

# Supplier Churn and Growth: A Micro-to-Macro Analysis

David R. Baqaee  
UCLA

Ariel Burstein  
UCLA

Cedric Duprez  
NBB and UMons\*

Emmanuel Farhi<sup>†</sup>

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## Abstract

Although consumer surplus from new suppliers is widely recognized as a key driver of economic growth and trade, empirical evidence quantifying its magnitude is scarce. We use Belgian data to quantify this effect and study its consequences for production at both the micro- and macroeconomic level. We instrument for changes in supplier access and find that for every 1% of suppliers gained or lost, the marginal cost of downstream firms falls or rises by 0.3%. We show that, regardless of functional forms, this elasticity measures the area under the input demand curve above the price (consumer surplus) relative to expenditures. Our estimates can be used to calibrate love-of-variety and quality ladder models. We quantify the importance of supplier addition and separation for aggregate growth by developing a growth-accounting framework. We discipline our growth-accounting formulas using firm-level production network data and our microeconomic estimates. We find that supplier churn plausibly accounts for about half of aggregate productivity growth.

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# 1 Introduction

If each individual producer generates surplus for their customers, then this surplus can motivate bilateral trade and the accumulation of input varieties over time can fuel growth. However, despite its critical role in theories of endogenous growth and trade, there is little direct evidence on the magnitude of this surplus. This study quantifies the surplus for the customer when firms trade with each other, and relates this surplus to both microeconomic and macroeconomic outcomes.

We define and estimate a statistic, the “inframarginal surplus” ratio, which quantifies consumer surplus from additional suppliers per unit of expenditures. This notion of surplus, which we denote by  $\delta$ , is an important statistic in many models of growth and trade, including expanding-variety and quality-ladder models, and it plays a crucial role for welfare and aggregate output counterfactuals.<sup>1</sup> The infra-marginal surplus ratio is also crucial in the industrial organization literature, as it directly relates to the degree of appropriability (Mankiw and Whinston, 1986). Indeed, Makowski and Ostroy (2001) argue that  $\delta = 0$  is *the* defining property of perfect competition.

Our study consists of a microeconomic and a macroeconomic part. In the microeconomic part of the paper, we propose a strategy to estimate  $\delta$  and implement this strategy using Belgian data. In the macroeconomic part of the paper, we develop a growth accounting framework to assess the contribution of supplier churn, whereby firms gain and lose efficiency as they add and drop suppliers, to economy-wide productivity growth. We apply our growth-accounting framework to Belgian firm-to-firm production network data from value-added tax (VAT) filings. To discipline the importance of supplier churn, we use our estimates of  $\delta$  from the first part of the paper.

We discuss the microeconomic and the macroeconomic parts of the paper in turn. To estimate the surplus ratio at the micro-level, we employ a unique approach that enables us to estimate the area under the input demand curve without specifying the demand system itself. Traditionally, inferring consumer surplus requires estimating and integrating demand curves. Demand estimation focuses on how quantities respond to prices. Us-

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<sup>1</sup>For example, in Krugman (1979) or Matsuyama and Ushchev (2020b), efficiency of the equilibrium depends on a comparison of  $\delta$  with the markup. Furthermore, optimal industrial policy and the response of aggregate output to shocks also depend critically on the value of  $\delta$  (see Dhingra and Morrow, 2019, Baqaee et al., 2020, or Baqaee and Farhi, 2020 for some examples). We also show that  $\delta$  shapes the surplus from a movement along the quality ladder in creative destruction models like Aghion and Howitt (1992) and Grossman and Helpman (1993).

ing this variation, one can estimate the price elasticity of demand over the region where prices and quantities vary. Given these estimates, and a functional form, one can then integrate the demand curve up to the choke price to arrive at an estimate for consumer surplus.

This standard approach has two shortcomings. First, two demand curves can look similar locally, over the region where price and quantity variation is observed, but yield very different amounts of consumer surplus due to extrapolation (e.g. a translog and CES can have the same value and shape locally, but imply very different amounts of consumer surplus). Second, disaggregated demand systems can be extremely high dimensional since there are many goods and the number of cross-price elasticities increases in the square of the number of goods. In practice, researchers rely on strong functional form assumptions that reduce the dimensionality of the demand system, like CES or symmetric translog, and infer consumer surplus by extrapolation of these functional forms.

Because we study the value of additional suppliers for producers rather than additional goods for consumers, we can use a different approach. We show that the surplus ratio can be estimated as the elasticity of a downstream firms' marginal costs with respect to upstream entry and exit, regardless of the input demand system.<sup>2</sup> We estimate this elasticity using a detailed survey of manufacturing firms in Belgium, called Prodcum, that tracks sales and output quantities. We merge Prodcum with firm-to-firm input-output linkage information from VAT returns. Using this tax information, we observe at annual frequency almost all domestic suppliers of the firms in Prodcum. We regress changes in marginal costs on supplier additions and separations. We show that, when this regression is consistently estimated, the coefficients identify the average inframarginal surplus ratio for additions and for separations.

To achieve consistent estimation, we instrument the addition and subtraction of suppliers using firm births and deaths. To ensure that births and deaths of upstream suppliers are not driven by idiosyncratic shocks to their downstream customers, we restrict attention to entry and exits of suppliers for whom the downstream firm is small as a share of their customer base (e.g., less than 5%). Identification requires that additions and separations of suppliers caused by our instruments are not correlated with idiosyncratic shocks to the downstream firms' marginal costs, like the downstream firm's productivity shocks. We also control for other input prices and include 6-digit product by year and firm fixed

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<sup>2</sup>Our approach cannot be applied to households. For a producer, marginal costs of production are, at least in principle, observable. However, for a household, the derivative of the expenditure function with respect to utility is an unobservable nuisance parameter that measures how the utility function is cardinalizing the underlying preference relation. This is because unlike quantity, utility is only defined up to monotone transformations.

effects to allow for industry-level shocks and differential trends among firms.

We find sizeable microeconomic effects of supply linkage destruction and creation on downstream marginal costs. That is, we reject the perfectly competitive benchmark of  $\delta = 0$ . According to our baseline estimates, if 1 percentage point of a firm's suppliers, in terms of its variable costs share, are lost or added, then this raises or lowers its marginal cost by around 0.3 percentage points. If demand for inputs is CES, our estimates imply a "love-of-variety" effect consistent with an elasticity of substitution between 4 and 5.

More generally, our estimates can be used to calibrate parameters of more flexible demand systems where the love-of-variety effect is not so tightly connected to the (local) elasticity of substitution. We also find a reduced-form pass-through from marginal costs into prices of around 60%. That is, a little over half the changes in marginal costs are passed onto downstream customers while the remaining 40% are absorbed by markups.

In the macroeconomic part of the paper, we develop a growth-accounting framework to quantify the importance of supplier churn for measured aggregate growth, adding an extensive margin for supplier additions and separations to otherwise standard growth accounting formulas (i.e. Solow, 1957; Hulten, 1978; Basu and Fernald, 2002; Baqaee and Farhi, 2019b).<sup>3</sup> We take into account how the formation and separation of supplier links affects the prices of downstream firms, and how these price changes are transmitted along existing supply chains from supplying firms to purchasing firms, all the way down to final consumers. This accounting exercise does not require a fully spelled-out model of market structure, factor markets, or link formation but is consistent with many different structural models.

In order to quantify the importance of supplier churn in our growth accounting, we require the firm-to-firm input-output matrix over time and knowledge of the inframarginal surplus ratio, i.e. area under the input demand curve. We discipline the former using Belgian VAT data and the latter by extrapolating our microeconomic estimates of the inframarginal surplus for Prodcom firms to the whole Belgian economy. We find that around half of aggregate productivity growth in Belgium between 2002 and 2018 can plausibly be accounted for by supplier churn.

The structure of the paper is as follows. Section 2 contains theoretical microeconomic results. These results motivate our microeconomic empirical strategy, which we describe and report in Section 3. Section 4 introduces the aggregation framework and presents our theoretical macroeconomic results. We use these results, and our earlier microeconomic

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<sup>3</sup>By extensive margin of additions and separations, we specifically mean a case where expenditure shares change discontinuously when suppliers are added or dropped. If expenditure shares change smoothly to or from zero, then standard growth accounting formulas apply without change.

estimates, to decompose aggregate growth in our data in Section 5. We conclude in Section 6. There is an accompanying online appendix containing additional proofs, details about the data, and robustness checks.

**Related literature.** Our paper is related to several different literatures. First, as discussed above, our analysis contributes to the literature on growth and trade with an extensive margin of inputs. A key object of interest and source of welfare gains in this literature comes from the love for product variety.<sup>4</sup> In models with monopolistic competition, the love-of-variety effect is usually defined using the elasticity of the utility function with respect to quantity, e.g. Vives (1999), Benassy (1996), Zhelobodko et al. (2012), and Dhingra and Morrow (2019). This elasticity is inherently unobservable since utility is only defined up to monotone transformations. We characterize the love-of-variety effect in terms of the area under the demand curve instead, which depends only on observables, and our characterization does not require a separable demand system. Although we study love-of-variety in production, the relationship between love-of-variety and the area under the demand curve also applies to consumption.

We further contribute to this literature by directly estimating the inframarginal surplus when firms lose or gain access to suppliers. We can do this because our data allows us to measure costs and output quantities and track firms' suppliers. In lieu of this data, researchers have typically relied on very indirect evidence to discipline the consumer surplus from new suppliers in their models. For example, expanding-varieties models typically use a CES demand system, where the price elasticity of residual demand at any point on the demand curve also controls the love-of-variety effect. Similarly, quality ladder models are often disciplined by indirect inference via matching moments on firm employment dynamics, patents, and growth (see Garcia-Macia et al., 2019 and Akcigit and Kerr, 2018 for example).<sup>5</sup>

The second literature our paper is related to is the one on production networks, particularly those with an extensive margin. For example, Baqaee (2018) and Baqaee and Farhi (2020) show that cascades of supplier entry and exit in production networks change how aggregate output responds to microeconomic shocks. The response of aggregate output to a microeconomic shock, in turn, crucially depends on the same notion of surplus as

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<sup>4</sup>The love-of-variety effect has been theoretically studied by Zhelobodko et al. (2012), Dhingra and Morrow (2019), Baqaee et al. (2020), and Matsuyama and Ushchev (2020b, 2023) amongst many others.

<sup>5</sup>There is a large literature that provides reduced-form evidence of how changes in policies (e.g. import tariffs or market access) impact firm outcomes such as size, productivity, markups, and firm product-scope. See, for example, Amiti and Konings (2007), Brandt et al. (2017), Goldberg et al. (2010), Bernard et al. (2019), and De Loecker et al. (2016). Although this literature provides evidence that input variety matters for firm-level outcomes, it does not provide an estimate of the surplus to the downstream firm.

discussed above. The importance of the extensive margin of firm-to-firm linkages has also been emphasized and studied by Oberfield (2018), Lim (2018), Tintelnot et al. (2018), Elliott et al. (2020), Taschereau-Dumouchel (2020), Acemoglu and Tahbaz-Salehi (2020) and Bernard et al. (2022).

Some papers in the literature model firm-to-firm link formation as the outcome of firms choosing amongst alternative production recipes, for example Boehm and Oberfield (2020), Acemoglu and Azar (2020), and Kopytov et al. (2022). In these models, once we minimize costs over all possible recipes, there is an induced cost function that maps input prices and output quantity to total cost. Our notion of surplus and our empirical strategy are applicable to the induced cost-function in such models.

Empirical studies by Jacobson and Von Schedvin (2015), Carvalho et al. (2014), and Miyauchi (2018) have shown firm failures are transmitted across supply chains and affect the sales of other firms in neighboring parts of the production network using reduced-form methods. Compared to this reduced-form literature, we use an instrumental variable strategy to study the causal effect of firm failures on marginal cost, and we link our estimates to the inframarginal surplus ratio, which is a deep parameter in many models.

