The Adoption and Dismissal of Suppliers over the Business Cycle*

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Abstract

We construct a firm-level dataset to study the adoption and dismissal of suppliers over the business cycle. We document positive returns to customer firms from expanding the number of suppliers and from adopting new suppliers. At the aggregate level, the total number of suppliers and the rate of adoption are procyclical, while the rate of dismissal is acyclical. The costs of managing, adopting, and dismissing suppliers are large in customer-supplier relations. On this evidence, we develop a simple model with optimizing firms that incur separate costs for the management, adoption, and dismissal of suppliers. Our model shows that these costs generate two distinct effects that determine the cyclical responses of the adoption and dismissal of suppliers to an increase in TFP: a *scaling* effect that increases the total number of suppliers by decreasing the dismissal of old suppliers while increasing the adoption of new suppliers, and a *switching* effect that increases the dismissal of old suppliers for the adoption of new suppliers. Both effects contribute to generating the observed procyclicality in the total number and the rate of adoption of suppliers, while they exert opposing forces on the rate of dismissal. The scaling (switching) effect generates countercyclical (procyclical) rate of dismissal and dominates for producers with high (low) productivity. At the aggregate level, the rate of dismissal is acyclical given the distribution of productivity among different producers.

Keywords: Adjustment and management costs, adoption and dismissal of suppliers, business cycle fluctuations.
JEL classifications: E32, L14, L24.

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1 Introduction

Since the neoclassical theory, economic models build on the premise that output tightly moves with labor inputs, and several studies show that the creation and dismissal of jobs are central to the response of labor inputs to cyclical disturbances.[1] In addition to the labor inputs, modern production also involves the use of intermediate inputs that require the adoption and dismissal of several suppliers to produce the final output. How do the adoption and dismissal of suppliers adjust over the business cycle? What are the driving forces of these cyclical patterns?

Despite the ample space dedicated to the strategy of the adoption and dismissal of suppliers in operation management textbooks and their relevance for international trade and product varieties, little is known about the cyclical regularities of these margins of adjustment.[2] We combine several comprehensive firm-level datasets to study the empirical regularities in the adoption and dismissal of suppliers and link those adjustments to aggregate fluctuations. Based on our new evidence, we develop a simple model of optimizing producers and suppliers that shows the central role of adjustment costs and technological differences across producers to account for the empirical patterns of adoption and dismissal of suppliers.

Our new evidence on the adoption and dismissal of suppliers is developed by merging two datasets: the FactSet Revere Relationships that record customer-supplier relations, including adoption and dismissal of suppliers, and the CompuStat Fundamentals that provide information on the output, the financial positions, and the administrative costs of firms. Our integrated data provides a comprehensive overview of customer-supplier relationships for US firms over the period 2003-2021. We combine this data on customer-supplier relations with the American Productivity & Quality Center (APQC) surveys of firms to quantify the costs of management, adoption, and dismissal of suppliers that several studies show to be critical for the firm's optimizing decisions. With our data, we establish five novel facts that link the adoption and dismissal of suppliers to firms' profits, aggregate fluctuations, and management and adjustment costs.

Facts 1 and 2 link sales and profits of customer firms to the adoption and dismissal of suppliers. Fact 1 establishes that the sales and profits of the customer firms increase with the

[1]The study of job flows is prominent in macroeconomics (Pissarides, 2000 and Mortensen, 2011). Caballero and Hammour (1994) show that the fall in the creation and the increase in the separation of jobs generate the cleansing of unproductive labor inputs during recessions.

[2]See textbooks by Heizer et al. (2016) and Stevenson (2018), and the studies by Gopinath and Neiman (2014), Fujii et al. (2017), and Huneeus (2018).

number of suppliers, evincing *positive returns from more suppliers*. Fact 2 shows *positive returns from establishing new relationships* compared to relationships with old suppliers, evinced by the decrease of profits and sales of the customer firm with the average age of its relationships.

Facts 3 and 4 study the dynamics of adoption and dismissal with macro aggregates over the business cycles. Fact 3 establishes that the total number of suppliers is procyclical: it increases during economic expansions and falls during contractions. Fact 4 decomposes the response of the total number of suppliers into the changes in the adoption and the dismissal of suppliers. It establishes that the rate of adoption is procyclical and the rate of dismissal is a-cyclical. We show that the a-cyclical rate of dismissal conceals large heterogeneity in the response of the dismissal rate across firms with different numbers of suppliers and different productivity. The dismissal rate is countercyclical for firms with many suppliers and high productivity, while it is procyclical for firms with few suppliers and low productivity. The aggregate acyclicality in the rate of dismissal of suppliers results from the countervailing behavior of the dismissal rate across customer firms.

Fact 5 documents the prevalence of the distinct costs of managing and adjusting suppliers. Management costs refer to resources spent by the customer firm to oversee the stock of existing suppliers, while adjustment costs refer to the direct costs involved by the customer firms for the adoption and dismissal of suppliers.[3] Using Compustat data, we find that administrative costs account for approximately 20% of net sales of listed companies, and they are positively correlated with the number and the adjustments of suppliers, evincing the importance of both management and adoption/dismissal costs. The APQC dataset further shows that supply-chain-related costs account for around 3% of firms' total revenues.[4]

To account for these facts, we develop a model with producers that use a continuum of intermediate inputs supplied by old and new vintages of suppliers. The producers have different

[3]The distinction between management and adjustment costs is well established in the theory of industrial organization. The management costs of suppliers are related to the *diminishing return to management* within firms dating back to the seminal paper Coase (1991) on the nature of firms. The adjustment costs of suppliers include the adoption cost and the dismissal cost, which are based on previous studies of searching and switching costs. In a dedicated chapter in the Handbook of Industrial Organization, Farrell and Klemperer (2007) provide a detailed appraisal of searching and switching costs. Searching costs are well studied in the literature and purely belong to the adoption cost, while costs for switching vendors involve both adoption and dismissal costs. Switching costs are high in practice and include many dimensions. Klemperer (1987, 1995) lay out a taxonomy of switching costs. Van Deventer (2016) shows that the share of the costs for switching IT vendors in the values of the organizations has a median of 6.6% and can be as high as 15%. Appendix C reviews the theory and empirical evidence on the switching cost and categorizes its various dimensions into adoption and dismissal costs.

[4]Unfortunately, the APQC dataset reports the management costs but has no information on the costs of adjusting suppliers.

idiosyncratic productivities, and they incur separate costs for the management, adoption, and dismissal of suppliers (consistent with Fact 5).

These separate costs have different implications for the movements in the adoption and dismissal of suppliers. The *management costs* constrain the scale of operation by decreasing the adoption of new suppliers and increasing the dismissal of old suppliers. The *adjustment costs* discourage both the adoption of new suppliers and the dismissal of old suppliers, which influence the age composition of suppliers. Accordingly, the two separate costs result in two separate effects of the aggregate TFP on the adoption and dismissal of suppliers. First, a *scaling effect*: the higher TFP decreases the relevance of management cost, leading to an optimal increase in the measure of suppliers for the production of the final goods. This fosters an increase in the adoption and a decrease in the dismissal of suppliers. Second, a *switching effect*: the higher TFP decreases the relevance of adjustment costs, leading to a stronger turnover of suppliers with a consequent increase in both the rates of adoption and dismissal of suppliers.

The scaling and switching effects jointly generate the positive correlation of the total number of suppliers and the adoption of new suppliers with aggregate TFP, consistent with our Fact 4. However, the two forces have countervailing effects on the correlation between TFP and the rate of dismissal: the switching effect involves an increase in the dismissal of suppliers and enables producers to renew the vintages of suppliers, while the scaling effect decreases the dismissal to enable producers to scale up production.

The model reveals that the different idiosyncratic productivities of the producers are critical to the heterogeneous responses of the rate of dismissal to the changes in aggregate TFP across producers and the overall acyclicality in the aggregate rate of dismissal. The model shows that the adjustment costs are low for producers with high idiosyncratic productivity and a large number of suppliers, generating small benefits from switching old with new suppliers when TFP increases (i.e., the scaling effect dominates). On the opposite, the adjustment costs are high for producers with low idiosyncratic productivity and a small number of suppliers, generating large benefits from switching old with new suppliers for these producers (i.e., the switching effect dominates). Thus, consistent with our Fact 4, producers with a large (small) number of suppliers display a negative (positive) response of the rate of dismissal to changes in aggregate TFP, driven by the dominating scaling (switching) effect. Based on this heterogeneity in the response of the rate of dismissal across producers, we show that our model replicates the a-cyclical aggregate rate of dismissal of suppliers with suitable sizes of management and adjustment costs and an empirically-grounded distribution of the idiosyncratic productivity of producers, consistent again with our Fact 4.

Our analysis links to several realms of research. It is related to the literature on the dynamics of inputs in production, including *product varieties* and *jobs*. Several studies show that the inputs from different varieties of products play an important role in the movements in output over the business cycle (Bilbiie et al., 2012; Bilbiie and Melitz, 2020; Broda and Weinstein, 2010; Chugh et al., 2020; Ghironi and Melitz, 2005, 2007; Hamano and Zanetti, 2017, 2020). Similarly, we relate to the literature that links the creation and destruction of jobs to output and business cycle fluctuations (Blanchard et al., 1990; Caballero and Hammour, 1994, 1996; Davis et al., 1998; Ferraro, 2018; Ferraro and Fiori, 2023; Fujita and Ramey, 2009; Pizzinelli et al., 2020; Shimer, 2005).

We link to the literature on international trade that studies the effect of imported inputs on economic growth and business cycle fluctuations (Feenstra et al., 1999; Goldberg et al., 2010; Halpern et al., 2015). Closest to our work is Gopinath and Neiman (2014), who establish that the adoption and dismissal of imported goods explain the large contraction of output in Argentina during the 2001-2002 crisis.

Finally, we connect to the literature that studies the influence of customer-supplier relations on business cycle fluctuations (Atalay, 2017; Fernández-Villaverde et al., 2019, 2021, 2023). While these studies focus on the input-output relations across several firms, we focus on the relationship of single producers with new and old suppliers.

The remainder of the paper is structured as follows. Section 2 presents the data and defines the empirical variables. Section 3 shows the empirical results. Section 4 develops a simple model to study the empirical evidence. Section 5 presents the analytical results. Section 6 concludes.

