the producer's idiosyncratic productivity, while the switching effect is significantly sensitive to the idiosyncratic productivity. The switching effect, which is positive and declines with a_i, dominates the changes in the total impacts to a_i and makes the termination rate more procyclical for small producers while more countercyclical for large producers, evinced by Panel (a) in Figure E.9.

Appendix F. Counterfactual analysis

In this appendix, we focus on the period of the Great Recession of 2008 and study the cyclicality of the termination rate at the aggregate level and across different producers in reaction to the imposition of optimal subsidies to management and adjustment costs.

To simulate the model for the Great Recession period, we compute the log aggregate TFP between 1997 and 2022 from the following equation:

$$log(A_t) = log(Y_t) - \alpha_X \cdot log(X_t) - \alpha_K \cdot log(K_t),$$

where Y_t, X_t, and K_t are the real gross output, intermediate inputs, and capital stock for private industries, respectively, constructed by the BEA. The intermediate inputs share, α_X, and capital share, α_K, are calibrated to 0.47 and 0.24, which are their average levels between 1997 and 2022 in the BEA data. We then detrend the obtained TFP series using an HP filter.

Figure F.12 shows the simulation of the benchmark model without subsidies by the government. It shows the (demeaned) aggregate rates of adoption (solid-blue curve) and termination (solid-red curve) for the period 2004-2020. Consistent with our empirical finding in Figure 1b, the aggregate rate of adoption is procyclical while the aggregate rate of termination is cyclical. Our stylized model shows a fall in the

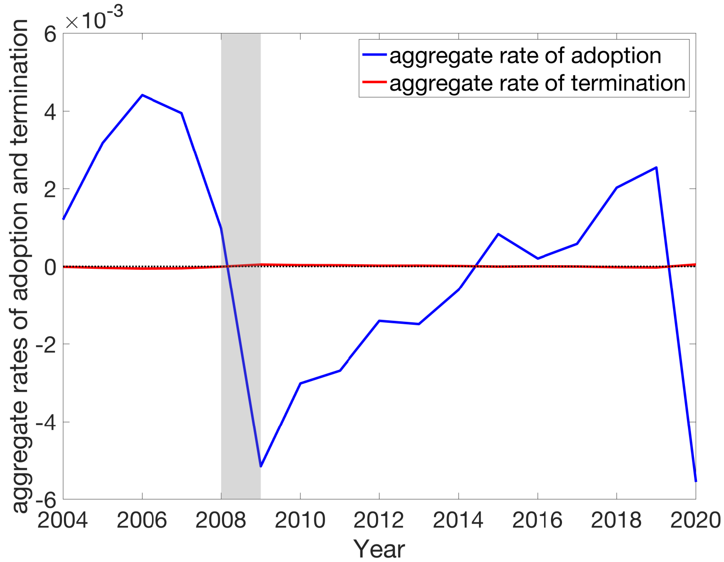


Figure F.12: Aggregate rate of adoption and termination from 2004 to 2020

Notes: The figure shows the (demeaned) aggregate rates of adoption and termination from 2004 to 2020 in the baseline case without any subsidies. The solid blue and red curves are (demeaned) aggregate rates of adoption and termination, respectively. The aggregate rate of termination is simulated using the aggregate TFP that is calibrated using the BEA quantity indices of gross output, intermediate inputs, and net stock of fixed assets. Shaded areas indicate NBER-defined recession years.

aggregate rate of adoption, but cannot replicate the full magnitude of the contraction.[25]