Huneus (2018), Miyauchi (2018), and Arkolakis et al. (2021) use fully-specified structural models to study adjustment costs in link-formation between firms and their aggregate consequences. Boehm and Oberfield (2020) document that link formation is affected by institutional distortions and that this can affect aggregate productivity. Our paper complements this literature in two ways: our micro estimates of the value of link formation can be used to discipline these models, and our growth accounting exercise provides moments about the aggregate importance of supplier churn that can be used as calibration targets. Unlike the structural literature, we take changes in firms' sizes and the formation and separation of links between firms as given (i.e. we take them from the data). Hence, we do not provide a fully specified model for counterfactuals. Since we do not model why firms form and break links, our exercise does not take a stance on the ultimate causes of firm growth (e.g. higher productivity or better ability to find matches).<sup>6</sup>

Finally, our paper is also related to a deep literature on correcting price indices to account for the entry and exit of goods. Our macroeconomic exercise quantifies the importance of supplier entry and exit for *measured* aggregate growth.<sup>7</sup> The macroeconomic and

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<sup>6</sup>In this sense, our results are not inconsistent with the findings of Bernard et al. (2022) who show that firms tend to grow primarily by adding new customers.

<sup>7</sup>There is a large body of work that decomposes changes in a weighted-average of firm-level productivities into reallocation, entry, and exit terms (see e.g. Baily et al., 1992; Foster et al. 2001). However, the object these studies decompose is not aggregate productivity in a growth accounting sense — that is, it does not measure the gap between real output and real input growth. See Petrin and Levinsohn (2012), Hsieh et al. (2018), Baqaee and Farhi (2019b), and Baqaee et al. (2020) for more details.

trade literatures on the importance of entry and exit, which trace their origins to Hicks (1940), have been greatly influenced by Feenstra (1994) who introduced a methodology for accounting for product entry and exit under a CES demand system.

This CES methodology owes its popularity to its simplicity and nondemanding information requirements. For example, Broda and Weinstein (2006) apply it to calculate welfare gains from trade due to newly imported varieties, and Broda and Weinstein (2010) compute the unmeasured welfare gains from changes in varieties in consumer non-durables. Using a similar methodology, Jaravel (2016) calculates the gains from consumer product variety across the income distribution, while Gopinath and Neiman (2014), Halpern et al. (2015), and Blaum et al. (2018) study the welfare gains from trade in intermediate inputs.<sup>8</sup> Aghion et al. (2019) build on this methodology to correct aggregate growth rates for expanding varieties and unmeasured quality growth. Outside of the CES literature, Hausman (1996), Feenstra and Weinstein (2017), and Foley (2022) have provided alternative price index corrections that dispense with the CES assumptions.

A universal theme in this literature is to estimate or calibrate price elasticities of demand and infer the value of entering and exiting products by inverting or integrating demand curves under parametric restrictions (e.g. isoelastic, linear, or translog demand). Our approach differs from this literature in that we attempt to identify the area under the input demand curve directly through its effect on downstream marginal costs rather than via implicit or explicit integration of demand curves. We can do this because we focus on production rather than consumption. For producers, the value of an input can be measured by its effect on an observable variable: marginal cost. In contrast, the literature mentioned above typically focuses on the value of new goods in consumption, where there is no observable counterpart to marginal cost.

Although we do not estimate price elasticities, our paper is related to the broader objective of estimating demand curves. Whereas we focus on the integral of demand, the literature on demand estimation tends to focus on its derivatives. For example, the first derivative of demand affects the price elasticity of demand; the second derivative of demand determines the pass-through of marginal cost into the price; and the third derivative disciplines the rate at which pass-through changes along the demand curve. We contribute to this literature by estimating the integral of demand, which determines the value of new goods, directly. The inframarginal surplus ratio is generically a complicated object that depends on where the perturbation occurs, just like the price elasticity

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<sup>8</sup>The methodology of Feenstra (1994) requires knowledge of the elasticity of substitution, which is typically estimated using data on expenditure switching. Blaum et al. (2018) instead uses changes in the buying firm's revenues (and parametric assumptions on the production function and demand for the buying firms' output) to estimate the elasticity of substitution between imports and domestic inputs.

and the degree of pass-through. However, as with estimates of price elasticities and pass-throughs, our estimates can help to pin down deeper parameters of the cost function given different parametric assumptions.

## 2 Microeconomic Results: Theory

In this section, we derive expressions for how supplier addition and separation affect a downstream firm’s marginal cost. The partial equilibrium results in this section serve as the basis for our firm-level regressions in Section 3. We delay general equilibrium and aggregation to Sections 4 and 5.

Consider a *downstream* firm, indexed by  $i$ , whose variable cost function is

$$C_i(\mathbf{p}, A_i, q_i) = mc_i(\mathbf{p}, A_i) q_i,$$

where  $\mathbf{p}$  is the vector of quality-adjusted input prices (including primary factor prices),  $A_i$  indexes technology, and  $q_i$  is the total quantity of output.<sup>9</sup> We allow the firm to have fixed costs of operation, but assume that variable production has constant returns to scale.

Assume that inputs are grouped into types. The cost function is symmetric in input prices that belong to the same type but not necessarily symmetric across types. Formally, two inputs are the same *type* if swapping their prices does not affect variable cost. This assumption ensures that the downstream firm’s input demand curve for all varieties of a given type  $J$  are the same function  $x_{iJ}(\mathbf{p}, A_i, q_i)$ . We do not restrict own-type or cross-type price elasticities. Without loss of generality, we assume that inputs of the same type also have the same initial price (if they have different prices, treat them as different types). For notational convenience, suppose there is a countable number of types. Almost all popular production technologies used in the macroeconomics and trade literatures feature a notion of “types.”<sup>10</sup> We introduce the notion of types so that we can perturb the availability of suppliers in Proposition 1.

The creation and destruction of buyer-supplier relationships are typically discrete in

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<sup>9</sup>In the body of the paper, we assume that firms take input prices as given. In Appendix B, we show that, under some additional assumptions, our empirical strategy is also valid if firms face a schedule of input prices as a function of input quantities instead. This input price schedule, which we take as given, could, for example, be the outcome of second-degree price discrimination or a bargaining process.

<sup>10</sup>For example, for CES, we say two inputs have the same type if they have the same share parameter and price. In Melitz (2003), two varieties are the same type if they have the same productivity draw. For the Kimball (1995) demand system, the homothetic demand systems introduced by Matsuyama and Ushchev (2017), and the separable demand system introduced by Fally (2022), we say that two inputs have the same type if they share the same residual demand function and the same price. Our results apply to these demand systems even though they are usually parameterized with an uncountable number of types.



the sense that when suppliers are added or dropped, expenditures change discontinuously to or from zero. To account for this phenomenon, we allow jumps in the price of inputs: when the price of an input jumps to infinity, we say that it became unavailable; when the price becomes finite, we say that it became available. The prices that jump to or from infinity could be market prices or shadow prices. For example, entry or exit of suppliers cause market prices to jump. On the other hand, the formation or destruction of bilateral matches or changes in the downstream firm's decision to pay fixed costs associated with linking to some supplier cause shadow prices to jump.<sup>11</sup>

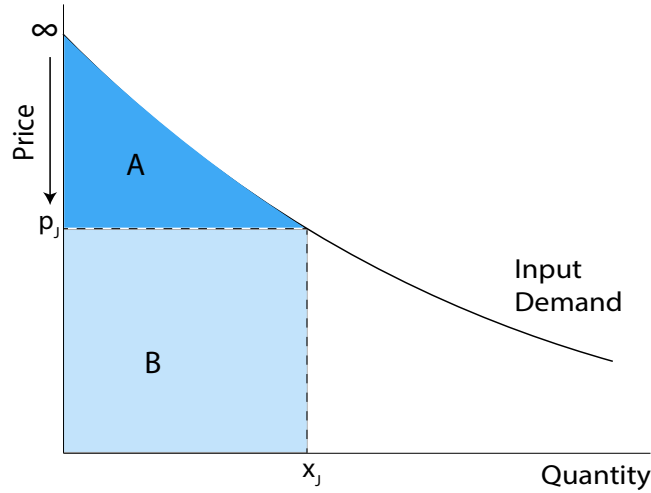


Figure 1: The inframarginal surplus ratio,  $\delta$ , is the ratio of  $A$  to  $B$ .

Define the *inframarginal surplus ratio* associated with a jump in the price of input of type  $J$  (holding the price of all other inputs constant) to be:<sup>12</sup>

$$\delta_{iJ}(p) = \frac{\int_p^\infty x_{iJ}(\xi) d\xi}{px_{iJ}(p)} \geq 0. \quad (1)$$

Equation (1) is the area under the demand curve for input  $J$  above the price  $p$  (i.e. consumer surplus) per unit of expenditures. This is depicted graphically in Figure 1 as the

<sup>11</sup> The availability of varieties to downstream firm  $i$  may be exogenous or endogenous to  $i$ . For example, it could be that the mass of varieties  $i$  has access to responds to  $i$ 's productivity. This could be because of decisions made by  $i$ 's suppliers if more suppliers choose to make their variety available to  $i$  when  $i$  is more productive. Or it could be because of decisions made by  $i$ , who may be willing to pay the fixed costs necessary for gaining access to more suppliers when it is more productive. We do not endogenize the availability of inputs and only consider  $i$ 's variable cost minimization taking the availability of varieties as given. A fully specified model would be required for counterfactuals.

<sup>12</sup>In equation (1), we suppress dependence of the conditional input demand  $x_{iJ}$  on arguments other than the price of  $J$  since those other arguments are being held constant. We include the additional arguments when it helps the exposition.

ratio of  $A$  to  $B$ . As long as the demand curve is strictly downward sloping,  $\delta_{iJ}$  is strictly positive. If the demand curve for an individual input variety is perfectly horizontal, as in perfectly competitive models, then  $\delta_{iJ} = 0$ .

Suppose that there is a continuum of input varieties of each type. Let  $\Delta M_{iJ}^{add}$  be the mass of inputs of type  $J$  that  $i$  gains access to (i.e. the price jumps down from infinity to  $p_J < \infty$ ), and  $\Delta M_{iJ}^{sep}$  be the mass of inputs of type  $J$  that  $i$  loses access (i.e. the price jumps to infinity from  $p_J$ ). Denote the input share of each type- $J$  variety purchased by firm  $i$  to be  $\Omega_{iJ}$ :

$$\Omega_{iJ} = \frac{p_J x_{iJ}(\mathbf{p}, A)}{C_i(\mathbf{p}, A_i, q_i)}.$$

The next proposition, proved in the appendix, loglinearizes the downstream firm's marginal cost and shows that  $\delta_{iJ}$  captures the consequences, per dollar of expenditures, associated with the availability of type  $J$  varieties for  $i$ 's unit cost.

**Proposition 1** (Downstream Marginal Cost). *Consider a downstream firm  $i$  facing a change in the vector of input prices by type  $\Delta \mathbf{p}$ , the measure of available inputs by type  $\Delta M_i^{add}$  and  $\Delta M_i^{sep}$ , and the technology parameter  $\Delta A_i$ . To a first-order approximation in these primitives, the change in the downstream firm's marginal cost is*

$$\Delta \log mc_i \approx \underbrace{\sum_J \Omega_{iJ} M_{iJ} \Delta \log p_J}_{\text{marginal changes}} - \underbrace{\sum_J \Omega_{iJ} \Delta M_{iJ} \delta_{iJ}}_{\text{inframarginal changes}} + \underbrace{\frac{\partial \log C_i}{\partial \log A_i} \Delta \log A_i}_{\text{own technology}} \quad (2)$$

where  $M_{iJ}$  is the initial mass of inputs of type  $J$  and  $\Delta M_{iJ} = \Delta M_{iJ}^{add} - \Delta M_{iJ}^{sep}$  is the net change in the mass of available inputs of type  $J$ .