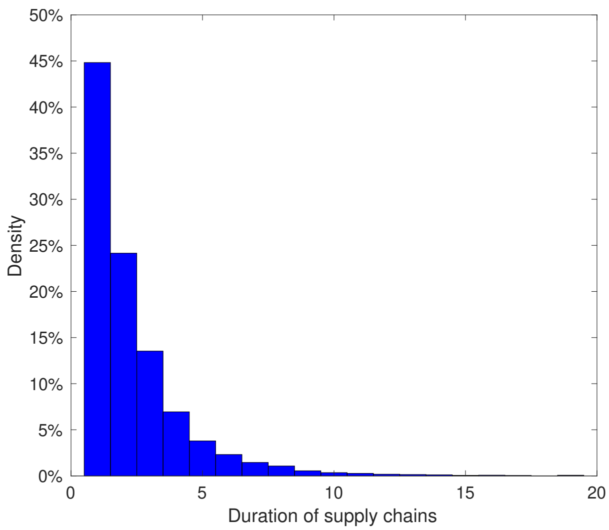
2 Data and variables

We use FactSet Revere Relationships that record customer-supplier relations from several sources, including SEC 10-K annual filings, investor presentations, and press releases reported by both customer and supplier firms in the US.[5] The data comprise a yearly record of 784,325 customer-supplier relationships that includes the start and end of relationships for 152,119 customers and

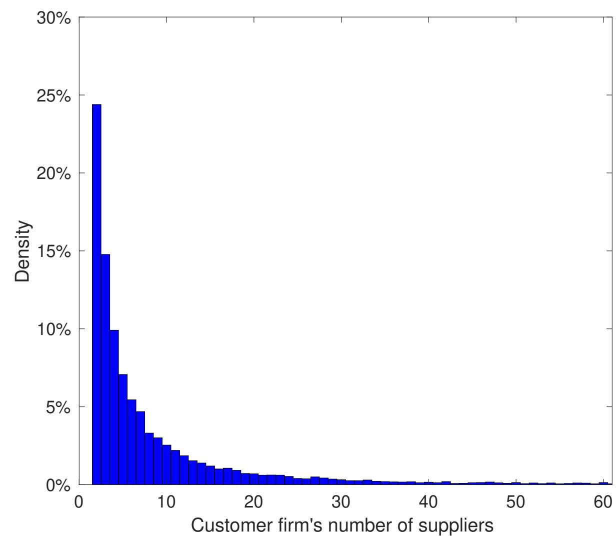
[5]FactSet is substantially more comprehensive than Compustat Customer Segment data, which fails to report data of firms that contributes less than 10% to the customer firm's revenue. In addition, Compustat Customer Segments are limited to publicly traded firms that must fulfill the Financial Accounting Standards No. 131. With these limitations, the sample size of Compustat Customer Segment is 3.4% compared to data based on FactSet Revere Relationships. In the overlapping sample years 2003 to 2017, FactSet Revere Relationships documents 142,984 customer-supplier-year observations, while Compustat Customer Segment documents 4,868.

95,932 suppliers collected over the period 2003-2021. We merge the FactSet Revere Relationships dataset with CompuStat Fundamentals to include income statements, balance sheets, and cash flows for each firm in the sample so that our dataset comprises financial variables (i.e., market returns, sales, and profits) for the firms.[6]

Figure 1: Distributions of customer-supplier relationship durations and the number of suppliers



(a) Distribution of duration of relationships



(b) Distribution of the number of suppliers

Note: In Panel (a), each par presents the percentage share of each value of duration in all customer-supplier relationships. In Panel (b), each bar presents the percentage share of each value of the customer firm's number of suppliers in all customer-by-year samples.

Duration of relations, number of suppliers, and the rates of adoption and dismissal. We begin by defining our main variables of interest and providing an overview of the main statistics for customer-supplier relations. Figure 1a shows the histogram of the duration of each customer-supplier relationship. The mean and the median duration are equal to 2.34 and 2 years, respectively, and approximately 84% of those relations terminate within three years, evincing similar, prevalent turnover of suppliers across all relationships with an average duration of roughly two years.

We denote with the variable $v_{i,t}$ the number of suppliers that form partnerships with each customer firm indexed by i during each year t. Figure 1b shows the histogram of the number of suppliers employed by each customer firm, revealing that the mean and the median number

[6]Appendix A describes the FactSet and the Compustat Customer Segment datasets, how we merge them, and the derivation of the variables used in the analysis. Our final annual panel data involves 2,742 customer firms with 22,985 customer-year observations.

of suppliers for each customer firm are equal to 12.2 and 5, respectively. The left skewness of the distribution evinces that despite the fact that the majority of customer firms employ five suppliers on average, a small and not trivial fraction of customer firms employ a higher number of suppliers, averaging around 12.

Our central interest is measuring the rates of adoption and dismissal of suppliers. We define the *adoption rate* of each customer i in period t with $s_{N,i,t} \equiv v_{N,i,t}/v_{i,t-1}$, where $v_{N,i,t}$ is the number of new suppliers adopted by the customer firm i in year t (the subscript N refers to a new supplier). Similarly, we define the *dismissal rate* for each customer firm i in year t as $s_{D,i,t} \equiv v_{D,i,t}/v_{i,t-1}$, $v_{D,i,t}$ is the number of suppliers dismissed by customer firm i in year t (the subscript D refers to the dismissal of suppliers). Table 1 shows the summary statistics of the two rates. The rate of dismissal is on average smaller, and less volatile than the rate of dismissal, with means of 0.144 vs. 0.287 and standard deviations of 0.203 vs. 0.449.

Table 1: Summary statistics of the rates of adoption and dismissal

VARIABLES	Mean	Standard deviation	Median	Min	Max
Rate of adoption ($s_{N,i,t}$)	0.287	0.449	0.0526	0	2
Rate of dismissal ($s_{D,i,t}$)	0.144	0.203	0	0	0.75

Note: *Rate of adoption* ($s_{N,i,t}$) and *Rate of dismissal* ($s_{D,i,t}$) are the numbers of new/old suppliers adopted/dismissed by the customer firm i in year t divided by its total number of suppliers in the last period, respectively. The top and bottom 2.5% of the samples for each rate are winsorized.

To study the economy-wise changes in the total number and turnover of suppliers, we weight the number of suppliers ($v_{i,t}$), the adoption rate ($s_{N,i,t}$), and the dismissal rate ($s_{D,i,t}$) of each customer firm by their intermediate-input expenditure to construct the indexes v_t, $s_{N,t}$, and $s_{D,t}$ that track the total number of suppliers, the average rate of adoption, and the average rate of dismissal in the economy, respectively.[7] Figure 2 in the next section shows the aggregate series for the total number of suppliers and the rates of adoption and dismissal of suppliers. The average adoption rate across firms is twice as large as the dismissal rate: the mean value for the adoption rate is 0.31, while the same statistics for the dismissal rate is equal to 0.15 over the sample period.

[7]We use the customer firm's costs of goods sold to compute its intermediate input expenditure share in the aggregate intermediate input expenditures throughout the paper. Appendix B describes the derivation of the variable.

3 Empirical results on adoption and dismissal of suppliers

We establish five novel facts on customer-supplier relations. Facts 1 and 2 link sales and profits of customer firms to the adoption and dismissal of suppliers. Facts 3 and 4 focus on the central theme of our study: the link between the average rate of adoption and dismissal across firms and business cycle fluctuations. Fact 5 shows that customer firms incur significant and separate costs for managing and adjusting suppliers.

Fact 1: Positive returns from more suppliers

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 firm i, respectively. α_i and γ_t are firm and year fixed effects.

Table 2: Number of suppliers is positively correlated with sales and profits

VARIABLES	(a) *Sales*	(b) *Profits*
Number of suppliers	0.0927***	0.0407***
	(0.0145)	(0.0154)
Observations	22,977	20,092
Firm number	2,742	2,484
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
R^2	0.213	0.077

Note: *Sales*, *Profits*, and *Total number of suppliers* are the log customer firm's real sales, real earnings before interest, taxes, depreciation, and amortization, and its number of suppliers (EBITDA), respectively. Data are annual and at the firm level. We restrict our sample to those customer firms whose maximum numbers of suppliers over time are more than one. Customer firm and year fixed effects are controlled. Standard errors are clustered at the firm level.

Column (a) in Table 2 shows that real sales of the customer firm are 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 customer firm. In column (b), we do the same regression for the profits of the customer firm that excludes the costs of intermediate inputs. Column (b) shows that a 1% increase in the number of suppliers is associated with about 0.04% increase in the real profits of the customer firm, consistent with the results in column (a). Our results on the positive returns of the customer firm from having more suppliers corroborate the central tenet of the "return from more varieties" in models of product varieties (see Bilbiie et al., 2012; Ethier, 1982; Feenstra et al., 1999; Goldberg et al., 2010; Gopinath and Neiman, 2014; Halpern et al., 2015; Hamano and Zanetti, 2017).[8]

Fact 2: Positive return from *new* relationships

We now show that new customer-supplier relationships are associated with larger sales and higher profits than old relationships, and we refer to this result as the *return to new relationships*. We study the issue by estimating the following regressions:

$$y_{i,t} = \eta_1 \ln(v_{i,t}) + \beta_1 \ln(age^{rel}_{i,t}) + \kappa_1 \ln(age^{cus}_{i,t}) + \alpha_i + \gamma_t + \epsilon_{i,t},$$

where $y_{i,t} \in \{\ln(q_{i,t}),\ \ln(\pi_{i,t})\}$ and $q_{i,t}$ and $\pi_{i,t}$ are firm's real sales and profits, respectively, and $v_{i,t}$ is the number of suppliers. The variable $age^{rel}_{i,t}$ is the average age of relationships for each customer firm i in year t, which is the central focus of our regression. We control for the customer firm's age, $age^{cus}_{i,t}$, which positively affects profit due to selection and is positively correlated with the age of the relationship.

Table 3 shows the estimation results. The age of the relationship has a negative effect on profits, implying that relationships formed with new suppliers entail larger sales and profits. Conditional on the number of suppliers and the age of the customer firm, a 1% increase in the average age of the relationship is associated with a 0.047% and 0.068% decline in sales and profits, respectively, of the customer firm. Consistent with the conventional finding of the positive correlation between firms' age and their performance (Coad et al., 2013; Haltiwanger et al., 1999), a customer firm's age is also positively correlated with its sales in our sample.