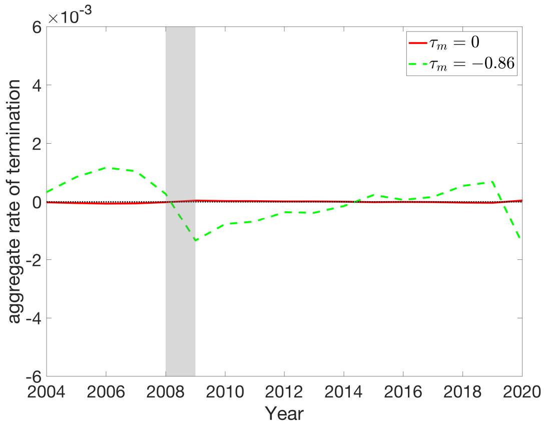
Figure F.13 studies the two counterfactual scenarios with the optimal subsidies to management costs (i.e., Panel a) and adjustment costs (i.e., Panel b), respectively. In the first scenario, we consider the optimal level of 86% subsidies to management costs and zero subsidies to adjustment costs. The dashed-green curve in Panel (a) of Figure F.13 shows the (demeaned) aggregate rate of termination. The solid-red curve shows the (demeaned) aggregate rate of termination in the benchmark case with no subsidy, which is the same scenario as the solid-red curve in Figure F.12. Compared to the benchmark case, the aggregate rate of termination in the counterfactual scenario is procyclical, indicating that the subsidies to management costs would have further discouraged the overall Schumpeterian cleansing during the Great Recession.

In the second scenario, we consider the optimal level of 86% subsidies to adjustment costs and zero subsidies to management costs. The dashed-green curve in Panel (b) of Figure F.13 shows the aggregate rate of termination. Again, the solid-red curve shows the aggregate rate of termination in the benchmark case without the subsidy. Compared to the benchmark case, the aggregate rate of termination in the coun-

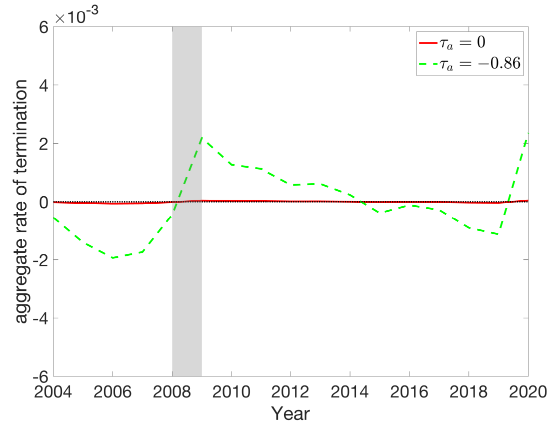
[25]Specifically, the aggregate adoption rate declined by 13% from 2007 to 2009 in the data while 1% in the model. Our parsimonious framework abstracts from several exogenous shocks that might have exerted a fall in the adoption of suppliers during the Great Recession (such as direct negative shocks to management and adjustment costs, or shocks specific to the use of intermediate inputs related to supply-chain issues). Finally, our baseline model assumes that the management cost is quadratic without a linear component. If, instead, we allow a strictly convex management cost with a linear component, the marginal cost of management will be closer to a constant, and the ratio of the marginal cost to the total profit will be more responsive to the aggregate TFP. These extensions to the baseline model, which are beyond the scope of this paper, could help strengthen the response of the rate of adoption to aggregate TFP shocks.

terfactual case is countercyclical, indicating that the subsidies to adjustment costs would have encouraged the overall Schumpeterian cleansing during the Great Recession.

Figure F.13: Aggregate rate of termination from 2004 to 2020: baseline vs. counterfactual subsidies