In words, the log change in the marginal cost of the downstream firm depends on the costs of its inputs, captured by the first two summands, as well as its own technology, captured by the last summand. The price of inputs can change on the margin or they can jump. If the change in input prices is small, then their effect on the downstream firm's marginal cost depends on the expenditures on the input. On the other hand, if input prices jump discretely, then their effect on the downstream firm's marginal cost depends on the area under the input demand, which is captured by the product of  $\delta_{iJ}$ , and expenditures on the inputs whose price jumps  $\Omega_{iJ} \Delta M_{iJ}$ . That is, changes in the availability of inputs generate surplus for the downstream producer according to the total area under the input demand curve above the price. Hence, the value of having access to suppliers is not  $\delta_{iJ}$  (the object we estimate) but the product of  $\delta_{iJ}$  and the expenditure share  $\Omega_{iJ}$  (which is directly observable).

Additions and subtractions of suppliers that happen smoothly, without a discontinuous change in the price, do not affect the marginal cost of the downstream firm to a first-order. The expenditure share on varieties that are added or dropped in this way is zero at the choke price where they are added or dropped. Hence, their impact on the downstream firm's marginal cost is also zero to a first order by Shephard's lemma. This comment also applies to additions and separations that are caused by shifts in the input demand curve (as opposed to movements along the input demand curve). That is, if a shock to other suppliers or technology causes a given supplier to be added or dropped by moving its input demand curve in a continuous fashion, then this has no first-order effect on the overall addition and separation share and does not affect (2).

To better understand Proposition 1, we work through some simple examples.

**Example 1** (CES with Expanding Varieties). Consider the CES special case where demand for inputs of type  $J$  is

$$x_{ij} = \frac{\omega_{ij} p_J^{-\sigma} q_i}{\left( \sum_K \omega_{iK} p_K^{1-\sigma} M_{iK} \right)^{\frac{-\sigma}{1-\sigma}}}, \quad (3)$$

where  $\omega_{ij}$  and  $\omega_{iK}$  are exogenous parameters and  $\sigma > 1$ . If some measure of  $J$  inputs become unavailable to  $i$ , then the price of those inputs jumps from  $p_J$  to infinity. In this case, the inframarginal surplus ratio is

$$\delta_{ij} = \frac{\int_{p_J}^{\infty} x_{ij}(\tilde{\xi}) d\tilde{\xi}}{p_J x_{ij}} = \frac{1}{\sigma - 1} \geq 0.$$

Hence, in response to a change in the availability of some varieties of type  $J$ , the change in the downstream marginal cost is

$$\Delta \log mc_i \approx -\Omega_{iJ} \Delta M_{iJ} \delta_{ij} = -\Omega_{iJ} \Delta M_{iJ} \frac{1}{\sigma - 1}. \quad (4)$$

This is the so-called "love-of-variety" effect.

Quality-ladder models can also be represented using this formalism by pairing additions and separations together as illustrated in the following example.

**Example 2** (CES with Quality Ladders). Consider the CES special case again. To capture creative destruction, suppose that a measure  $\Delta M$  of producers of inputs of a certain type with quality-adjusted price  $p_J$  exit and are replaced by a measure  $\Delta M$  of competitors with the same input demand curve but lower price  $p_{J+1}$ , where the sub-index  $J + 1$  indicates a higher rung of the quality ladder.

Proposition 1 implies that the change in the marginal cost of  $i$  is

$$\Delta \log mc_i \approx \Omega_{ij} \delta_J \Delta M - \Omega_{iJ+1} \delta_{J+1} \Delta M = \Omega_{ij} \Delta M \left( 1 - \left( \frac{p_{J+1}}{p_J} \right)^{1-\sigma} \right) \frac{1}{\sigma-1} < 0. \quad (5)$$

The effect on the downstream firm's marginal cost is depicted graphically in Figure 2.

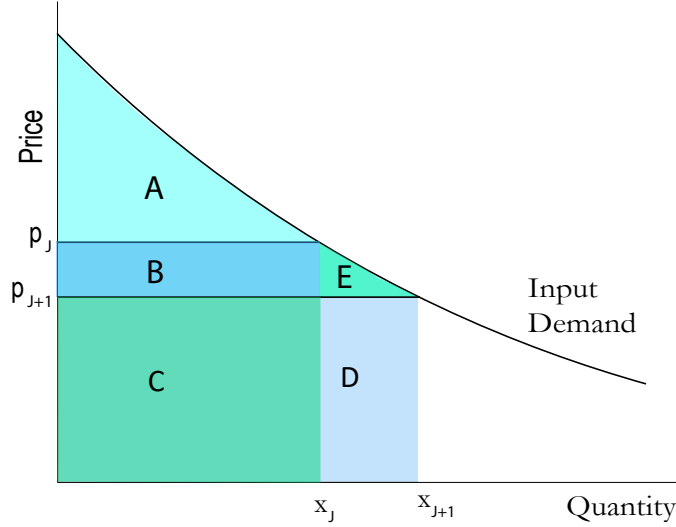


Figure 2: The inframarginal surplus ratio is  $\delta_J = \frac{A}{B+C}$  and  $\delta_{J+1} = \frac{A+B+E}{C+D}$  for suppliers selling at price  $p_J$  and  $p_{J+1}$ . The decline in marginal cost is proportional to the change in consumer surplus,  $(B + E)$ .

The inframarginal surplus ratio associated with the suppliers selling at  $p_J$  and  $p_{J+1}$  is the same since the residual demand curve is isoelastic,  $\delta_J = \delta_{J+1} = 1/(\sigma - 1)$ . However, the marginal cost of the downstream firm falls since the expenditure share on  $J + 1$  suppliers is higher than  $J$  suppliers.<sup>13</sup> The size of the reduction in  $i$ 's marginal cost depends on the elasticity of substitution,  $\sigma$ , and the quality/price gap between  $p_J$  and  $p_{J+1}$ . In many quality-ladder models, the elasticity of substitution between varieties is equal to one. In the limit as  $\sigma$  approaches one, the change in marginal cost in (5) converges to  $\Omega_{ij} \Delta M \log(p_{J+1}/p_J)$ , where  $\log(p_{J+1}/p_J)$  is the step-size of the quality-ladder.

The inframarginal surplus ratio need not be the same for all input types, as the example below demonstrates.

<sup>13</sup>Equivalently, the value of a supplier to the downstream firm in quality ladder models can be represented by the area under the input demand of  $J + 1$  suppliers minus expenditures on this supplier. Input demand for any individual supplier  $J + 1$  drops to zero if its price exceeds that of a competitor in the lower rung  $p_J$ , so the surplus is again  $B + E$  in Figure 2.

**Example 3** (Heterogenous Surplus Ratios). Consider a unit cost function defined by<sup>14</sup>

$$1 = \sum_J M_{iJ} \frac{\omega_{iJ}}{\sigma_J - 1} \left( \frac{p_J}{mc_i} \right)^{1-\sigma_J}.$$

If  $\sigma_J = \sigma$  for every  $J$ , then this is a CES technology. The input demand curve for a type  $J$  variety is

$$x_{iJ} = \frac{\omega_{iJ} \left( \frac{p_J}{mc_i} \right)^{-\sigma_J} q_i}{\sum_K M_{iK} \omega_{iK} \left( \frac{p_K}{mc_i} \right)^{1-\sigma_K}},$$

where  $q_i$  is total quantity. Accordingly, the inframarginal surplus associated with input  $J$  is

$$\delta_{iJ} = \frac{\int_{p_J}^{\infty} x_{iJ}(\xi) d\xi}{p_J x_{iJ}} = \frac{1}{\sigma_J - 1},$$

which need not be the same for all inputs and can be independent from spending shares  $\Omega_{iJ}$ .

Due to the near-ubiquitous use of the CES demand system, “love-of-variety” is sometimes conflated with the price elasticity of demand. However, as pointed out by Dixit and Stiglitz (1977), outside of the expanding-variety CES model, these two statistics are not the same. In fact, under a plausible condition (Marshall’s second law of demand), the surplus produced by new varieties is strictly lower than that implied by the CES demand system.

**Example 4** (Inframarginal Surplus with Marshall’s Second Law). Denote the own-price elasticity of  $i$ ’s demand for input  $J$  by  $\sigma_{iJ}(\mathbf{p}) = -\frac{\partial \log x_{iJ}(\mathbf{p})}{\partial \log p_J} > 1$ . Marshall’s second law of demand holds if  $\partial \sigma_{iJ} / \partial p_J > 0$ . Under this condition,

$$\delta_{iJ}(\mathbf{p}) < \frac{1}{\sigma_{iJ}(\mathbf{p}) - 1} \tag{6}$$

as long as  $\sigma_{iJ}(\mathbf{p}) \geq 1$ . The right-hand side of (6) is the inframarginal surplus ratio implied by a CES demand system calibrated to match the same price elasticity of demand.<sup>15</sup> Hence, under Marshall’s second law of demand and matching a given elasticity of demand, CES maximizes the inframarginal surplus ratio.

<sup>14</sup>See Matsuyama and Ushchev (2020a) who introduce and provide more information on this demand system.

<sup>15</sup>The proof of (6) in the appendix uses ideas from Matsuyama and Ushchev (2020b) and Grossman et al. (2021). They prove a similar result assuming the input demand system belongs to the HSA/HDIA/HIIA class.

Inframarginal surplus ratios can vary even if all types face the same input demand curve when the input demand curve is not isoelastic. When Marshall's second law holds, we can show that the inframarginal surplus ratio systematically falls with the price of the input:

$$\frac{\partial \delta_J}{\partial p_J} < 0. \quad (7)$$

### 3 Microeconomic Results: Empirics

In this section, we consider regressions aimed at identifying the inframarginal surplus ratio associated with gaining and losing access to suppliers. We begin by describing our specification, which is motivated by Proposition 1. We then describe the instruments, discuss the identification assumptions, and describe our data. We end the section with our regression results.

#### 3.1 From Theory to Baseline Regression

Define

$$\Delta M_{iJ,t}^{add} = \sum_{j \in J} \mathbf{1}(\Omega_{iJ,t+1} > 0) \mathbf{1}(p_{ij,t} = \infty) \mathbf{1}(p_{ij,t+1} = p_{iJ,t+1}) \quad (8)$$

to be the mass of inputs of type  $J$  that  $i$  did not have access to in  $t$  but does have access to in  $t + 1$ . The notation  $j \in J$  above means that  $j$  is an individual variety of type  $J$ . Similarly, define the mass of varieties that  $i$  loses access to be

$$\Delta M_{iJ,t}^{sep} = \sum_{j \in J} \mathbf{1}(\Omega_{iJ,t} > 0) \mathbf{1}(p_{ij,t} = p_{iJ,t}) \mathbf{1}(p_{ij,t+1} = \infty). \quad (9)$$

This is the mass of varieties with positive demand in  $t$  whose price goes to infinity at  $t + 1$  and are no longer available to  $i$ .

In our empirical work, we do not explicitly map suppliers to types but instead estimate average effects over all types. To that end, define the (weighted) average inframarginal surplus associated with additions and separations as

$$\bar{\delta}_{i,t}^{add} = \sum_J \left( \frac{\Omega_{iJ,t} \Delta M_{iJ,t}^{add}}{\sum_K \Omega_{iK,t} \Delta M_{iK,t}^{add}} \delta_{iJ,t+1} \right), \quad \bar{\delta}_{i,t}^{sep} = \sum_J \left( \frac{\Omega_{iJ,t} \Delta M_{iJ,t}^{sep}}{\sum_K \Omega_{iK,t} \Delta M_{iK,t}^{sep}} \delta_{iJ,t} \right).$$

As an example, if the cost function is CES with elasticity  $\sigma$ , then  $\bar{\delta}_{i,t}^{add} = \bar{\delta}_{i,t}^{sep} = 1/(\sigma - 1)$ .