Our result on the negative relationship between the age of customer-supplier relationships and sales provides the basis for the positive comovement of new adoptions with sales and profits. We formally test the significance of this comovement using the following regression:

$$y_{i,t} = \eta_2 \ln(v_{i,t}) + \beta_2 s_{N,i,t} + \kappa_1 \ln(age^{cus}_{i,t}) + \alpha_i + \gamma_t + \nu_{i,t},$$

where $y_{i,t} \in \{\ln(q_{i,t}),\ \ln(\pi_{i,t})\}$ and $q_{i,t}$ and $\pi_{i,t}$ are firm's real sales and profits, respectively, and $s_{N,i,t}$ is the adoption rate of the customer firm i. Columns (c) and (d) in Table 3 show that sales

[8] The return from more suppliers is also important to models with productions networks to generate amplification of TFP shocks, see Baqaee (2018). Xu (2021) documents a positive relationship between the number of suppliers and the customer firm's TFP.

Table 3: Sales, profits and the average age of relationships

VARIABLES	(a) Sales	(b) Profits	(c) Sales	(d) Profits
Number of suppliers	0.0854***	0.0286	0.0821***	0.0281
	(0.0161)	(0.0181)	(0.0161)	(0.0182)
Relationship age	-0.0472**	-0.0666**		
	(0.0239)	(0.0278)		
Adoption rate			0.0920***	0.0840***
			(0.0210)	(0.0294)
Customer age	0.322***	0.137	0.303***	0.0965
	(0.0960)	(0.112)	(0.0963)	(0.116)
Observations	18,224	16,074	18,226	16,077
Firm number	2,601	2,359	2,601	2,359
Firm fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
R^2	0.269	0.0817	0.275	0.0893

Note: Data are annual. *Sales*, *Profits*, and *Number of suppliers* are the log customer firm's real sales, real earnings before interest, taxes, depreciation, and amortization, and its total number of suppliers (EBITDA), respectively. *Profitability* is the ratio of the customer's EBITDA to its sales. We restrict our sample in columns (c) and (f) to those with profitability in $(0, 1)$. *Relationship age* is the log average age of customer firm i's customer-supplier relationships in year t. *Customer age* is the log age of customer firm i in year t since the establishment of the firm. *Adoption rate* is the share of new suppliers in last year's total number of suppliers of the customer firm. Samples include US and international customer firms. Customer firm and year fixed effects are controlled. We restrict our sample to those whose maximum numbers of suppliers are more than one over time and the adoption rate is below one. Standard errors are clustered at the firm level.

and profits significantly increase with the rate of adoption of the customer firm. Conditional on the number of suppliers, a 1% increase in the adoption rate is associated with an increase in the customer firm's sales and profits by 0.083% and 0.084%, respectively. Thus, our results suggest a positive relationship between profits and sales and the adoption of new suppliers.

Fact 3: The total number of suppliers is pro-cyclical

Figure 2 shows our aggregate index of the total number of suppliers ($\Delta \ln v_t$, dashed-green line), the growth rates of aggregate real intermediate inputs ($\Delta \ln X_t$, dotted-red line), and real output (black line), respectively, for the period 2004-2020.[9] The variables strongly comove with production and sharply declined around the Great Recession of 2008, rebounding back quickly in 2009 after the US economy began recovering. Similarly, the variables considerably dropped in 2020 at the outset of the Covid-19 recession. The average correlations between real output growth with the number of suppliers and intermediate input are equal to 0.63 and 0.98, respectively, and they are statistically significant at the 1% level. These comovements prove strong synchronization between the aggregate number of suppliers, the intensity in the adoption

[9] We measure aggregate real intermediate inputs, X_t, with the BEA chain-type quantity index of intermediate inputs that covers the universe of US private firms.

of intermediate input, and aggregate output. While we are the first study to document these comovements for the US economy, our findings are consistent with the results in Gopinath and Neiman (2014), who document strong pro-cyclicality of imported intermediate inputs from foreign suppliers in Argentina, showing a similar, sharp contraction in the number of imported intermediate inputs during the recession of 2001-2002.[10]

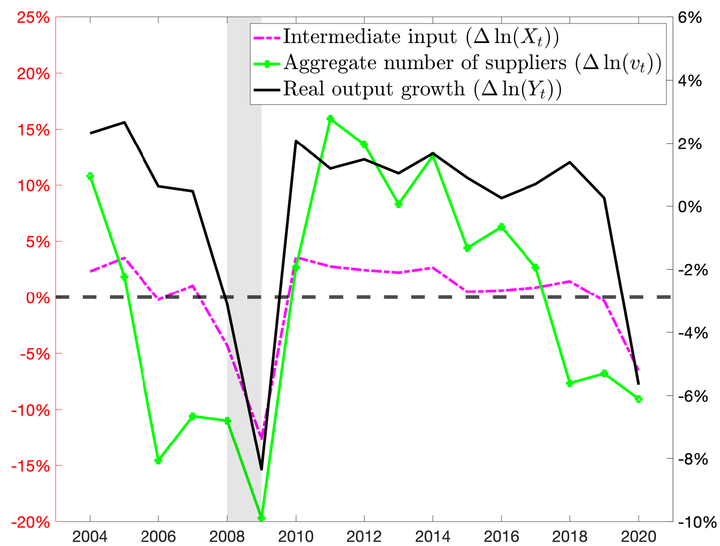


Figure 2: Pro-cyclical number of suppliers

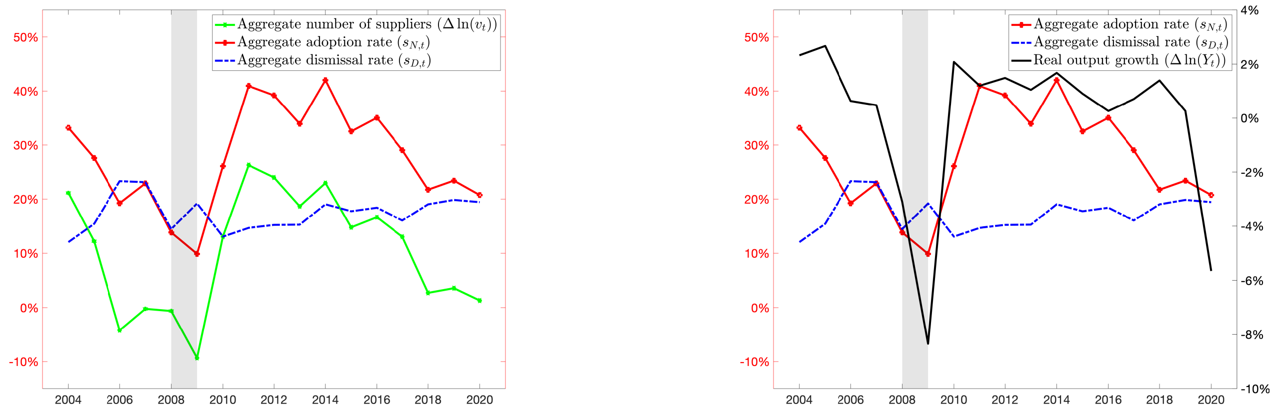
Note: The figure shows the growth rates of the aggregate real intermediate inputs (dotted red line), the aggregate number of suppliers (circle-marked green line), and real output (black line). The aggregate index of the number of suppliers is the average number of suppliers across customer firms weighted by each customer firm's costs of goods sold and demeaned. The growth rates of the aggregate real intermediate inputs and the real output are demeaned growth rates of the BEA chain-type quantity indexes of intermediate inputs and gross output of private industries, respectively. Shaded areas indicate NBER-defined recession years. We restrict our sample to those customer firms whose maximum numbers of suppliers over time are more than one.

Fact 4: Pro-cyclical adoption and a-cyclical dismissal of suppliers

We now focus on aggregate adoption and dismissal rates that jointly determine the total number of suppliers. Figure 3a decomposes the growth rate of the aggregate index of the number of suppliers (Δv_t, solid-green line) into: (i) the rates of adoption ($s_{N,t}$, solid-red line), and (ii)

[10]The movement in the total number of suppliers, the adoption, and the dismissal of suppliers may relate to the associated creation and destruction of products. However, we do not have detailed enough data on the list of products for the customer firms, which prevents us from telling whether the adoption and dismissal of suppliers are associated with the creation (destruction) of new (old) product lines, or simply for the improvement of old products in their production efficiency or product quality.

Figure 3: Pro-cyclical adoption and a-cyclical dismissal of suppliers



(a) Decompose growth of number of suppliers

(b) Cyclicality of adoption and dismissal

Note: *Aggregate number of suppliers* is the growth rate of the aggregate index of the number of suppliers ($\Delta \ln(v_t)$). *Aggregate adoption rate* ($s_{N,t}$) and *Aggregate dismissal rate* ($s_{D,t}$) are the aggregate share of suppliers adopted and the aggregate share of suppliers dismissed in last year's number of suppliers, respectively. *Real output growth* is the demeaned growth rate of the BEA chain-type quantity indexes for the gross output of private industries. Shaded areas indicate NBER-defined recession years. We restrict our sample to those customer firms whose maximum numbers of suppliers over time are more than one.

dismissal ($s_{D,t}$, blue-dashed line) of suppliers (i.e., $\Delta v_t = s_{N,t} - s_{D,t}$).[11] The strong comovement between the changes in the aggregate number of suppliers (Δv_t) and the rate of adoption ($s_{N,t}$) shows that fluctuations in the number of suppliers are primarily driven by the large fluctuations in the adoption rate while the dismissal rate ($s_{D,t}$) remains substantially unchanged over the sample period. The changes in the adoption rate are large and cyclical: the rate of adoption ranges from 18% in 2008 to 70% in 2011. In general, the adoption rate is higher than the dismissal rate, generating an upward trend in the growth rate of the number of suppliers.[12]

To study the comovements between the rates of adoption and dismissal with aggregate activity, Figure 3b shows the rates of adoption (solid-green line) and dismissal (solid-red line) together with the growth rate of real output (solid-black line). The rate of adoption closely

[11]Note that by definition, both of the aggregate adoption and dismissal rates are always positive because they are the rates of the numbers of suppliers adopted/dismissed. By construction, the growth rate of the aggregate index of the number of suppliers is the positive aggregate adoption rate net of the positive aggregate dismissal rate.

[12]The long-run growth in the total number of suppliers is consistent with the increasing connectedness between customers and suppliers, i.e., denser and denser input-output networks among firms. Acemoglu and Azar (2020), for example, argue that the introduction of one more new input supplier increases the combination of inputs exponentially, enabling significant cost reductions which spread to other industries and incentivize them to adopt additional inputs. As a result, the entire production network of the economy becomes increasingly denser over time.

comoves with the growth rate of real output and is highly procyclical, the two series have a pair-wise correlation equal to 0.53. In contrast, the rate of dismissal is substantially a-cyclical with a pair-wise correlation with the growth rate of output equal to 0.22.