(a) Subsidizing management costs

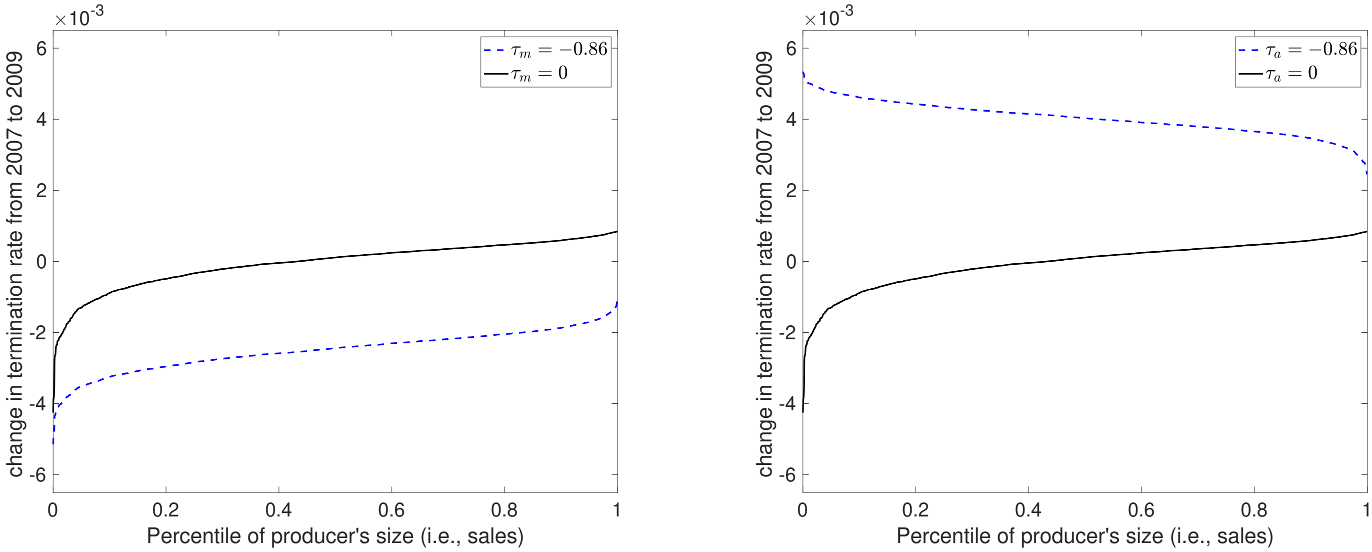


(b) Subsidizing adjustment costs

Notes: Panels (a) and (b) show the (demeaned) aggregate rate of termination from 2004 to 2020 with subsidies to management and adjustment costs, respectively. The solid red curve in both panels is the baseline case without any subsidies. The dashed green curve in Panel a (vs. Panel b) corresponds to an optimal level of 86% subsidy on the management (vs. adjustment) costs. The aggregate rate of termination is simulated using the aggregate TFP that is calibrated using the BEA quantity indices of gross output, intermediate inputs, and net stock of fixed assets. Shaded areas indicate NBER-defined recession years.

Figure F.14 examines the effect of the optimal subsidies on the heterogeneous rates of termination across different producers. It shows the changes in the termination rate from 2007 to 2009 for different sizes of producers in the benchmark and in the two counterfactual scenarios where the optimal subsidies to management costs (i.e., Panel a) and adjustment costs (i.e., Panel b) are imposed.

Figure F.14: Change in the rate of termination from 2007 to 2009: baseline vs. subsidies



(a) Subsidizing management costs

(b) Subsidizing adjustment costs

Notes: Panels (a) and (b) show the changes in the rate of termination from 2007 to 2009 with the optimal levels of 86% subsidies to management and adjustment costs, respectively. The dashed blue curve and the solid black curve in Panel a (vs. Panel b) correspond to 86% subsidy and zero subsidy on the management (vs. adjustment) costs, respectively.

Panel (a) of Figure F.14 compares the counterfactual case with subsidies to management costs (i.e., dashed-blue curve) to the benchmark case without subsidies (i.e., solid-black curve). In both cases, small producers suffer a larger reduction in the Schumpeterian cleansing during the recession period compared to large producers, evinced by the upward-sloping curves. With the optimal subsidy to management costs of 86% (i.e., dashed-blue curve), the overall termination is lower than the baseline calibration, consistent with the decline in the aggregate rate of termination in Panel (a) of Figure F.13 during the recession period comparing to the benchmark case. This decline in the termination is roughly homogeneous across different producers, evinced by the approximately parallel curves.

Panel (b) of Figure F.14 compares the counterfactual case with subsidies to adjustment costs (i.e., dashed blue curve) to the benchmark case with no subsidies (i.e., solid black curve). With an optimal subsidy to adjustment costs of 86%, the aggregate rate of the termination of suppliers is higher than that with the baseline calibration, consistent with the increase in the aggregate rate of termination in Panel (b) of Figure F.13 during the recession period. The distance between the two curves decreases with the size of the producer, showing that the effects of the subsidy on the countercyclicality of termination are more pronounced for small producers.