Given these definitions, we can rewrite Proposition 1 as

$$\Delta \log mc_{i,t} \approx -\bar{\delta}_{i,t}^{add} \sum_J \Omega_{iJ,t+1} \Delta M_{iJ,t}^{add} + \bar{\delta}_{i,t}^{sep} \sum_J \Omega_{iJ,t} \Delta M_{iJ,t}^{sep} + \sum_J \Omega_{iJ,t} M_{iJ,t} \Delta \log p_{J,t} + \mathcal{E}_{Ai,t} \Delta \log A_{i,t}, \quad (10)$$

where  $\mathcal{E}_{Ai,t}$  is the elasticity of the cost function with respect to productivity shocks and we ignore higher order terms.

The first two terms on the right-hand side of (10) capture the effect of gaining and losing access to varieties. In the expression above, the per-variety expenditure share of added suppliers is measured at  $t + 1$ , whereas the per-variety expenditure share of separating suppliers is measured at  $t$ . Since we work with a first-order approximation, we can use elasticities before the shock, at  $t$ , or after the shock, at  $t + 1$ , and both are valid first-order approximations. We use the expenditure share of added suppliers in  $t + 1$  because the type-specific expenditure share,  $\Omega_{iJ,t}$ , for a variety that is added in  $t + 1$  is not known in  $t$  (unless one maps a supplier added at  $t + 1$  to suppliers who are of the same type at  $t$ ). Similarly, we use the expenditure share of separating suppliers in  $t$  because the type-specific expenditure share,  $\Omega_{iJ,t+1}$ , of a variety that separates in  $t$  is not known in  $t + 1$ .

We wish to use a regression to identify the average inframarginal surplus ratios  $\bar{\delta}^{add}$  and  $\bar{\delta}^{sep}$  in (10). Unfortunately, we cannot perfectly observe any of the right-hand variables. The potential confounders in (10) are marginal price changes,  $\sum_K \Omega_{iK,t} M_{iK,t} \Delta \log p_{K,t}$ , and own technology shocks,  $\mathcal{E}_{Ai} \Delta \log A_{i,t}$ . Since we do not observe all continuing input price changes and technology shocks, a simple regression can suffer from omitted variable bias.

More subtly, we also may not be directly observing the addition and separation regressors in (10). In the data, we observe overall additions and separations of suppliers. In principle, we do not know if these additions are due to movements along the input demand curve, as in (8) and (9), or due to shifts of the input demand curve.

As explained in Section 2, additions and separations that happen smoothly due to shifts in the input demand curve, without a jump in expenditure shares, do not affect either the marginal cost of the downstream firm or the addition and separation shares (since expenditure shares on these suppliers are zero).

However, we might worry that some additions and separations are caused by discontinuous shifts in the input demand curve rather than by price jumps. To allow for this possibility, in this section we enrich the model to allow for discontinuous jumps in input demand curves due to biased downstream technology shocks, similar to the way we allow for jumps in input prices. Additions and separations caused by these input demand

shocks affect the addition and separation shares but have no independent first order effect on the downstream firm's marginal cost (beyond the direct effect of the shock that caused the demand curve to shift in the first place). That is, when biased discrete downstream technology shocks are present, equation (10) is unaltered except that the direct effect of these shocks is included in the technology term  $\mathcal{E}_{Ai,t}\Delta \log A_{i,t}$ .

Define the overall addition share

$$\Delta \tilde{M}_{ij,t}^{add} = \sum_{j \in J} \mathbf{1}(\Omega_{ij,t+1} > 0) \mathbf{1}(\Omega_{ij,t} = 0)$$

and the overall separation share

$$\Delta \tilde{M}_{ij,t}^{sep} = \sum_{j \in J} \mathbf{1}(\Omega_{ij,t} > 0) \mathbf{1}(\Omega_{ij,t+1} = 0)$$

to be the measure of suppliers that  $i$  adds and separates from between  $t$  and  $t + 1$ . Unlike (8) and (9), the overall addition and separation shares are directly observable. However, due to the possibility that some separations and additions may be caused by biased downstream shocks,  $\Delta \tilde{M}_{ij,t}^{add}$  and  $\Delta \tilde{M}_{ij,t}^{sep}$  are not necessarily equal to  $\Delta M_{ij,t}^{add}$  and  $\Delta M_{ij,t}^{sep}$ . The difference is additions and separations caused by discontinuous shifts of the input demand curve.

We consider a regression of the form

$$\Delta \log mc_{i,t} = -\hat{\delta}^{add} \underbrace{\sum_J \Omega_{ij,t+1} \Delta \tilde{M}_{ij,t}^{add}}_{\text{addition share}_{i,t}} + \hat{\delta}^{sep} \underbrace{\sum_J \Omega_{ij,t} \Delta \tilde{M}_{ij,t}^{sep}}_{\text{separation share}_{i,t}} + \hat{\gamma}' W_{i,t} + \varepsilon_{i,t}, \quad (11)$$

where  $W_{i,t}$  are controls. The error term contains the same potential confounds as (10), the additional terms associated with  $\Delta \tilde{M}_{ij,t}^{add} - \Delta M_{ij,t}^{add}$  and  $\Delta \tilde{M}_{ij,t}^{sep} - \Delta M_{ij,t}^{sep}$ , and errors from the first order approximation.

To overcome the identification challenges, we use an instrumental variables strategy that we describe in the next section.

## 3.2 Identification Strategy

In this section we describe our identification strategy and our instruments. Since we have two regressors, we need two instruments. We instrument for separations and additions using a subset of firm deaths and births. Let  $S_{j,t}$  be the sales of supplier firm  $j$  in period  $t$ .



For each Prodcum firm  $i$  in year  $t$ , our first instrument is

$$Z_{i,t}^{death} = \sum_j \Omega_{ij,t} \mathbf{1}(S_{j,t+1} = 0) \mathbf{1}(p_{j,t} x_{ij,t} / S_{j,t} < \text{cutoff}). \quad (12)$$

In words, we add up the expenditure share relative to variable costs,  $\Omega_{ij,t}$ , of  $i$ 's suppliers that exit the market ("die") between  $t$  and  $t + 1$  and for whom  $i$  is a small customer in the sense that  $i$ 's purchases from  $j$  as a fraction of  $j$ 's total sales are lower than some cutoff (in our benchmark results, 5%). We call this the *restricted death* instrument.

Our second instrument is

$$Z_{i,t}^{birth} = \sum_j \Omega_{ij,t+1} \mathbf{1}(S_{j,t} = 0) \mathbf{1}(p_{j,t+1} x_{ij,t+1} / S_{j,t+1} < \text{cutoff}). \quad (13)$$

In words, we add up the expenditure share relative to variable costs,  $\Omega_{ij,t+1}$ , of  $i$ 's suppliers that enter the market (are "born") between  $t$  and  $t + 1$  and for whom  $i$  is a small customer (in our benchmark results, less than 5% of  $j$ 's sales). We call this the *restricted birth* instrument.

The following proposition formalizes our identification strategy.

**Proposition 2** (Identification). *Consider the regression in (11). Suppose that, conditional on the controls  $W_{i,t}$ , the instruments are mutually independent of the error term in the first and second stage as well as  $\bar{\delta}_{i,t}^{add}$  and  $\bar{\delta}_{i,t}^{sep}$ . Then the estimates  $\hat{\delta}^{add}$  and  $\hat{\delta}^{sep}$  consistently estimate  $\mathbb{E}[\bar{\delta}_{i,t}^{add}]$  and  $\mathbb{E}[\bar{\delta}_{i,t}^{sep}]$  respectively.*

In words, we require that, conditional on the controls, our two instruments are independent of own-technology shocks, changes in unobserved prices of competing inputs, and additions and separations that are due to shifts of the demand curve (these are the error terms in the second stage). We also require that, conditional on the controls, additions and separations that are uncorrelated with our instruments (these are the error terms in the first stage) are also independent of our instruments. Furthermore, since the average inframarginal surplus ratio for additions and separations for each downstream firm is itself a random variable, we require that they be independent of the restricted birth and death instruments. Under these conditions, the IV regression yields consistent and unbiased estimates of the average inframarginal surplus ratio for additions and separations.

Our instruments isolate churn due to births and deaths of suppliers. This is to ensure that those additions and separations reflect a movement along the input demand curve rather than a shift of the input demand curve. That is, if a supplier separates because it ceased operations or a supplier is added because it began operations, the price of the

inputs the supplier provides must be jumping from infinity to finite values (for additions) or vice versa (for separations).

Although the birth or death of a supplier causes its price to jump, there is no guarantee that this price jump is uncorrelated with idiosyncratic shocks to the downstream firm. For example, a supplier may cease or begin operations because its main client received a technology shock. The requirement that the downstream firm be a small customer for the supplier is to ensure that idiosyncratic shocks to the downstream firm do not cause the upstream firm to enter or exit the marketplace.<sup>16</sup>

We include controls for prices of continuing suppliers (if we observe them), industry by time fixed effects (defined as the product code of each firm’s best selling product), and a firm fixed effect. Prices of continuing suppliers and industry by year fixed effects control for the possibility that suppliers’ decisions to exit or enter the market may be caused by shocks to competitors. Firm fixed effects control for the possibility that our instruments are correlated with trends in the downstream firm’s marginal cost.

Our formal identification result also requires that, conditional on controls, the average inframarginal surplus ratio for each downstream firm is independent of the restricted births and deaths of suppliers (this is automatic if  $\delta$  is a constant, as in CES). This assumption does not imply that  $\delta$  is unrelated to expenditure shares within types. Instead, it requires that the average  $\delta$  for the downstream firm be uncorrelated with total (rather than per variety) expenditures on restricted births and deaths. Appendix E provides Monte Carlo simulations showing that even when  $\bar{\delta}_{i,t}^{add}$  and  $\bar{\delta}_{i,t}^{sep}$  are correlated with the instruments, the bias in our estimates is quite small.<sup>17</sup>

### 3.3 Data

In this section we describe how we map our model to data and how we construct the terms in the baseline regression (11). Our empirical analysis makes use of a rich micro-level data structure on Belgian firms in the period 2002-2018. The data structure brings together information drawn from six comprehensive panel-level data sets: (i) the National Bank of Belgium’s (NBB) Central Balance Sheet Office (CBSO), which we refer to

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<sup>16</sup>Even if downstream productivity shocks are uncorrelated with supplier births for which the firm is a small customer, the firm’s adoption or link formation decision may be correlated with own productivity shocks. In this case, firm births would predict adoption not only of newly-born suppliers but also of pre-existing suppliers. However, our birth instrument does not predict additions of non-newly-entering suppliers (see Table A6 in Appendix D).

<sup>17</sup>We can weaken this assumption by modeling how  $\delta$  depends on observables (e.g. the sector or expenditure share of the supplying firm). However, this comes at the expense of reduced power. Table A10 in Appendix D provides some analysis along these lines.

as the annual accounts; (ii) the Belgian Prodcom Survey, which covers firms that produce goods covered by the Prodcom classification and that have at least 20 employees or 5 million euros turnover in the previous reference year; (iii) the NBB Business-to-Business (B2B) Transactions data; (iv) International Trade data at the NBB; (v) VAT returns; and (vi) the Crossroads Bank of Enterprises (CBE) which we use to identify mergers and acquisitions.<sup>18</sup> Additional details are provided in Appendix C.

**Downstream firms.** Our sample of downstream firms are firms in the Prodcom survey, where we observe data on quantities sold (which are required to measure marginal costs). We restrict the sample to non-financial corporations that file the annual accounts. To ensure that Prodcom variables are representative of a firm's overall activities, we restrict the sample to those firms whose Prodcom sales are at least 30% of the firm's total sales.<sup>19</sup> Our micro sample contains roughly between 2,000 and 4,000 downstream firms per year. We now describe how we measure a number of key variables for these downstream firms.