We study the separate contributions of the adoption and dismissal rates to the growth rate of the changes in the total number of suppliers using the following variance decomposition:[13]

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

which establishes that the contribution of the adoption margin to total changes in the number of suppliers (first term in the equation) is equal to 88%, while the contribution of the dismissal margin is 12%. Together with the results shown in Figure 3a, the analysis consistently shows that the adoption rate is the main driver of fluctuations in the aggregate number of suppliers while the dismissal rate plays a subsidiary role.

In sum, our results show that the processes of adoption and dismissal of suppliers are notably different from the hiring and dismissal of workers in the labor market. While the labor market features the cleansing effect of recessions that lead to a countercyclical job separation that cleans the labor market from low-productivity jobs in recessions, the separation margin remains inactive in customer-supplier relations.[14]

Heterogeneous response of the dismissal rate among customer firms. The first part of Fact 4 establishes that at the aggregate level, the pro-cyclicality in the number of suppliers is uniquely driven by the rise in the adoption of new suppliers since the dismissal of suppliers is substantially insensitive to business cycle conditions.

In this second part, we link this insensitivity of the aggregate rate of dismissal to the different cyclicality of the dismissal rate across customer firms with different numbers of suppliers. Figure 4 shows the logarithm of the number of suppliers for the customer firms in our sample (x-axes) against the correlation between the rate of dismissal and sales (y-axes).[15] Each blue dot in the figure represents the average number of suppliers (correlation) for the 40 closest customer firms. The figure shows that the correlation between the dismissal rate and the sales is heterogeneous across firms with different numbers of suppliers. The correlation is positive for customer firms

[13] Appendix B (see equation(26)) describes the derivation of equation (1).

[14] The cleansing effect of the recession was originally outlined in the seminal studies by Blanchard et al. (1990) and Caballero and Hammour (1994).

[15] We use the logarithm of the number of suppliers to facilitate the comparison. The data for the number of suppliers is the same as Figure 1b.

with a small number of suppliers: they dismiss old suppliers during economic expansions and retain old suppliers during economic downturns. In contrast, it is negative for customer firms with a large number of suppliers: they retain old suppliers during economic expansions and dismiss old suppliers during economic downturns.

Figure 4 shows the shares of customer firms displaying positive and negative correlations of the rate of dismissal with sales are both large, which balance out on average. The average correlation between the rate of dismissal and sales is approximately equal to zero, consistent with the a-cyclical rate of dismissal at the aggregate level documented in the first part of Fact 4.

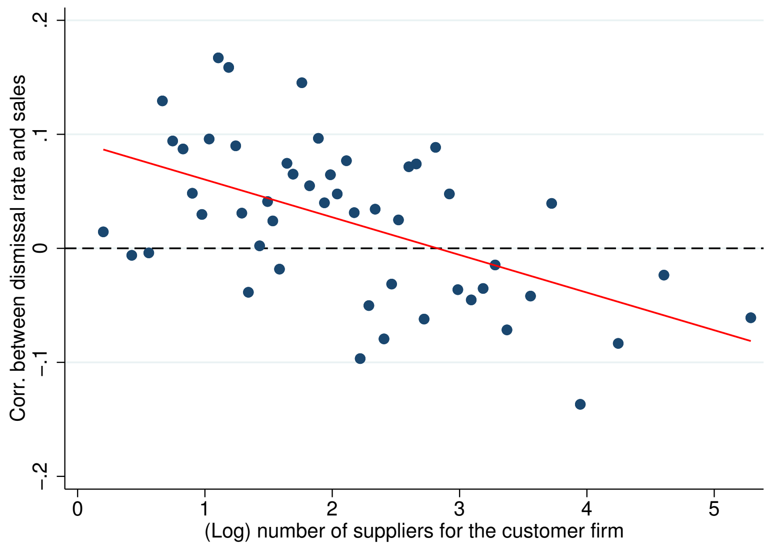


Figure 4: Correlation between dismissal rate and sales for different number of suppliers

Note: The figure plots the firm-level correlation between the dismissal rate and the sales against the (log) number of suppliers for the customer firm. In this bin scatter plot, each blue dot is the average of around 40 closest customer firms. The solid red line is a linear fit of the correlation (between the dismissal rate and the sales) on the (log) number of suppliers. Our sample excludes customer firms with no more than ten observations/years of both the dismissal rate and the sales for the calculation of their correlation.

Productivity and the number of suppliers. Why is the response of the dismissal rate to sales related to the number of suppliers? A natural conjecture is that the heterogeneous number of suppliers reflects the difference in firm-specific productivity across the customer firms, which accounts for the heterogeneous dynamics of the dismissal rate. Figure 5 shows the bin scatter plot of the (log) number of suppliers (y-axis) with the (log) labor productivity (x-axis) of the customer firms. The strong positive correlation between the two variables suggests a systematic relationship between the number of suppliers and the productivity of customer firms. Overall, our results show that the differences in the number of suppliers and productivity of the customer firms are important for changes in the rate of dismissal.

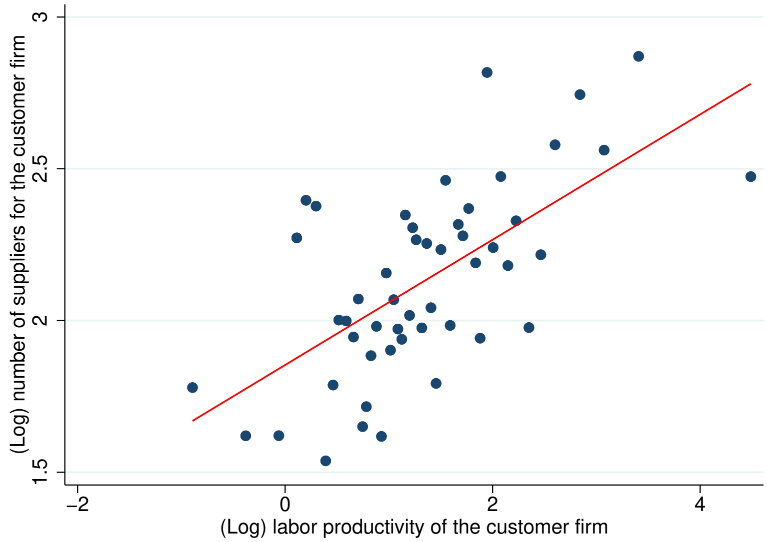


Figure 5: (Log) labor productivity and no. of suppliers

Note: The figure plots the log labor productivity against the log number of suppliers for the customer firm. We use Compustat "Sales/Turnover" deflated by the GDP deflator, and averaged over time to measure the customer firm's real sales. The labor productivity is computed as the ratio of real sales to employment, and averaged over time for each customer. In particular, we deduct the cost share of intermediate input at the BEA 3-digit I-O industry level from the labor productivity to remove the heterogeneity in the labor productivity that is due to different intermediate input cost shares among firms. In this bin scatter plot, each blue dot is the average of around 40 closest customer firms. The solid red line is a quadratic/linear fit of the log labor productivity on the log number of suppliers. Our sample excludes customer firms with no more than ten observations/years of both the dismissal rate and the sales for the calculation of their correlation.

Fact 5: Management and adjustment costs of suppliers

In this section, we use Compustat data to study the relevance of the administrative costs for customer firms, which include the costs of managing and adjusting suppliers.[16] On average, these costs account for approximately 20% of the net sales by a firm, evincing substantial resources devoted to administration-related activities.

Compustat data omit the separate components in the general administrative costs, thus precluding the direct measurement of the distinct costs of management and adjustment of suppliers. To illustrate that the management and adjustment costs are significant components of

[16] Our variable in Compustat data for administrative costs is under the voice "Selling, General, and Administrative Expense" (mnemonic *xsga*). See the survey by Bond and Van Reenen (2007) and the more recent studies by Bloom et al. (2016); Lanteri (2018) for an overview of the literature on adjustment costs.

the large administrative costs, we study the co-movements between the administrative costs with the total number of suppliers and the rates of adoption and dismissal of suppliers. Our conjecture is that the correlation must be positive and significant for the management and adjustment costs to play a role in the adjustment of the number of suppliers and the rates of adoption and dismissal. We test our hypothesis with the following regression:

$$\ln(xsga_{i,t}) = \eta \ln(v_{i,t}) + \beta s_{N,i,t} + \kappa s_{D,i,t} + \alpha_i + \gamma_t + \epsilon_{i,t},$$

where $xsga_{i,t}$ is the administrative expense deflated by the GDP deflator, $v_{i,t}$ is the number of suppliers, $s_{N,i,t}$ and $s_{D,i,t}$ are the adoption and dismissal rates, respectively. α_i and γ_t are fixed effects for firm and time, respectively.

Table 4: Administrative cost increases with supplier number, adoption, and dismissal

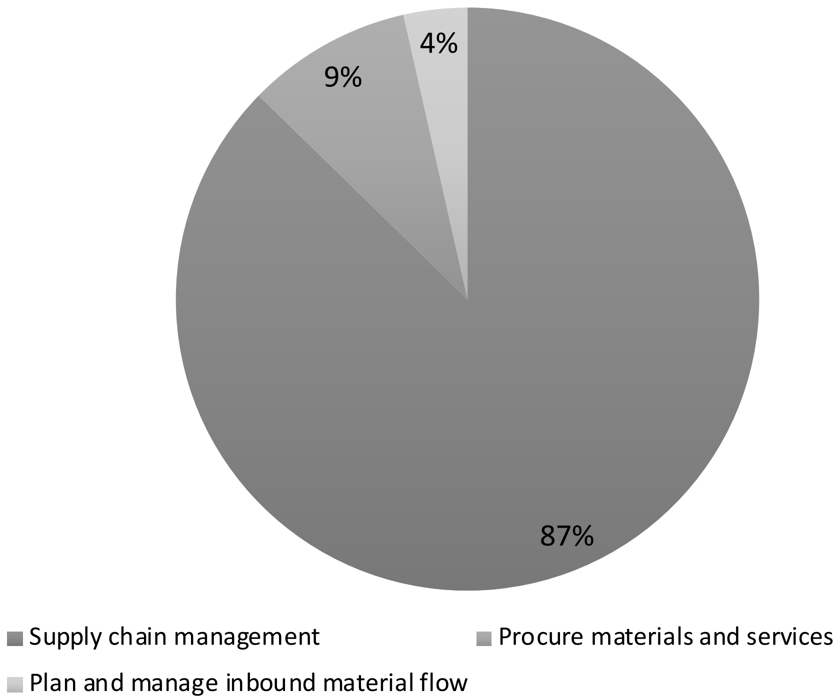
DEPENDENT VARIABLE	Admin cost
Number of suppliers	0.104***
	(0.0154)
Adoption rate	0.0419**
	(0.0199)
Dismissal rate	0.0537**
	(0.0217)
Observations	15,228
Firm number	2,276
Firm fixed effect	Yes
Year fixed effect	Yes
R^2	0.296

Note: *Admin cost* is the log customer firm's Selling, General, and Administrative Expense deflated by the GDP deflator. *Number of suppliers* is the log customer firm's total number of suppliers, respectively. *Adoption rate* is the number of adopted suppliers divided by last year's total number of suppliers for the customer firm i. *Dismissal rate* is the number of dismissed old suppliers divided by last year's total number of suppliers for the customer firm i. Data are annual and at the firm level. We restrict our sample to those whose maximum numbers of suppliers are more than one over time and adoption and dismissal rates are both below one. Customer firm and year fixed effects are controlled. Standard errors are clustered at the firm level.

Table 4 shows the estimation results. Administrative costs are positively and significantly related to the number of suppliers. More concretely, a one percent increase in the number of suppliers raises the administrative cost by 0.104%. Similarly, higher adoption and dismissal rates also involve an increase in administrative costs conditional on the number of suppliers, despite amounting to a lower increase in administrative costs equal to 0.042% and 0.054%, respectively. These results show the significant role of adjustment costs for the adoption and dismissal of suppliers.

To further investigate the issue and strengthen the robustness of our analysis on the relevance of adjustment costs, we use the American Productivity & Quality Center (APQC) dataset that

Figure 6: Supply chain related costs



provides information about supplier management and adjustment costs by surveying around 4,000 North American firms about their business practices, which includes the costs for the customer firm for supply chain planning, procurement, and developing/maintaining contracts with suppliers. While APQC data provides the averages of costs across many years rather than the variation of costs over time (whereas Compustat does), it provides precise information about the magnitude of management and adjustment costs that we cannot infer from Compustat.

In the APQC dataset, management and adjustment costs linked to the supply chain of production, recorded under the cost category "supply chain related cost," account for approximately 3% of total firms' revenues.[17] Figure 6 shows the overall composition of the different types of supply-chain-related costs recorded by firms, which provides a metric on the share of those costs in the broader context of supply-chain-related costs. The costs related to the management of the supply chain represent the largest share, accounting for 87% of the total supply-chain-related costs. Costs of procuring materials and services and planning and managing inbound material flow retain smaller shares of 9% and 4%, respectively.[18] Our results extensively show that

[17] Supply chain management costs include the expenses for planning and managing demand for products and services.

[18] Procuring materials and services include the development of sourcing strategies, the selection of suppliers and developing/maintaining contracts, ordering materials and services, and appraising and developing suppliers.

management and adjustment costs are a non-trivial part of total revenues and represent the bulk of supply-chain costs between customers and suppliers.

4 A simple model of adoption and dismissal of suppliers

In this section, we develop a simple model with optimal choices for the adoption and dismissal of suppliers. The key assumptions of our model are the adjustment costs in the adoption and dismissal of suppliers and the management costs, motivated by the evidence in Fact 5.[19] In the next section, we show that our simple model provides an empirically congruous characterization of our empirical facts.

4.1 Baseline environment and timing

The economy is static, and it is populated by a continuum of final-goods producer $i \in [0, 1]$ with different productivity a_i, which is the source of heterogeneity that drives the heterogeneous cyclicality of dismissal across producers in our model. The final good market is perfectly competitive, with the price normalized to one. Each producer manufactures goods by assembling intermediate inputs supplied by old (O) and new (N) vintages of suppliers. Each vintage $k \in \{O, N\}$ is populated by a continuum of suppliers with unit measure. Each supplier supplies intermediate inputs to different producers.

At the beginning of the period, each producer starts with some old suppliers and optimally sets the mix of old and new suppliers to maximize profits. The adjustment in the number of suppliers involves costs for the dismissal (c^-) and adoption (c^+) of suppliers. The price of intermediate goods is determined by Nash bargaining between the producer and the suppliers. The producers manufacture the final good (Y) using the supplied inputs from new and old suppliers at the established price. Figure 7 summarizes the timeline in the model.

4.2 Suppliers

Each supplier provides a distinct input to the producer. Suppliers are indexed by their vintage and match-specific efficiency $z_k \in [0, 1]$.[20] Within each vintage k, match-specific efficiency is

[19] The *return from more suppliers* from our Fact 1 results from any CES production function. By assuming that a supplier provides exactly one unit of input, our model is consistent with the class of CES production functions in embedding the returns from more suppliers.

[20] Here, we assume that new and old suppliers have the same maximum match-specific efficiency, which equals one for simplicity. We can allow them to be different without affecting our main mechanism and results.

Figure 7: Timeline

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

uniformly distributed over the interval $[0, 1]$ with unitary density.

4.3 Producers and the bargained 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 production technology:

$$y_{i,k}(z_k) = Aa_i z_k, \quad \forall\, k \in \{O, N\}, \forall\, z_k \in [0, 1], \tag{2}$$

where A and a_i are aggregate and idiosyncratic productivity, respectively.

We assume that each supplier manufactures intermediate goods costlessly. The total surplus $TS_{i,k}(z_k)$ from the producer-supplier relationship is the output produced by the corresponding production line:

$$TS_{i,k}(z_k) = y_{i,k}(z_k) = Aa_i z_k, \quad \forall\, i \in [0, 1], \forall\, k \in \{O, N\}, \forall\, z_k \in [0, 1]. \tag{3}$$

The total surplus 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:

$$p_{i,k}(z_k) = (1 - \alpha) TS_{i,k}(z_k), \quad \forall\, i \in [0, 1], \forall\, k \in \{O, N\}, \forall\, z_k \in [0, 1], \tag{4}$$

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

4.4 Measure of adoption and dismissal

We denote with $z_{i,k}$ the marginal supplier of vintage k used by producer i. The producer i adopts new suppliers whose idiosyncratic productivity is sufficiently high to generate profits and therefore adopts new suppliers with $z_N \in [z_{i,N}, 1]$). Similarly, the producer i dismisses the old suppliers whose idiosyncratic productivity is insufficient to generate profits and therefore dismisses old suppliers with $z_O \in [0, z_{i,O})$). The measures of adopted new and dismissed old suppliers are equal to $1 - z_{i,N}$ and $z_{i,O}$, respectively. To use the same notation in Section 2, we denote with $s_{i,N}$ and $s_{i,D}$ the rates of adoption (of new suppliers) and the dismissal (of old suppliers), respectively, with $s_{i,N} = 1 - z_{i,N}$ and $s_{i,D} = z_{i,O}$.[21]

4.5 Costs of management, adoption, and dismissal of suppliers

Costs of managing suppliers. Producers incur costs in managing suppliers, consistent with the *span of control* problem and the "diminishing returns to management" (Coase, 1991 and Williamson, 1967). Following Gopinath and Neiman (2014), we assume quadratic management costs that are proportional to the size of each production line:

$$G(z_{i,N}, z_{i,O}) = \xi \cdot V_i^2/2, \tag{5}$$

where $V_i = 2 - z_{i,N} - z_{i,O}$ is the total number of active suppliers for each producer i, or the total number of suppliers with productivities above the thresholds for selection in each vintage.[22]

Costs of adjusting suppliers. In addition to the costs of managing suppliers, the adoption and dismissal of suppliers are also costly, and they involve unitary costs of adoption c^+ and dismissal c^-.[23] Consistent with the seminal idea in Coase (1991) and several subsequent studies, we assume that the adjustment costs are not contractable and therefore outside the bargaining set and paid entirely by producers.

4.6 Optimal choices of adoption and dismissal

This section describes the optimization of each producer i that chooses the adoption and dismissal of suppliers to maximize profits. For a given set of marginal suppliers $z_{i,O}$ and $z_{i,N}$, each producer i manufactures final output with the linear production function:

$$Y_i = \int_{z_{i,O}}^{1} y_{i,O}(z_O) dz_O + \int_{z_{i,N}}^{1} y_{i,N}(z_N) dz_N, \tag{6}$$

[21] Specifically, they are equal to the measures of adoption and dismissal divided by the total measure of suppliers from the last period, respectively.

[22] To simplify our exposition, we assume that the producer pays the management cost before bargaining with suppliers. Hence the management cost does not enter into the Nash bargaining problem.

[23] Examples of adoption costs include due diligence and the adoption of patents. Examples of dismissal costs include penalties for breaching contracts and internal appraisal.

where the marginal suppliers $z_{i,O}$ and $z_{i,N}$ are optimally chosen by maximizing the profit function:

$$\Pi_i = \max_{\{z_{i,O}, z_{i,N}\}} \underbrace{\int_{z_{i,O}}^{1} y_{i,O}(z_O)dz_O + \int_{z_{i,N}}^{1} y_{i,N}(z_N)dz_N}_{\text{Final output}} - \underbrace{\left(\int_{z_{i,O}}^{1} p_{i,O}(z_O)dz_O + \int_{z_{i,N}}^{1} p_{i,N}(z_N)dz_N\right)}_{\text{Input costs}}$$
$$- \underbrace{\left[c^- z_{i,O} + c^+ \left(1 - z_{i,N}\right)\right]}_{\text{Adjustment costs}} - \underbrace{\xi \cdot \left(2 - z_{i,N} - z_{i,O}\right)^2 /2}_{\text{Management cost}}, \tag{7}$$

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

By combining the bargained input price in equation (4) into equation (7), it yields:

$$\Pi_i = \max_{\{z_{i,O}, z_{i,N}\}} \alpha \left\{\int_{z_{i,O}}^{1} Aa_i z_O dz_O + \int_{z_{i,N}}^{1} Aa_i z_N dz_N\right\} - \left[c^- z_{i,O} + c^+ \left(1 - z_{i,N}\right)\right] \tag{8}$$
$$- \xi \cdot \left(2 - z_{i,N} - z_{i,O}\right)^2 /2.$$

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

$$z^*_{i,O} + \frac{c^-}{\alpha A a_i} = \frac{\xi V^*_i}{\alpha A a_i}, \tag{9}$$

and

$$z^*_{i,N} - \frac{c^+}{\alpha A a_i} = \frac{\xi V^*_i}{\alpha A a_i} \tag{10}$$

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

Equations (9) and (10) outline the distinct roles of the adjustment and management costs for the adoption and dismissal of suppliers. The management costs increase the marginal costs of using new and old suppliers and therefore deter the expansion in the total number of suppliers. The costs of adoption (c^+) decrease the marginal benefit of using new suppliers, while the costs of dismissal (c^-) increase the marginal benefit of retaining old suppliers.