**Sales and value-added.** We obtain value added from the annual accounts, which is used to construct the National Income and Product Accounts in Belgium.<sup>20</sup> We define firms' total sales as the highest value between sales reported in the annual accounts (reported mainly by large firms) and sales reported in the VAT returns. We replace this measure of sales by the sum of exports reported in the international trade data set and sales to other Belgian firms reported in the B2B VAT data set if the latter exceeds the former. We drop observations where value added exceeds sales.

**Total variable costs.** Firms' input costs consist of purchases of intermediates, labor costs, and the user cost of capital. We let a fraction of labor and capital be overhead inputs, but assume intermediates purchases are fully variable inputs. Intermediate input purchases are defined to be sales minus value added, measured as defined above. Labor costs are reported in the annual accounts. The cost of capital is defined as the product of the capital

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<sup>18</sup>See [https://www.nbb.be/doc/dq/e\\_method/gni\\_methodological\\_inventory\\_belgium\\_version\\_2022\\_publication.pdf](https://www.nbb.be/doc/dq/e_method/gni_methodological_inventory_belgium_version_2022_publication.pdf) for a description of the annual accounts (page 589), VAT returns (page 589), and Prodcom (page 603) data sets.

<sup>19</sup>Total sales may differ from Prodcom sales because, for example, firms sell products that they do not produce (Bernard et al. 2019) or they sell services along with the goods they produce (Ariu et al. 2020). The ratio of Prodcom sales to total sales is 0.89 for the median firm in our sample.

<sup>20</sup>Page 81 in [https://www.nbb.be/doc/dq/e\\_method/gni\\_methodological\\_inventory\\_belgium\\_version\\_2022\\_publication.pdf](https://www.nbb.be/doc/dq/e_method/gni_methodological_inventory_belgium_version_2022_publication.pdf) states that the annual accounts are the preferred source for estimating aggregates of the production and primary distribution of income account of non-financial corporations. The empirical results are similar if we measure sales using values reported in the annual accounts and, if the latter is missing, using values reported in the VAT returns.

stock reported by firms in the annual accounts (which includes plants, property, equipment, and intellectual property) and an industry-specific user cost of capital. The latter is the sum of a risk premium (set as 5 percent) and the risk-free real rate (defined as the corresponding governmental 10 year-bonds nominal rate minus consumer price inflation at that time period) minus the industry-level depreciation rate,  $(1 - d) \times g$ , where  $d$  is the industry level depreciation rate (defined as consumption of fixed capital as a ratio of net capital stock) and  $g$  is the expected growth of the relative price of capital at the industry level (defined as the growth in the relative price of capital computed from the industry-specific investment price index relative to the consumer prices index in each year).

We allow for a fraction,  $\phi$ , of labor and capital costs to be variable and the remaining fraction,  $1 - \phi$ , to be overhead costs. To calibrate  $\phi$ , we follow a similar strategy to Dhyne et al. (2022). We regress the change in labor and capital costs on the change in intermediate costs (which we assume are fully variable) instrumented using a demand shock. We set  $\phi = 0.5$  because our estimates indicate that labor and capital costs rise by roughly 0.5 percent when intermediate purchases rise by 1 percent in response to a demand shock. (See Appendix C for more details). Our estimate of  $\phi$  is similar to that found by Dhyne et al. (2022).<sup>21</sup>

Given uncertainty over the extent of overhead costs, we redo our analysis under alternative assumptions. The results are quite robust to the value of  $\phi$ . First, we set  $\phi = 0.4$ . Second, we set  $\phi = 0.6$ . Third, we assume that capital costs are all overhead and keep  $\phi = 0.5$  for labor costs. Fourth, we abstract from overhead costs all together, setting  $\phi = 1$ . We report these robustness exercises in Appendix D.

**Prodcom quantities and unit values.** We construct changes in output quantities and unit values for the sample of firms in the Prodcom survey. Products are identified at the 8-digit level of the Prodcom product code (PC) classification, which is common to all EU member states.<sup>22</sup> Sales values (in euros) and quantities are available at the firm-PC8-month level. Quantities are reported in one of several measurement units (over two thirds of observation are in kilograms; other units include liters, meters, square meters, kilowatt, and kg of active substance). We aggregate monthly observations to yearly values to match the other data sets, and calculate log differences in quantities and unit values by PC8 product from year  $t$  to  $t + 1$ . As quantities and unit values can be noisy, we trim changes in these two variables at the 5-95th percentile level.

<sup>21</sup>Dhyne et al. (2022) also show that  $\phi$  is not correlated with firm size, which is consistent with our approach.

<sup>22</sup>As product codes tend to vary from year to year, we use the correspondence of 8-digit products in the Prodcom classifications that trace products over time used by Duprez and Magerman (2018).

For multi-product firms (defined as Prodcom firms that produce multiple PC8 products), we aggregate changes in quantities of individual products to the firm-level using a Divisia index, with weights given by the firm’s sales share of each product in the corresponding year. This quantity index is valid if we assume that demand for multi-product firms in Prodcom is homothetic. In this case, a Divisia index reliably aggregates multiple products into a single product bundle. For each firm, we also construct changes in unit values as log changes in Prodcom sales minus the Divisia quantity index.<sup>23</sup> We assign a product code to each firm according to its highest-selling product.

**Marginal cost.** For each firm in the Prodcom survey, we calculate the log change in marginal cost as

$$\Delta \log mc = \Delta \log \text{total variable costs} - \Delta \log \text{total quantity}, \quad (14)$$

which is valid as long as the scale elasticity of the variable cost function is constant. Unfortunately, we only observe changes in Prodcom quantities and not changes in total quantities. To address this, write

$$\Delta \log \frac{\text{total quantity}}{\text{Prodcom quantity}} = \Delta \log \frac{\text{total sales}}{\text{Prodcom sales}} + \text{error},$$

where the unobserved error term is the difference in log changes of average unit values between Prodcom and non-Prodcom sales of the same firm. We use this equation to impute the log change in total quantity, which we then use in (14). This imputation is innocuous as long as the unobserved error term is uncorrelated with our instruments.

We provide sensitivity analysis where we measure changes in marginal costs as log changes in Prodcom unit values minus log changes in markups. To do this, we calculate markups either as total sales relative to total variable costs, or using the methodology of De Loecker and Warzynski (2012) with production function estimates using the approach in Levinsohn and Petrin (2003).

Having described how we construct the left-hand side variable in (11), we now discuss how we construct the right-hand side variables. Constructing the right-hand side variables requires knowing the input shares of the downstream firms. For this purpose, we use the NBB B2B transactions data.

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<sup>23</sup>We obtain very similar results if we calculate changes in unit values as a Divisia index (sales-weighted) of changes in unit values by product rather than deflating sales by the quantity Divisia index.

**Intermediate input shares.** We construct input shares of Prodcum firms using the confidential NBB B2B Transactions data set. At the end of every calendar year, all VAT-liable in Belgium have to file a complete listing of their Belgian VAT-liable customers over that year. An observation in this data set refers to the sales value in euros of enterprise  $j$  selling to enterprise  $i$  within Belgium, excluding the VAT amount due on these sales. The reported value is the sum of invoices from  $j$  to  $i$  in a given calendar year. As every firm in Belgium is required to report VAT on all sales of at least 250 euros, the data has nearly universal coverage of all businesses active in Belgium. To control for misreporting errors, we drop a transaction if its value is higher than the seller's aggregate sales and higher than the buyer's total intermediate input purchases (which is reported separately). Since we are interested in variable inputs, we exclude suppliers that produce capital goods, identified from the Main Industrial Groupings (MIG) Classification of the EU (we report sensitivity to including these suppliers in the network). We also drop suppliers with unknown VAT numbers or that are part of the downstream firm (due to mergers and acquisitions).

**Separation and addition share.** For each Prodcum firm  $i$  and period  $t$ , using the B2B data, we identify the set of separating suppliers as those the firm buys from in  $t$  but does not buy from in  $t + 1$ . Similarly, the set of added suppliers are those that  $i$  does not buy from in  $t$  but does buy from in  $t + 1$ . We calculate the separation share $_{i,t}$  as the ratio of purchases of  $i$  from separating suppliers relative to variable costs at  $t$ . We calculate the addition share $_{i,t}$  as the ratio of purchases of  $i$  from added suppliers relative to variable costs at  $t + 1$ . In our regressions we drop observations with separation or addition shares higher than 0.5, and perform sensitivity analysis to this cutoff.<sup>24</sup>

**Restricted death and birth shares.** We construct the instruments defined in (12) and (13) by calculating for each downstream firm separation and addition shares over a restricted set of suppliers: those that exit or enter the market (firm deaths and births) and for whom the downstream firm accounts for less than 5% of the suppliers sales. We perform extensive sensitivity analysis to the value of this cutoff in Table 2.

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<sup>24</sup>Our data is annual, so the separation and addition share depend on the specific month that a supplier is added or subtracted. For example, a supplier that is dropped in the middle of the year contributes less to the separation share than a supplier that is dropped at the end of the year. However, because our measure of marginal cost is also based on annual data, the increase in marginal cost is also smaller if the supplier exits in the middle of the year than if the supplier exits at the end. This means that, up to the first order approximation, our estimates are not contaminated by the fact that suppliers may enter and exit at different points in time during the year.

**Controls.** In our regressions, we control for changes in the other components of marginal cost to the extent possible. For continuing upstream suppliers that happen to belong to Prodcom, we construct and control for the change in the unit values (see Duprez and Magerman, 2018 and Cherchye et al., 2021). We also measure and control for the price of labor by dividing total labor costs by total full time employed workers. We measure and control for the price of capital services via the user cost of capital as described above. We measure and control for changes in unit values of imported inputs using a firm-level Divisia index of changes in unit values faced by firm  $i$  at the CN8 product level, trimming changes in unit values at the 5th-95th percentile. We also construct, for each Prodcom firm, a price index of general input costs using industry-level price indices from Eurostat, with weights given by the firm’s industry shares in non-Prodcom input purchases.

Table A2 in Appendix D reports summary statistics for our Prodcom sample on the share of factors and intermediate inputs in variable costs, the number of suppliers, separation and addition share, and restricted death and birth shares. The average firm has 227 suppliers, and the average addition and separation share are around 6%. The restricted birth and death shares are much smaller than the overall separation and addition shares at around 0.2%.

Table A3 in Appendix D reports correlations of firm size (employment and sales) with the number of suppliers, additions and separations, and our instruments. Larger firms are connected to a higher number of suppliers. We also find that additions and separations are slightly negatively correlated with the size of the downstream firms (the addition and separation shares are lower for larger firms). Importantly, our instruments are not correlated with downstream firm size (restricted birth and death of suppliers are not correlated with size of downstream firms). This suggests that our instruments do not differentially cause exogenous variation in additions and separations for large versus small downstream firms. We also check for heterogeneous effects by interacting our point estimates with a dummy for firm size.

### 3.4 Results

Having discussed how the terms in the baseline regression (11) are constructed, we now turn our attention to the results.