By combining equations (9) and (10), it yields:

$$z^*_{i,N} - z^*_{i,O} = \frac{c^+ + c^-}{\alpha A a_i} > 0. \tag{11}$$

Equation (11) shows that the adjustment costs generate the differential in the marginal productivity between new and old suppliers, such that new suppliers have higher marginal productivity than old suppliers in equilibrium. As we discuss in the next section, the productivity differential is critical to the incentives for producers to adopt new suppliers (Lemma 2), and for the different responses of the rate of dismissal across producers with different idiosyncratic productivity (Proposition 3).

5 Analytical results

In this section, we show that our simple model based on optimizing producers, distinct adjustment and management costs, and idiosyncratic productivity for producers generates the empirical results in Facts 1-4.

5.1 Return from more suppliers and new relationships (Facts 1-2)

Fact 1 and Fact 2 show that the profits and sales of producers increase with the number of suppliers, and the effect is magnified for new suppliers. It is straightforward to show that these empirical regularities are consistent with our model. By combining equations (10) and (9), the following lemma holds.

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

$$\frac{\partial \ln Y^*_i}{\partial \ln V^*_i} = \frac{Aa_i V^*_i}{Y^*_i} z^*_{i,O} > 0, \forall A. \tag{12}$$

Proof: see Appendix D.

Equation (12) shows that the elasticity of output to the total measure of suppliers is always positive, consistent with the observed positive *returns from more suppliers* established by Fact 1.

The model also generates the *returns to new relationships*, as formalized by the next Lemma.

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

$$\frac{\partial ln Y^*_i}{\partial s^*_{i,N}} = \frac{c^+ + c^-}{\alpha Y^*_i}. \tag{13}$$

Proof: see Appendix D.

Equation (13) shows that the elasticity of output to the rate of adoption is positive, consistent with our Fact 2 that establishes positive returns to new relationships. Lemma 2 also shows that the *returns to new relationships* is proportional to the adjustment costs.

5.2 The response to aggregate TFP (Facts 3-4)

Next, we show that the model generates the procyclical total number of suppliers (Fact 3), procyclical adoption, and a-cyclical dismissal of suppliers (Fact 4).

We denote the steady state of a variable x by $\overline{x}$, and the deviation of x from the steady state by $dx \equiv x - \overline{x}$.[24]

5.2.1 Scaling and switching effects

Before focusing on our new facts, we show that changes in aggregate TFP exert two distinct scaling and switching effects on the total number and the composition of suppliers that are critical for the responses of the number of suppliers and the rate of adoption and dismissal to TFP.

The scaling effect. The higher TFP leads producers to increase the total number of suppliers to benefit from the reduction in management costs arising from the improvement of productivity. To do so, producers raise the adoption of new suppliers and diminish the dismissal of old suppliers, which we call the *scaling effect*, as formalized by the next Lemma.

Lemma 3. ***Scaling effect.*** *The producer increases the number of new and old suppliers to raise the scale of capacity in response to an increase in TFP.*

$$\textit{\textbf{Scaling effect}} \equiv \frac{dV_i^*}{d\ln A} = \frac{2\xi\overline{V_i^*} + (c^+ - c^-)}{2\xi + \alpha\overline{A}a_i} > 0. \tag{14}$$

Proof: see Appendix D.

Equation (14) shows that the degree of management costs, encapsulated by the parameter ξ, must be sufficiently positive to guarantee a significantly positive scaling effect (especially when c^+ and c^- are close), which is critical to replicate negative responses of the rate of dismissal to TFP among some producers as in Figure 4.

Equation (14) also shows that the *scaling effect* has limited sensitivity to the producer's idiosyncratic productivity (a_i) due to two countervailing forces: on the one hand, an increase in the producer's idiosyncratic productivity (a_i in the numerator) lowers the management costs relative to the producer's profits; on the other hand, the scale of production in terms of the total

[24]For instance, the steady state of TFP is denoted by $\overline{A}$ and the deviation of TFP from the steady state is denoted by $dA \equiv A - \overline{A}$.

number of suppliers ($\overline{V_i^*}$ in the numerator) increases in a_i, as we show in Lemma 6 later. As we will discuss later, this small sensitivity of the *scaling effect* to a_i is critical to replicate the observed heterogeneous responses of the rate of dismissal across different producers evinced in Figure 4.

The switching effect. The adjustment costs generate a positive comovement in the rates of adoption and dismissal of suppliers in reaction to changes in aggregate TFP. For instance, the increase in aggregate TFP reduces the productivity differential between old and new suppliers (see equation 11), and it incentivizes the producer to adjust the composition of suppliers by increasing the rates of dismissal and adoption to switch from old to new suppliers. We call this phenomenon the *switching effect*, as formalized by the next lemma.

Lemma 4. ***Switching effect.*** *For a given number of suppliers, an increase in aggregate TFP generates the switching from old to new suppliers equal to:*

$$\textit{\textbf{Switching effect}} \equiv \frac{\partial s_{i,N}^*}{\partial \ln A} = \frac{\partial s_{i,D}^*}{\partial \ln A} = \frac{c^+ + c^-}{2\alpha \overline{A} a_i} > 0. \tag{15}$$

Proof: see Appendix D.

Since the substitution of suppliers involves the simultaneous adoption and dismissal of suppliers, the switching effect entails the equal rate of adoption ($s_{i,N}^*$) and dismissal ($s_{i,D}^*$) of suppliers. An important implication from equation (15) is that the size of the switching effect decreases with the idiosyncratic productivity (a_i). The intuition is straightforward, the relevance of adjustment costs for the profits of the producers decreases with the scale of production that is determined by the producer's idiosyncratic productivity. This finding is summarized by the next lemma.

Lemma 5. *The size of the* switching effect *decreases with the productivity of the producer a_i.*
Proof: see Appendix D.

As we will discuss in section 5.2.3, the decrease of the switching effect with the idiosyncratic productivity a_i will be critical to generate the different responses of the rate of dismissal across the producers with different productivity, and to produce the a-cyclical aggregate rate of dismissal consistent with Fact 4.

5.2.2 The total number of suppliers is procyclical (Fact 3)

A direct implication of the *scaling effect* in Lemma 3 is the positive relationship between the total number of suppliers and aggregate TFP, summarized by the next proposition.

Proposition 1. ***The total number of suppliers is procyclical (Fact 3).*** *The total number of suppliers, V_i^*, increases in A.*

Proof: see Appendix D.

Proposition 1 is consistent with the procyclical total number of suppliers in Fact 3.

5.2.3 The adoption rate is procyclical and the dismissal rate is acyclical (Fact 4)

Fact 4 studies the response of the rate of adoption and dismissal to aggregate TFP and comprises three results: (i) the rate of adoption is procyclical, (ii) the rate of dismissal is different across producers, and (iii) the rate of dismissal is acyclical on average. We discuss each of them in turn.

The rate of adoption is procyclical. Combining equations (9) and (10), we obtain the rate of adoption as a function of the number of producers, V_i^*, and the size of the adjustment costs relative to productivity, $(c^+ + c^-)\ /\ (2\alpha A a_i)$:

$$s_{i,N}^* = \frac{V_i^*}{2} - \frac{c^+ + c^-}{2\alpha A a_i}. \tag{16}$$

Using equation (16), we find that the response of the rate of adoption ($s_{i,N}^*$) to aggregate TFP (A) is the linear combination of the scaling and switching effects:

$$\frac{ds_{i,N}^*}{d\ln A} = \underbrace{\frac{1}{2}\frac{dV_i^*}{d\ln A}}_{\text{Scaling effect} > 0} + \underbrace{\frac{c^+ + c^-}{2\alpha \overline{A} a_i}}_{\text{Switching effect} > 0}. \tag{17}$$

Since the switching and scaling effects are positive, the response of the rate of adoption to the aggregate TFP is always positive, as stated in the next proposition.

Proposition 2. ***The rate of adoption is procyclical (Fact 4).*** *The rate of adoption increases with aggregate TFP.*

Proof: see Appendix D.

Different rates of dismissal across producers. Combining equations (9) and (10), we express the rate of dismissal as a function of the number of producers, V_i^*, and the size of the adjustment costs relative to productivity, $(c^+ + c^-)\ /\ (2\alpha A a_i)$:

$$s_{i,D}^* = 1 - \frac{V_i^*}{2} - \frac{c^+ + c^-}{2\alpha A a_i}. \tag{18}$$

Using equation (18), we write the response of the rate of dismissal ($s^*_{i,D}$) to aggregate TFP (A) as a linear combination of the scaling and switching effects:

$$\frac{ds^*_{i,D}}{d\ln A} = \underbrace{-\frac{1}{2}\frac{dV^*_i}{d\ln A}}_{\text{Scaling effect} < 0} + \underbrace{\frac{c^+ + c^-}{2\alpha\overline{A}a_i}}_{\text{Switching effect} > 0} . \tag{19}$$

The scaling effect implies a negative effect on the rate of dismissal since producers achieve a large increase in the scale of production by reducing the rate of dismissal of old suppliers. In contrast, the switching effect implies a positive response of the rate of dismissal – consistent with the positive impact on the rate of adoption to enact the switching from old to new suppliers.

Equation (19) shows that the sign of the response of the rate of dismissal to aggregate TFP is determined by the relative strength of the switching and scaling effects. The scaling effect is insensitive to the idiosyncratic productivity a_i. In contrast, as shown by Lemma 5, the switching effect diminishes with the idiosyncratic productivity a_i, and therefore the differences in the response of the rate of separation to aggregate TFP are mainly accounted for by the reduction of the switching effect for the producers with high idiosyncratic productivity.

As a result, producers with high idiosyncratic productivity a_i have small switching effects, and therefore the scaling effect is the dominant force in equation (19), and generates a negative response of the rate of dismissal to the TFP shock (i.e., $ds^*_{i,D}/dlnA < 0$). Conversely, producers with low a_i have a large switching effect that dominates the scaling effect, which generates a positive response of dismissal to the aggregate TFP shock, i.e., $ds^*_{i,D}/dlnA > 0$.

Overall, our analysis shows that the different responses of the rate of dismissal to TFP shocks across producers are driven by the differences in the idiosyncratic productivity a_i. Those differences in idiosyncratic productivity also determine the number of suppliers ($\overline{V^*_i}$) across producers. As in our empirical results, the number of suppliers is proportional to the idiosyncratic productivity of the producer, as established by the following lemma.

Lemma 6. *The total number of suppliers in the steady state ($\overline{V^*_i}$) increases with the idiosyncratic productivity of the producer (a_i).*
Proof: see Appendix D.

Lemma 6 is consistent with Fact 4 (Figure 5), which shows that the number of suppliers increases with the productivity of the producer. Using Lemma 6, we show that the response of the rate of dismissal to TFP decreases with the number of suppliers, consistent with the empirical results, as stated in the next proposition.

Proposition 3. ***Heterogeneous cyclical responses of the rate of dismissal across producers.*** *When both ξ and $c^+ + c^-$ are sufficiently large, the rate of dismissal is countercyclical for producers with a large number of suppliers, while is procyclical for producers with a small number of suppliers.*
Proof: see Appendix D.

The intuition of Proposition 3 is as follows. When ξ and $c^+ + c^-$ are sufficiently large, both the scaling and the switching effects exist and they jointly determine the cyclical response of the rate of dismissal.[25] For producers with high idiosyncratic productivity, and thus a large number of suppliers, the scaling effect dominates the switching effect, resulting in the countercyclical responses of the rates of dismissal to an increase in TFP. In contrast, for producers with low idiosyncratic productivity, and thus a small number of suppliers, the switching effect dominates the scaling effect, resulting in the procyclical responses of their rates of dismissal to an increase in TFP.

Proposition 3 indicates that our model is consistent with Fact 4 (Figure 4), which shows that the cyclicality of the rate of dismissal is linked with the productivity and the number of suppliers of the producer, and producers with high (low) productivity and a large (small) number of suppliers have a countercyclical (procyclical) rate of dismissal.[26]

The aggregate response of the rate of dismissal is determined by the distribution of idiosyncratic productivity across producers. When the adjustment costs $c^+ + c^-$ are small relative to the mean of the idiosyncratic productivity a_i, the switching effect is tiny while the scaling effect is large, generating a negative response of the rate of dismissal to TFP for the majority of producers. On the contrary, when the adjustment costs $c^+ + c^-$ are large, the scaling effect dominates and generates positive responses of the rate of dismissal for the majority of producers, leading to a procyclical rate of dismissal on average. Only when the adjustment costs are close to the mean of the producer's productivity a_i, the rate of dismissal of supplier is acyclical, as summarized by the following proposition.

Proposition 4. ***The a-cyclical aggregate rate of dismissal (Fact 4).*** *For a given ξ, the response of the aggregate rate of dismissal is acyclical when the total adjustment costs ($c^+ + c^-$) are close to the mean of*

[25] When xi ($c^+ + c^-$) is close to zero, only switching (scaling) effects remains, and all producers will display procyclical (countercyclical) rate of dismissal.

[26] As discussed after equation (14), the management costs ξ must be sufficiently positive to generate a non-trivial scaling effect for the countercyclical dismissal among producers with a large number of suppliers. When adjustment costs are close to zero (i.e., $c^+ + c^- = 0$), the switching effect is trivial, and the scaling effect alone determines the rates of adoption and dismissal. In such case, the dismissal rate responds negatively to the aggregate TFP across all producers, which is inconsistent with the a-cyclical rate of dismissal at the aggregate level in Fact 4 (Figure 3).

the idiosyncratic productivity of producers (a_i).
Proof: see Appendix D.

Proposition 4 shows that the acyclicality of the aggregate rate of dismissal in Fact 4 depends on the size of the adjustment costs, which determines the distribution of the response of the dismissal rate across producers with different idiosyncratic productivity and numbers of suppliers.

Overall, the analysis shows that our parsimonious model with optimizing producers and distinct costs for the adjustment and management of suppliers (motivated by Fact 5) generates the new empirical findings on the adoption and dismissal of suppliers in Facts 2-4.

6 Conclusion

Our analysis based on a new, comprehensive, firm-level, supply-chain data establishes several novel facts on the adoption and dismissal of suppliers over the business cycle. At the firm level, the profits and sales of customer firms comove with the adoption of new suppliers and the expansion in the total number of suppliers. At an aggregate level, the rate of adoption of new suppliers and the total number of suppliers are procyclical, while the dismissal of old suppliers is acyclical. The acyclical rate of dismissal at the aggregate level arises from the different responses of the rate of dismissal across customer firms with different numbers of suppliers.

Building on this new evidence, we develop a simple model of producers that optimally adjust the number and the composition of new and old suppliers subject to distinct management and adjustment costs. The model shows the central and separate roles of the costs of management, adoption, and dismissal of suppliers in generating incentives to scale up the number of suppliers and switch old with new suppliers. We show that the scaling and switching effects are critical to replicate the observed procyclicality of the acquisition of new suppliers and the total number of supplier, and the a-cyclical dismissal of suppliers.

Our study opens 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 customer firms and the resulting movements in the aggregate rates of adoption and dismissal of suppliers. Second, the analysis could be extended to consider the intertemporal dimension in the adoption and dismissal of suppliers, which will link the optimal choices of producers to the discount rate, asset prices, and the expected benefits of the customer-supplier relationship. Third, we find that the heterogeneity in productivity drives the differences in the number of suppliers at the firm level, future work could focus on the role of heterogeneity in the response of the aggregate rates of adoption and dismissal of suppliers. Finally, while we focus on the relationship between a single producer and several suppliers, the analysis could be extended to allow linkages between producers and suppliers in the context of a network economy. We plan to investigate some of these issues in future work.

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A Data

Our data combine two datasets: the FactSet Revere Relationships data that allows tracking the extensive margin (i.e., the adoption and dismissal of suppliers), and Compustat data provide the financial statement variables and administrative costs of each customer firm.

The FactSet Revere Relationships dataset collects 784,325 customer-supplier relationship records between 152,119 customers and 95,932 suppliers from 2003 to 2021. Each record includes the start and end dates of the relationship. The database systematically collects customer-supplier relationship information from public sources such as SEC 10-K annual filings, investor presentations, and press releases reported by either the customer or supplier firms. Compared to the commonly used Compustat Customer Segment database, which only includes major customers that contribute to more than 10% of a firm's revenue[27], FactSet Revere provides a much less truncated set of suppliers. The broader coverage results in more accurate measures of customer-supplier relationships, the number of suppliers, and their adoption and dismissal. As a result, FactSet Revere captures many refreshments of input variables that would be otherwise missing if we use Compustat data instead.

To measure the extensive margin, we use the start and end years of each customer-supplier relationship. Based on this information, we calculate the total number of suppliers of customer firm i in year t and denote it by $v_{i,t}$, which is our measure of the extensive margin. We also calculate the number of suppliers adopted and dismissed by the customer firm i in year t and denote with $v_{N,i,t}$ and $v_{D,i,t}$, respectively, which we use to construct the rates of adoption and dismissal.

Then, we further merge the FactSet Relationships dataset with Compustat data using the first six digits of customer firms' CUSIP numbers, which uniquely identify a company. With the above merger, we obtain a sample of 2,742 customer firms with 22,985 customer-year observations spanning 2003 to 2021.

B Decomposition of the growth rate of aggregate extensive margin

This section describes how we derive the growth rates of the extensive margins.

To compute the aggregate growth rates of the extensive margins, we need the share of each customer firm's intermediate input expenditure in the total intermediate input expenditure

[27] Public-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.

of the entire economy. First, we denote the share of industry n, firm i's intermediate input expenditure in the total intermediate input expenditure of industry n as $COGS\_share_{n,i,t}$, which is computed as

$$COGS\_share_{n,i,t} = \frac{cogs_{n,i,t}}{\sum_{i'} cogs_{n,i',t}}, \tag{20}$$

where $cogs_{n,i,t}$ is the *cost of goods sold* (COGS) of firm i in industry n documented in Compustat.[28]

Second, we also compute the Bureau of Economic Analysis (BEA) intermediate input share of each industry n as

$$X\_share^{ind}_{n,t} = \frac{X^{ind}_{n,t}}{\sum_{n'} X^{ind}_{n',t}}, \tag{21}$$

where $X^{ind}_{n,t}$ is the total nominal intermediate input expenditure of industry n in year t published by the BEA.

With the firm and industry-level intermediate input shares defined above, we define the aggregate growth rate of the extensive margin as

$$\frac{\Delta v_t}{v_{t-1}} \equiv \sum_n \sum_i \left(X\_share^{ind}_{n,t} \cdot COGS\_share_{n,i,t} \cdot \frac{\Delta v_{i,t}}{v_{i,t-1}} \right). \tag{22}$$

The firm-level decomposition of the growth rate of the extensive margin is

$$\frac{\Delta v_{i,t}}{v_{i,t-1}} = s_{N,i,t} - s_{D,i,t}, \tag{23}$$

where $s_{N,i,t} \equiv v_{N,i,t}/v_{i,t-1}$ and $s_{D,i,t} \equiv v_{D,i,t}/v_{i,t-1}$ are the firm-level rates of adoption and dismissal, which are defined as the shares of the number of newly adopted ($v_{N,i,t}$) and dismissed old ($v_{D,i,t}$) suppliers in the last year's total number of suppliers, respectively. Similar to the aggregation of the extensive margins in equation (22), we use the weighted averages of adoption and dismissal rates as the aggregate rates of adoption and dismissal, i.e.,

$$\text{aggregate acquisition margin}: \quad s_{N,t} \equiv \sum_n \sum_i \left(X\_share^{ind}_{n,t} \cdot COGS\_share_{n,i,t} \cdot s_{N,i,t} \right), \tag{24}$$

$$\text{aggregate dismissal margin}: \quad s_{D,t} \equiv \sum_n \sum_i \left(X\_share^{ind}_{n,t} \cdot COGS\_share_{n,i,t} \cdot s_{D,i,t} \right). \tag{25}$$

[28] COGS in Compustat is a commonly used measure of the variable cost. According to 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."