The baseline results are shown in Table 1. Column (i) is an OLS regression of the overall addition and separation shares on the change in marginal costs with all controls. We find that separations have no effect on marginal costs and, paradoxically, additions

Table 1: Baseline estimates of  $\delta$ 

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
	$\Delta \log mc$		First stage		$\Delta \log mc$		$\Delta \log p$
			Separat.	Addit.			
Separation share	-0.001 (0.014)				0.306*** (0.105)	0.303*** (0.106)	0.209*** (0.080)
Addition share	0.037*** (0.013)				-0.329*** (0.090)	-0.335*** (0.090)	-0.188*** (0.070)
Restricted death share		0.240*** (0.091)	0.929*** (0.052)	0.126** (0.062)			
Restricted birth share		-0.288*** (0.083)	0.170*** (0.064)	1.012*** (0.046)			
Specification	OLS	OLS	OLS	OLS	IV	IV	IV
F-stat			282	345	113	108	108
Controls	Y	Y	Y	Y	N	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y
Observations	37,898	37,898	37,898	37,898	37,898	37,898	37,898

*Notes:* Columns (i), (v), and (vii) report estimates of regression (11), where columns (iii) and (iv) show the first stage, and column (vii) uses changes in unit values instead of marginal cost. Restricted exit share and restricted entry share are the instruments,  $Z_{i,t}^{death}$  and  $Z_{i,t}^{birth}$ , defined by equations (12) and (13). Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms and from other industries, changes in log wages, and changes in the log user cost of capital. All regressions are unweighted. Industry by time fixed effects are at the 6-digit product code level. Standard errors are clustered at the firm-level. The F-stat for the first-stage is the Sanderson-Windmeijer (SW) statistic and the F-stat for the second stage is the Kleibergen-Paap (KP) statistic.

slightly raise marginal costs. Of course, there is good reason to expect that this regression does not have a causal interpretation due to omitted variable bias. Column (ii) is a reduced-form regression of changes in marginal cost directly on the instruments. As expected, an increase in the restricted death share raises marginal costs and an increase in the restricted birth share lowers marginal costs.

Columns (iii) and (iv) are the first stage regressions showing that restricted death primarily predicts separations and restricted birth primarily predicts additions. However, restricted birth also has an effect on separations (due to creative destruction). Similarly, restricted death has an effect on additions (due to replacements of the exiting suppliers). Table A6 in Appendix D shows that the restricted birth instrument positively predicts separations from suppliers that continue to operate. Similarly, the restricted death instrument positively predicts additions of suppliers that previously operated. Hence,



our instruments do not solely affect additions of newly-born and separations from dying suppliers. Instead, restricted births predicts separations from continuing suppliers and restricted deaths predicts additions from continuing suppliers.

Columns (v) and (vi) are the IV regressions without and with controls. The point estimates are quite insensitive to the inclusion of the controls. We find that a 1% increase in the separating share raises marginal costs by around 0.3%. On the other hand, a 1% increase in the addition share lowers marginal costs by around 0.33%. Even though the inframarginal surplus point estimates for suppliers additions exceeds that for separations, we cannot reject that they are equal.<sup>25</sup>

The final column, (vii), replaces the change in marginal cost on the left-hand side with the change in the price (unit value) charged by the downstream firm. The effect of separations and additions on the price is smaller in magnitude than on marginal cost. The reduced-form pass-through of marginal cost into prices implied by this regression is about 65%. This is very close to the pass-through estimates from Amiti et al. (2019), who use the same data but a very different identification strategy.

Table 2 displays the results of the IV regression for different cut-off values of what constitutes a “small” customer in (12) and (13). The benchmark results in Table 1 use 5%. Table 2 shows that our results are reasonably robust to this choice and the point estimates remain between 0.25 and 0.35 for both additions and separations as long as the cut-off value is not too high (less than 15%).

The point estimates do start to change if the cut-off value becomes too large, however. Column (xi) shows the results if we use unconditional entry and exit of suppliers as instruments. The point estimates are very different in this case, where we include birth and death of suppliers who are heavily reliant on the downstream firm for their sales. In this case, shocks to the downstream firm can be responsible for supplier entry and exit, confounding our point estimates. The final column, column (xii), uses all separations and additions below a 5% cut-off, rather than separations and additions associated with

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<sup>25</sup>Table A7 in the appendix reports results from a specification of (11) where we regress changes in marginal cost on separations and additions separately. The point estimates are similar but slightly smaller in magnitude. If supplier births were not associated with separations, and if supplier deaths were not associated with additions, then the joint regression and the univariate regressions would give the same estimates for  $\bar{\delta}^{sep}$  and  $\bar{\delta}^{add}$ . However, as shown in columns (iii) and (iv) of Table 1, restricted death has an effect on additions and restricted birth has an effect on separations. The fact that the point estimates in the univariate regression are smaller in magnitude can be rationalized via quality-ladders and creative destruction. Consider a quality ladder model where separations and additions are paired together. If input demand is CES, as in Example 2, then the univariate regressions identify  $\frac{1}{\sigma-1} (1 - (p_{J+1}/p_J)^{1-\sigma})$  (in the separation regression) and  $\frac{1}{\sigma-1} ((p_{J+1}/p_J)^{1-\sigma} - 1)$  (in the addition regression) where  $p_{J+1}/p_J$  is the step-size in the quality ladder. These are necessarily smaller than  $1/(\sigma - 1)$ , which is what the joint regression estimates. In the limit  $\sigma \rightarrow 1$ , both univariate regressions identify the step size, whereas the joint regression cannot be considered because the addition and separation share are collinear.

birth and death of suppliers, as instruments. The point estimates are both zero — again, this reflects the fact that supplier addition and separation can be endogenous to other shocks that hit the downstream firm and shifts of the input demand curve, even if the downstream firm is small as a share of those suppliers’ overall sales.

Table 2: Sensitivity of point estimate of  $\delta$  to cut-off for small customer

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)
	$\Delta \log mc$											
Separation share	0.361*** (0.128)	0.331*** (0.110)	0.303*** (0.106)	0.327*** (0.101)	0.331*** (0.098)	0.318*** (0.093)	0.291*** (0.089)	0.246*** (0.087)	0.206** (0.080)	0.122** (0.057)	0.117*** (0.045)	0.021 (0.019)
Addition share	-0.271*** (0.104)	-0.263*** (0.091)	-0.335*** (0.090)	-0.327*** (0.089)	-0.296*** (0.085)	-0.273*** (0.080)	-0.267*** (0.078)	-0.251*** (0.076)	-0.223*** (0.064)	-0.066 (0.054)	0.047 (0.048)	0.015 (0.015)
Specification	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
F-stat	66	95	108	116	127	137	144	158	197	379	833	23941
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cutoff	3	4	5	6	7	8	9	10	15	50	100	5
Suppliers	D&B	D&B	D&B	D&B	D&B	D&B	D&B	D&B	D&B	D&B	D&B	All

*Notes:* Columns (i)-(xi) rerun the benchmark regression, column (vi) in Table 1, but vary the cut-off value from 3% to 100% for what constitutes a small customer for exiting and entering suppliers when defining restricted deaths and births (labeled D&B in the table). The benchmark regressions use a value of 5%. Column (xii) uses all separations and additions with a 5% cutoff, rather than only D&B. The number of observations is 37,898 in all regressions.

**Other sensitivity and placebo analyses.** Table 3 provides sensitivity of our estimates for different configurations of fixed effects. Column (i) is our baseline specification with 6-digit industry by year and firm fixed effects. Column (ii) replaces the industry by year fixed effect with a year fixed effect. Columns (iii) drops the firm fixed effect. Columns (iv) and (v) vary the disaggregation in the industry by year fixed effects, considering 4 or 8 digit product codes (rather than 6 digits). Our estimates are significant and quite robust across specifications with more or less stringent fixed effects. Column (vi) is a placebo test using lagged changes in marginal costs, which gives estimates close to zero and rules out pre-trends.

Additional sensitivities are included in Appendix D. We summarize the findings below. Table A8 in the appendix provides sensitivity to alternative measures of marginal cost. We vary the fraction of labor and capital costs that are overhead and we use a production function estimation approach to measure the change in marginal cost. We find similar results to our benchmark specification. Table A8 also considers a case where we allow for decreasing returns in the production function which slightly raises the magni-

Table 3: Estimates of  $\delta$  under different fixed effect configurations and a placebo test

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	$\Delta \log mc$					lagged $\Delta \log mc$
Separation share	0.303*** (0.106)	0.298*** (0.094)	0.268*** (0.091)	0.236** (0.103)	0.257*** (0.096)	-0.003 (0.145)
Addition share	-0.335*** (0.090)	-0.253*** (0.080)	-0.283*** (0.079)	-0.345*** (0.095)	-0.256*** (0.077)	0.060 (0.086)
Specification	IV	IV	IV	IV	IV	IV
F-stat	108	152	111	88	145	71
Controls	Y	Y	Y	Y	Y	Y
6d industry $\times$ year FE	Y	N	Y	N	N	Y
8d industry $\times$ year FE	N	N	N	Y	N	N
4d industry $\times$ year FE	N	N	N	N	Y	N
Year FE	N	Y	N	N	N	N
Firm FE	Y	Y	N	Y	Y	Y
Observ.	37,898	41,264	38,670	33,854	40,915	31,255

Notes: Columns (i)-(v) report estimates of regression (11) for different fixed effect configurations. Column (i) is our baseline. Other controls are as in Table 1. All regressions are unweighted. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

tude of our point estimates.<sup>26</sup>

Table A8 also provides two and three year cumulative changes in marginal costs. We find that the effect of supplier exits and entries are persistent, without much evidence of mean reversion. The fact that our estimates are not significantly larger at longer horizons suggests that inventories do not play a large role in helping the downstream firm smooth shocks in the short run. This is not unexpected since we focus on suppliers of non-durable/non-capital inputs. The fact that our estimates do not shrink at longer horizons suggests that downstream firms are unable to find better replacements over time when they lose suppliers. Similarly, the benefits of new suppliers to the downstream firm do not disappear over time (e.g. due to expiring discounts for new customers).

Table A9 in the appendix considers how results change if we vary the sample of firms. To reduce the possibility that the downstream firm changes the quality of its output in response to supplier additions and separations, column (i) restricts attention to downstream firms that do not change the mix of 8-digit products they offer and column (ii) focuses only on single product firms. In the latter case, the sample shrinks by half, and

<sup>26</sup>We assume an iso-elastic cost function,  $C_i(p, A_i, q_i) = c_i(p, A_i) q_i^{1.15}$ . Log changes in average variable costs are still equal to log changes in marginal costs, however, the change in marginal cost now depends on the change in output quantity, which we move to the left hand side of (11).

the estimated surplus ratio for separations increases but the one for additions stays similar.<sup>27</sup>

Table A9 also considers a more demanding formulation of the instruments where the downstream firm has to be a small customer for exiting suppliers not just in the year the supplier exits but also in the year prior to exit (column iii) and two years prior to exit (column iv). Similarly, when constructing the entry instrument, the downstream firm has to be a small customer for entering suppliers not just in the year of entry, but also the year after (column iii) or two years after (column iv) entry. The estimates are quite robust, except for the 3-year separation instrument, for which estimates lose precision.

To probe the possibility that the magnitude of the effects vary by the size of the downstream firm, column (v) weighs observations by employment and this raises our point estimate for separations to 0.42 but also raises the standard errors. We also consider, but do not report in the table, a specification where we interact separation and addition shares with an indicator for downstream firms larger than median firm size in each year. The estimated coefficient on this indicator is statistically insignificant from zero suggesting that the effects do not vary systematically by the size of the downstream firm.

The remaining columns in Table A9 provide sensitivity to choices that we make in our baseline specification, such as the minimum threshold in the ratio of a firm's Prodcom sales to the firm's total sales from the annual accounts as well as to our treatment of outliers.