It follows that the growth rate of the aggregate extensive margin can be decomposed into the aggregate rates of adoption and dismissal, i.e.,

$$\frac{\Delta v_t}{v_{t-1}} = s_{N,t} - s_{D,t}. \tag{9}$$

Based on equation (23), we compute the variation of the growth rate of the extensive margin as

$$\begin{aligned} Var\left(\frac{\Delta v_{i,t}}{v_{i,t-1}}\right) &= Cov\left(\frac{\Delta v_{i,t}}{v_{i,t-1}}, s_{N,i,t} - s_{D,i,t}\right) \\ &= Cov\left(\frac{\Delta v_{i,t}}{v_{i,t-1}}, s_{N,i,t}\right) + Cov\left(\frac{\Delta v_{i,t}}{v_{i,t-1}}, -s_{D,i,t}\right), \end{aligned} \tag{26}$$

which indicates the following equation showing the percentage contributions of the rates of adoption and dismissal to the growth of the aggregate extensive margin

$$\frac{Cov\left(\frac{\Delta v_t}{v_{t-1}}, s_{N,t}\right)}{Var\left(\frac{\Delta v_t}{v_{t-1}}\right)} + \frac{Cov\left(\frac{\Delta v_t}{v_{t-1}}, -s_{D,t}\right)}{Var\left(\frac{\Delta v_t}{v_{t-1}}\right)} = 1, \tag{10}$$

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

C A brief literature review of switching costs

This section of the Appendix reviews the literature on the switching cost and categorizes its various dimensions into adoption and dismissal costs. Switching costs are mainly incurred in two types of situations, when consumers/households switch suppliers or retailers and when firms switch suppliers/vendors. Our adoption and dismissal costs correspond to the switching costs in the second situation.[29]

Theoretical works on switching costs mostly build on the switching costs for consumer/household purchasing. However, most of their analysis on the switching costs can be applied to our situation of firms switching suppliers as well. Among these works, Klemperer (1987, 1995) first lay out a taxonomy of switching costs. They classified the switching cost 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 acquire customers, contractual costs, and psychological costs.

[29] Van Deventer (2016); Whitten and Wakefield (2006) provide comprehensive reviews on the research of switching 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 dismissal costs; while loyalty costs are purely dismissal costs. With the taxonomy of switching costs, Klemperer (1995) uses a model to show that switching costs reduce competition and raise prices.

Compared to the theories, empirical works on switching costs are more recent. In particular, empirical studies on the costs for firms to switch suppliers cover (vendor's) industries of hardware, computer purchasing, chemical, insurance, and IT outsourcing, with IT outsourcing as the most studied industry. (Barroso and Picón, 2012; Heide and Weiss, 1995; Nielson, 1996; Ping Jr, 1993; Whitten, 2010; Whitten et al., 2010; Whitten and Wakefield, 2006) These works survey managers and executives to empirically study various dimensions of switching costs. Most of these dimensions are consistent with the taxonomy of switching costs in Klemperer (1987, 1995), with some additional dimensions specific to the customer-supplier relationship environment. For example, Nielson (1996); Whitten (2010); Whitten et al. (2010); Whitten and Wakefield (2006) study the costs of hiring and retaining skilled workers during switching, which belong to the adoption costs. Whitten (2010); Whitten et al. (2010); Whitten and Wakefield (2006) study the costs of upgrading the management system along vendor switching, which involve both adoption and dismissal costs. Whitten (2010); Whitten and Wakefield (2006) study the sunk costs associated with vendor switching, i.e., the non-recoverable time/money/effort associated with the old vendor. The sunk costs are psychological but greatly influence the switching decision. The sunk costs belong to dismissal costs.

The empirical works on switching costs also document the important role of the costs in vendor switching. Whitten and Wakefield (2006) find that switching costs may prevent firms from switching from unsatisfactory vendors. Whitten (2010) find that high switching costs promote the continuation of customer-supplier relationships.

Regarding the size of switching costs, comprehensive data is lacking. However, Van Deventer (2016) collects recent examples of dis-continued IT outsourcing contracts, which provide an approximate size of costs for switching vendors. The share of switching costs in the values of the organizations has a median of 6.6% and can be as high as 15%.

D Proofs to propositions

Using equations (9) and (10), we have

$$
\begin{aligned}
1-\left(V_i^*-s_{i,N}^*\right) &= \frac{\xi V_i^*-c^-}{\alpha A a_i} \\
\Longleftrightarrow 1+s_{i,N}^* &= V_i^*+\frac{\xi V_i^*-c^-}{\alpha A a_i},
\end{aligned} \tag{27}
$$

and

$$
1-s_{i,N}^* = \frac{\xi V_i^*+c^+}{\alpha A a_i}. \tag{28}
$$

Take difference between equations (27) and (28), we have

$$
\begin{aligned}
2s_{i,N}^* &= -\frac{c^-+c^+}{\alpha A a_i}+V_i^* \\
\Longrightarrow s_{i,N}^* &= \frac{1}{2}\left(V_i^*-\frac{c^-+c^+}{\alpha A a_i}\right) < \frac{1}{2}V_i^*,
\end{aligned} \tag{29}
$$

and

$$
\begin{aligned}
s_{i,D}^* &= 1-\left(V_i^*-s_{i,N}^*\right) \\
&= \frac{1}{2}\left(V_i^*-\frac{c^-+c^+}{\alpha A a_i}\right)-V_i^*+1 \\
&= -\frac{1}{2}\left(V_i^*+\frac{c^-+c^+}{\alpha A a_i}\right)+1.
\end{aligned} \tag{30}
$$

In equilibrium, the output of producer i satisfies:

$$
\begin{aligned}
Y_i^* =& a_i A\frac{\left(2-s_{i,O}^*\right)s_{i,O}^*+\left(2-s_{i,N}^*\right)s_{i,N}^*}{2} \\
\Longleftrightarrow lnY_i^* =& lna_i+lnA+ln\left[\frac{\left(2-s_{i,N}^*\right)s_{i,N}^*+\left(2-s_{i,O}^*\right)s_{i,O}^*}{2}\right] \\
=& lna_i+lnA+ln\left[\frac{\left(2-s_{i,N}^*\right)s_{i,N}^*+\left(2-V_i^*+s_{i,N}^*\right)\left(V_i^*-s_{i,N}^*\right)}{2}\right].
\end{aligned} \tag{31}
$$

Lemma 1

Proof. Take partial derivative of equation (31) wrt. lnV_i^*,

$$
\frac{\partial lnY_i^*}{\partial lnV_i^*} = \frac{Aa_iV_i^*}{Y_i^*}z_{i,O}^* > 0.
$$

□

Lemma 2

Proof. Take partial derivative of equation (31) wrt. $s_{i,N}^*$, we have

$$\frac{\partial lnY_i^*}{\partial s_{i,N}^*} = \frac{V_i^* - 2s_{i,N}^*}{\frac{(2-s_{i,N}^*)s_{i,N}^*+(2-V_i^*+s_{i,N}^*)(V_i^*-s_{i,N}^*)}{2}}$$
$$= \frac{a_i A V_i^* \left(1 - 2\frac{s_{i,N}^*}{V_i^*}\right)}{Y_i^*} > 0,$$

where the last equality comes from equation (29). □

Lemma 3

Proof. Sum equations (27) and (28), we have

$$2 = V_i^* + \frac{\xi V_i^* - c^-}{\alpha A a_i} + \frac{\xi V_i^* + c^+}{\alpha A a_i}. \tag{32}$$

Apply implicit function theorem to equation (32), we have

$$\frac{dV_i^*}{dlnA} = \frac{2\xi \overline{V_i^*} + (c^+ - c^-)}{2\xi + \alpha \overline{A} a_i}$$
$$= \frac{\alpha \overline{A} a_i \left(z_{i,O}^* + z_{i,N}^*\right)}{2\xi + \alpha \overline{A} a_i} > 0.$$

□

Lemma 4

Proof. Take partial derivative of equation (29) wrt. $\ln A$, we have

$$\frac{\partial s_{i,N}^*}{\partial \ln A} = \frac{\partial s_{i,D}^*}{\partial \ln A} = \frac{c^+ + c^-}{2\alpha \overline{A} a_i} > 0. \tag{33}$$

□

Lemma 5

Proof. Take partial derivative of equation (33) wrt. a_i, we have

$$\frac{\partial^2 s_{i,N}^*}{\partial \ln A \partial a_i} = \frac{\partial \left(\frac{c^+ + c^-}{2\alpha \overline{A} a_i}\right)}{\partial a_i}$$
$$= -\frac{c^+ + c^-}{2\alpha \overline{A} a_i^2} < 0.$$

□

Proposition 1

Proof. Follows immediately from Lemma 3.

□

Proposition 2

Proof. Take total derivative of equation (29) wrt. $\ln A$, we have

$$\frac{ds^*_{i,N}}{d\ln A} = \underbrace{\frac{1}{2}\frac{dV^*_i}{d\ln A}}_{\text{Scaling effect} > 0} + \underbrace{\frac{c^+ + c^-}{2\alpha\overline{A}a_i}}_{\text{Switching effect} > 0} > 0.$$

□

Lemma 6

Proof. Apply implicit function theorem to equation (32) in the steady state, we have

$$\begin{aligned}\frac{d\overline{V^*_i}}{da_i} =& \frac{2\xi\overline{V^*_i} + (c^+ - c^-)}{a_i\left(2\xi + \alpha\overline{A}a_i\right)} \\ =& \frac{\alpha\overline{A}\left(z^*_{i,O} + z^*_{i,N}\right)}{2\xi + \alpha\overline{A}a_i} > 0.\end{aligned}$$

□

Proposition 3

Proof. Take total derivative of equation (30) wrt. $\ln A$, we have

$$\begin{aligned}\frac{ds^*_{i,D}}{d\ln A} =& \underbrace{-\frac{1}{2}\frac{dV^*_i}{d\ln A}}_{\text{Scaling effect} < 0} + \underbrace{\frac{c^+ + c^-}{2\alpha\overline{A}a_i}}_{\text{Switching effect} > 0} \\ =& -\frac{1}{2}\frac{2\xi\overline{V^*_i} + (c^+ - c^-)}{2\xi + \alpha\overline{A}a_i} + \frac{c^+ + c^-}{2\alpha\overline{A}a_i}.\end{aligned}$$

When both ξ and $c^+ + c^-$ are sufficiently large, small a_i leads to a large scaling effect but an even larger switching effect because a_i is in the only term of the denominator of the switching effect, and in turn, a positive response of the rate of dismissal to A.

In contrast, large a_i leads to a small scaling effect but an even smaller switching effect because a_i is in the only term of the denominator of the switching effect, and in turn, a negative response of the rate of dismissal to A.

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

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

i.e., pro-cyclical adoption, and

$$\frac{ds^*_{i,D}}{d\ln A} = -\frac{1}{2}\frac{dV^*_i}{d\ln A} < 0,$$

i.e., creative destruction.

□