Finally, Table A10 in the appendix considers different subsets of suppliers. This table shows that the effects are strongest and significant when focusing on service-providing suppliers (including wholesale and retail traders who are in service sectors, even though they sell goods). This is expected given that suppliers in the service sector account for the majority of intermediate inputs (see the summary statistics in Table A2). Additionally, our separation and addition instruments do not include imports, which plausibly are a very important source of goods trade for Belgian manufacturers. Table A10 also provides estimates if we include suppliers of capital goods as part of materials. Our benchmark excludes these suppliers because variable cost only includes the user cost of capital not

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<sup>27</sup>If quality changes are associated with changes in product codes, then restricting attention to firms that do not change their product mix or have only a single product should help alleviate mismeasurement associated with quality change. Even though the 8 digit product codes are very detailed (e.g. "throat pastilles and cough drops consisting essentially of sugars and flavouring agents excluding pastilles or drops with flavouring agents containing medicinal properties") a remaining concern is that, within 8 digit product codes, the downstream firm downgrades output quality in response supplier separation. In this case, we underestimate the rise in marginal cost because quality-adjusted quantity falls by more than measured quantity (and vice versa for supplier additions). In this case, our estimates of the inframarginal surplus ratio are biased towards zero.

investment. Nevertheless, including capital goods as part of variable costs barely affects our benchmark estimates. Table A10 also provides estimates where we exclude suppliers that are self-employed, government, and financial entities. This slightly lowers the magnitude of our point estimates.

## 4 Macroeconomic Results: Theory

In the previous section, we show that input suppliers generate a considerable amount of inframarginal surplus per unit of spending for their downstream customers. In this section we develop a growth accounting framework to decompose the fraction of aggregate productivity growth that can be accounted for by observed churn in supply chains. The model explicitly accounts for how changes in one firm’s marginal cost, due to additions and separations of suppliers, spill over to that firms’ customers, customers’ customers, and so on.

We discipline our macro growth accounting results using estimates from the micro sample which, recall, are estimated using only the Prodcom sample of manufacturing firms. However, we apply our growth accounting formulas to a much larger sample of Belgian firms.

We specify minimal structure on the aggregative model and do not fully specify the environment. This is because we take advantage of the fact that endogenous variables, like changes in factor prices, are directly observable and capture whatever resource constraints the economy is subject to.

### 4.1 Environment

Consider a set of producers, denoted by  $N$ , called the *network*. There is a set of *external inputs* denoted by  $F$ . An external input is an input used by producers in the network,  $N$ , that those producers do not themselves produce. In practice, the set  $F$  includes labor, capital, and intermediate inputs purchased from firms not in the network  $N$ . The firms in  $N$  collectively produce *final outputs*. Final output is the production by firms in  $N$  that firms in  $N$  do not themselves use. A stylized representation is given in Figure 3 showing the flow of goods and services.

**Production.** Each producer  $i \in N$  has a constant-returns-to-scale production technology in period  $t$  given by

$$q_{i,t} = A_{i,t} F_{i,t} \left( \{x_{ij,t}\}_{j \in N}, \{l_{if,t}\}_{f \in F} \right).$$

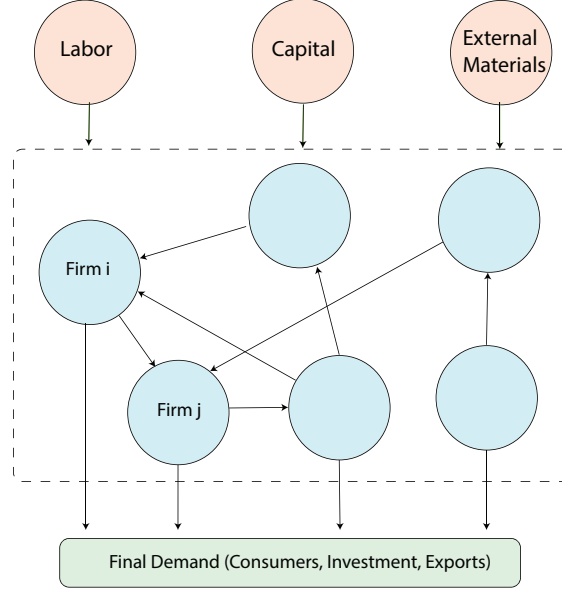


Figure 3: Graphical illustration of the economy. External inputs are red nodes and final output are green nodes. The set  $N$  is depicted by the dotted line.

In the expression above,  $l_{if,t}$  is the quantity of external input  $f$  and  $x_{ij,t}$  is the quantity of intermediate input  $j$  used by  $i$  at time  $t$ . The exogenous parameter  $A_{i,t}$  is a technological shifter. There may be fixed overhead costs that must be paid in addition to the variable production technology defined above, and we do not take a stance on these fixed costs for the time being. We abstract from multi-product firms and associate each firm with a single output.<sup>28</sup>

After having paid fixed costs, which could include the costs required to access specific inputs, the total variable costs of production paid by firm  $i$  are

$$\sum_{j \in N} p_{j,t} x_{ij,t} + \sum_{f \in F} w_{f,t} l_{if,t},$$

where  $p_{j,t}$  and  $w_{f,t}$  are the prices of internal and external inputs. The markup charged by each producer  $i$ ,  $\mu_{i,t}$ , is defined to be the ratio of its price  $p_{i,t}$  and its marginal cost of production.

We say that  $i$  is *continuing* between  $t$  and  $t + 1$  if  $i$  has positive sales in both  $t$  and  $t + 1$ . Denote by  $C_t$  the set of all goods who are continuing at time  $t$ .

<sup>28</sup>More precisely, we assume that demand for the products of multi-product firms can be aggregated into a single representative bundle.

**Resource constraints.** We construct a measure of net or final production by the set of continuing,  $C_t$ , firms. Let the total quantity of external inputs used by continuing firms be

$$L_{f,t} = \sum_{i \in C_t} l_{if,t} + \sum_{i \in C_t} l_{if,t}^{\text{fixed}},$$

where  $l_{if,t}$  is used in variable production and  $l_{if,t}^{\text{fixed}}$  are fixed costs. Firm  $i$ 's final output is defined to be the quantity of its production that is not sold to other firms in  $C_t$ :

$$y_{i,t} = q_{i,t} - \sum_{j \in C_t} x_{ji,t}.$$

That is, final output of good  $i \in C_t$ , denoted by  $y_{i,t}$ , is the quantity produced of  $i$  that is not used by any  $j \in C_t$  and is either consumed by households, used for investment, sold as exports, or sold to other suppliers that are not in the network of continuing producers.

**Aggregate growth.** We measure aggregate growth by deflating nominal final output by a price index. Growth in *real final output* of the set of continuing goods, denoted by  $\Delta \log Y_t$ , is the change in nominal final output minus the final output price deflator:

$$\Delta \log Y_t = \Delta \log \left( \sum_{i \in C_t} p_{i,t} y_{i,t} \right) - \Delta \log P_t^Y. \quad (15)$$

The change in the *final output price deflator* between  $t$  and  $t + 1$  is defined to be the share-weighted change in the price of continuing goods

$$\Delta \log P_t^Y = \sum_{i \in C_t} b_{i,t} \Delta \log p_{i,t},$$

where the weights are final output shares

$$b_{i,t} = \frac{p_{i,t} y_{i,t}}{\sum_{j \in C_t} p_{j,t} y_{j,t}}.$$

To calculate growth in real final output between  $t$  and  $t + T$ , we cumulate  $\Delta \log Y$ :

$$\log Y_{t+T} - \log Y_t = \sum_{s=t}^{t+T} \Delta \log Y_s.$$

Theoretically, this measure of aggregate growth accurately reflects social welfare over continuing goods if final demand for continuing goods is derived from a homothetic ag-

gregator (see Baqaee and Burstein, 2023 for a discussion of the necessary assumptions). Of course, this measure does not capture welfare from entry and exit of goods in final demand. Empirically, this measure of aggregate growth is constructed in a way that is similar to how real GDP is constructed. The primary difference is in how we treat external intermediate inputs (e.g. imported intermediate inputs). GDP-style measures subtract the value of imported intermediate inputs from final output. By not subtracting the value of external materials from final output, we treat external materials like factors of production (labor and capital).<sup>29</sup> The objective of this section is to decompose the contribution of supplier churn to growth in real final output.

## 4.2 Theoretical Results

To state our decomposition result, we need to set up some input-output notation. Define the  $C_t \times C_t$  cost-based input-output network of continuing firms with  $ij$ th element

$$\Omega_{ij,t} = \frac{p_{j,t}x_{ij,t}}{\sum_{k \in C_t} p_{k,t}x_{ik,t} + \sum_{f \in F} w_{f,t}l_{if,t}}.$$

Let  $\Omega^F$  be the  $C_t \times F$  matrix of external input usages, where the  $if$ th element is

$$\Omega_{if,t}^F = \frac{w_{f,t}l_{if,t}}{\sum_{k \in C_t} p_{k,t}x_{ik,t} + \sum_{f \in F} w_{f,t}l_{if,t}}.$$

We build on Proposition 1, which is about a single firm, to decompose aggregate growth  $d \log Y_t$ . To do this, rewrite Proposition 1 for all firms in  $C_t$  in matrix notation as

$$\Delta \log \mathbf{p}_t \approx \Delta \log \boldsymbol{\mu}_t - \Delta \log \mathbf{A}_t + \Omega_t \Delta \log \mathbf{p}_t + \Omega_t^F \Delta \log \mathbf{w}_t + \bar{\delta}_t^{\text{sep}} \Delta \mathcal{X}_t - \bar{\delta}_t^{\text{add}} \Delta \mathcal{E}_t,$$

where  $\mu_{i,t}$  is the markup of firm  $i$ , the ratio of price to marginal cost,  $\Delta \mathcal{X}_{i,t} = \sum_J \Omega_{iJ,t} \Delta M_{iJ,t}^{\text{sep}}$  is the cost share of suppliers who separate due to price jumps, and  $\Delta \mathcal{E}_{i,t} = \sum_J \Omega_{iJ,t+1} \Delta M_{iJ,t}^{\text{add}}$  is the cost share of suppliers who are added due to price jumps. In the expression above, we normalize the elasticity of the cost function with respect to the productivity shock to

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<sup>29</sup>If we subtract the value of external materials from final output, then our growth accounting expressions have an additional term involving the difference between expenditures on external materials and the elasticity of aggregate output with respect to external materials. This difference is nonzero in the presence of markups. See Baqaee and Farhi (2019a) for more details.



be one. Solve out for changes in the prices of continuing firms:

$$\Delta \log p_t \approx \Psi_t \left[ \Delta \log \mu_t - \Delta \log A_t + \Omega_t^F \Delta \log w_t + \bar{\delta}_t^{\text{sep}} \Delta \mathcal{X}_t - \bar{\delta}_t^{\text{add}} \Delta \mathcal{E}_t \right], \quad (16)$$

where  $\Psi_t$  is the *cost-based continuing* Leontief inverse

$$\Psi_t = (I - \Omega_t)^{-1} = \sum_{s=0}^{\infty} \Omega_t^s.$$

Equation (16) shows that changes in the price of continuing goods depend on changes in markups,  $\Delta \log \mu_t$ , productivity shifters,  $\Delta \log A_t$ , prices of external inputs,  $\Delta \log w_t$ , as well as the extensive margin terms,  $\Delta \mathcal{X}_t$  and  $\Delta \mathcal{E}_t$ . All of these effects are mediated by the forward linkages in the Leontief inverse  $\Psi_t$ .

Define the *cost-based continuing Domar weights* of  $i \in C_t$  and  $f \in F$  to be

$$\lambda_{i,t} = \sum_{j \in C_t} b_{j,t} \Psi_{ji,t}, \quad \text{and} \quad \Lambda_{f,t} = \sum_{j \in C_t} \lambda_{j,t} \Omega_{f,t}^F.$$

The cost-based continuing Domar weight  $\lambda_{i,t}$  measures the exposure of each continuing firm  $j$  to each continuing supplier  $i$ , captured by  $\Psi_{ji,t}$ , and averages this exposure by  $j$ 's share in the final output price deflator  $b_{j,t}$ . Substituting (16) into the definition of the final output price deflator yields the following first order approximation for the change in the output price deflator

$$\Delta \log P_t^Y \approx \sum_{i \in C_t} \lambda_{i,t} \left[ \Delta \log \frac{\mu_{i,t}}{A_{i,t}} + \bar{\delta}_{i,t}^{\text{sep}} \Delta \mathcal{X}_{i,t} - \bar{\delta}_{i,t}^{\text{add}} \Delta \mathcal{E}_{i,t} \right] + \sum_{f \in F} \Lambda_{f,t} \Delta \log w_{f,t}.$$

That is, shocks to  $i$  are transmitted into the final output price according to the cost-based Domar weight  $\lambda_{i,t}$ . Similarly, changes in the price of external input  $f$  affects the final output price deflator according to its cost-based Domar weight  $\Lambda_{f,t}$ .

Plugging this into the definition of real final output in equation (15) yields the following decomposition.

**Proposition 3** (Growth-Accounting with supplier-churn). *The change in real final output is*

given, to a first-order, by

$$\begin{aligned}
\Delta \log Y_t \approx & \underbrace{\sum_{i \in C_t} \lambda_{i,t} \Delta \log A_{i,t}}_{\text{technology}} + \underbrace{\sum_{f \in F} \Lambda_{f,t} \Delta \log L_{f,t}}_{\text{factor quantities}} \\
& - \underbrace{\sum_{i \in C_t} \lambda_{i,t} \Delta \log \mu_{i,t}}_{\text{markups}} - \underbrace{\sum_{f \in F} \Lambda_{f,t} \Delta \log \check{\Lambda}_{f,t}}_{\text{factor shares}} \\
& + \underbrace{\sum_{i \in C_t} \lambda_{i,t} \left( \bar{\delta}_{i,t}^{\text{add}} \Delta \mathcal{E}_{i,t} - \bar{\delta}_{i,t}^{\text{sep}} \Delta \mathcal{X}_{i,t} \right)}_{\text{supplier churn due to price jumps}},
\end{aligned}$$

where  $\check{\Lambda}_{f,t} = w_{f,t} L_{f,t} / \sum_{j \in C_t} p_{j,t} y_{j,t}$  is the income share of factor  $f$  at  $t$ .

Start by considering the neoclassical benchmark where inframarginal surplus is zero,  $\bar{\delta}^{\text{add}} = \bar{\delta}^{\text{sep}} = 0$ , and prices are equal to marginal cost,  $\mu = 1$ . In this case, Proposition 3 collapses to the standard Solow-Hulten formula, where only the first line is non-zero and cost-based Domar weights are equal to sales shares.

In the more general case, aggregate output growth can be broken down into the following terms. The first term is exogenous productivity growth weighted by cost-based Domar weights. This accounts for how exogenous improvements in technology affect output, taking into account the fact that improvements in each firm's technology will mechanically raise production by its consumers, and its consumers' consumers, and so on. The second term captures a similar effect but for changes in factor quantities — if the quantity of factor  $f$  rises, then that raises the production of all firms that use factor  $f$ , which raises the production of all firms that use the products of factor  $f$ , and so on.<sup>30</sup>

The second line captures the way changes in markups and factor prices affect output. An increase in  $i$ 's markup will raise  $i$ 's price, which raises the costs of production for  $i$ 's consumers, and  $i$ 's consumers' consumers, and so on. Similarly, if the factor share  $\check{\Lambda}_f$  of factor  $f$  rises more quickly than the quantity  $L_f$  of factor  $f$ , then this means that the relative price of factor  $f$  has increased. An increase in  $f$ 's price will raise the costs of production for all firms. An increase in markups or factor shares, therefore, raises prices and lowers output.<sup>31</sup>

<sup>30</sup>When we apply Proposition 3, we use a Tornqvist second-order adjustment. That is, although Proposition 3 is a first order approximation, we average the  $t$  and  $t + 1$  coefficients on each shock to provide a second order approximation. For example, we weigh  $\Delta \log L_{f,t}$ , the change in factor quantity  $f$  between  $t$  and  $t + 1$ , using the average of  $\Lambda_{f,t}$  and  $\Lambda_{f,t+1}$ .

<sup>31</sup>For counterfactuals, we need to be able to solve for changes in factor shares. This requires modeling

The last line is what this paper is focused on and captures the effects of supplier churn on output. It measures the reduction in the final-goods price deflator caused by jumps in input prices due to supplier churn, holding fixed technologies of continuing firms, markups, and factor prices. Churn at the level of each individual firm percolates to the rest of the economy through the input-output network and this effect is captured by weighing the extensive margin terms by the cost-based Domar weight of each firm and summing across all firms. This captures the idea that if one firm's marginal costs change from separations and additions of suppliers, then those marginal cost changes will propagate to that firm's consumers, its consumers' consumers, and so on. The elasticity of aggregate output with respect to additions and separations for firm  $i$  is  $\lambda_i \bar{\delta}^{add}$  and  $\lambda_i \bar{\delta}^{sep}$ .

In the next section, we show results for different values of  $\bar{\delta}$  given observed additions and separations. This exercise is analogous to computing the contribution of, say, capital to growth given observed investment under different assumptions about the elasticity of output with respect to capital. Although useful for inspecting the mechanisms driving aggregate growth, as in standard growth accounting, the results cannot be used to make counterfactual statements since, just like capital, supplier churn is endogenous.

## 5 Macroeconomic Results: Empirics

In this section, we apply Proposition 3 to decompose aggregate growth for a large subset of the Belgian economy. In the first part of this section, we describe how we map the data to the terms in Proposition 3. In the second part of this section, we show the results.

### 5.1 Mapping to Data

Proposition 3 is exact in continuous time if the primitive shocks are smooth functions of time. Following standard practice in the growth accounting literature (Solow, 1957), we map our model to data using a discrete-time approximation of the continuous time limit. To apply Proposition 3, we need to define the set of continuing firms  $C_t$ , the matrices  $\Omega_t$  and  $\Omega_t^F$ , the average inframarginal surplus parameters  $\bar{\delta}_{i,t}^{add}$  and  $\bar{\delta}_{i,t}^{sep}$ , the share of additions and separations due to price jumps,  $\Delta \mathcal{E}_t$  and  $\Delta \mathcal{X}_t$ , changes in markups  $\Delta \log \mu_{i,t}$ , the growth in external input quantities (labor, capital, and external materials), and the growth in final real output. The exogenous technology term in Proposition 3 is a residual. We discuss how we construct these terms in turn.

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the details of fixed costs and entry decisions. However, conditional on changes in factor shares, we do not need to specify these details.

**Assigning the continuing network set.** We construct the network of domestic firms using the NBB B2B Transactions data set, which has near-universal coverage of domestic firms. This data set contains the values of yearly sales relationships among all VAT-liable companies for the years 2002 to 2018, and is based on the VAT listings collected by the tax authorities. We calculate an output measure for a subset of continuing, non-financial domestic Belgian corporations. We exclude self-employed, government, financial entities, and non-financial corporations in non-market services (NACE codes 84 and higher) because these sectors are not well-covered by VAT data (for example, hospitals and health centers are not required to submit VAT returns) and markups are hard to measure.<sup>32</sup> Even though we exclude from  $N$  self-employed, government, financial entities and non-market services, we include purchases from these suppliers in variable costs and treat them as a separate external factor.

We define a firm in  $N$  to be continuing in  $t$  if the following conditions are met: its sales, employment, capital stock, and intermediate inputs are positive in  $t$  and  $t + 1$ . This gives us the set  $C_t$ , which covers around 70% of both value-added and total employment of the non-financial corporate sectors in Belgium as measured by the National Accounts Institute (see Table A4). Crucially, our output measure is much broader than the Prodcum sample that we used in Section 3. Whereas our Prodcum sample contains roughly 3,000 downstream firms per year, the growth accounting sample contains roughly 100,000 firms per year.

**Calibrating input-output shares and markups.** We construct the  $C_t \times C_t$  network of domestic suppliers of Belgian firms using the NBB B2B Transactions data set. As mentioned before, almost all firms in Belgium are required to report sales of at least 250 euros, and the data has universal coverage of all businesses in  $C_t$ . We drop from the network purchases of capital inputs and outlier transactions as described in Section 3. There are four external inputs: labor, capital, imported materials, and materials from outside the set  $N$  (i.e. purchased from self-employed firms, finance, and government entities).<sup>33</sup> We construct the  $C_t \times F$  matrix of external input requirements using data from the annual accounts, B2B transactions, and customs declarations. For capital, as in Section 3, we

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<sup>32</sup>We exclude self-employed because of data-privacy considerations. Government (including education) and non-market services, such as health, art, and entertainment are not well-covered by VAT data. We exclude financial entities because (i) banks fill special annual accounts that we do not have access to, and (ii) interest receipts by banks and insurance premia receipts by insurance companies are not included in the VAT data. Our micro estimates are slightly smaller than our baseline if we exclude input purchases from self-employed, government, and finance suppliers (see Table A10).

<sup>33</sup>We also include in this external factor purchases from suppliers that do not report VAT, intra-firm purchases (due to mergers and acquisitions), and purchases from zero-employment continuing suppliers.

multiply the industry-specific user cost of capital by firms' reported capital stocks. We measure firm-level markups by dividing sales by total variable costs. Total variable costs is the sum of intermediate inputs and the non-overhead component of the wage bill and the cost of capital (which we assume is a fraction  $\phi = 0.50$  of labor and capital costs). Any other expenditures the firm incurs are treated as overhead costs.<sup>34</sup>

**Calibrating final output.** Final output is defined to be the sales of continuing firms in the network,  $C_t$ , minus sales of materials to other firms in the production network. That is, final output are sales to households, exports, investment, and any other sales that are not considered to be intermediate purchases by firms in  $N$ .<sup>35</sup> We convert nominal final output into a real measure by deflating nominal growth in final output using the Belgian GDP deflator from the national accounts. That is, we assume that the price deflator of our measure of final output grows at the same rate as the Belgian GDP deflator.

**Calibrating external input quantities.** We measure growth in labor quantity using total equivalent full time employees for firms in our sample. We measure growth in the capital stock of each firm by deflating the nominal value of its capital stock (which includes plants, property, equipment, and intellectual property) using the aggregate investment price deflator from the national accounts of Belgium. We measure the growth in imported materials by deflating the nominal imported material input growth with the import price deflator used for constructing the national accounts in Belgium. We cannot measure growth in the quantity of materials purchased from excluded domestic firms (self-employed, finance, and government entities, as well as continuing zero employment suppliers), so growth in the quantity of these materials is part of the residual.

**Calibrating the addition and separation share.** To apply Proposition 3, we need  $\Delta\mathcal{X}$  and  $\Delta\mathcal{E}$  at the firm level. These are the variable cost shares of additions and separations that are due to price jumps. For our growth accounting exercises in this section, we rule out discontinuous biased downstream technology shocks, which can result in discontinuous jumps in the input demand curve. Without such shocks, any additions and sepa-

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<sup>34</sup>For each firm, we rescale intermediate purchases from the B2B network and intermediate imports to ensure that their sum equals our measure of intermediate input purchases (sales minus value added). When we use these rescaled values of intermediate purchases to calculate addition and separation shares, our micro estimates are very similar to our baseline regressions.

<sup>35</sup>Given data on sales ( $p_i q_i$ ) for each firm  $i \in C_t$ , and the input-output matrix relative to sales,  $\Omega_{ij}^s = \frac{p_j x_{ij}}{p_i q_i}$ , we calculate total final output as  $E = \sum_{i \in C_t} p_i q_i - \sum_{i \in C_t} p_i q_i \sum_{j \in C_t} \Omega_{ij}^s$ . Final demand shares are given by  $b_i = (p_i q_i - \sum_{j \in C_t} \Omega_{ji}^s p_j q_j) / E$ .

rations that happen due to shifts in the input demand curve must be smooth (the input demand curve continuously shifts until the choke price is below the input price). In the continuous-time limit we consider, such additions and separations have no effect on the addition and separation share since the expenditure share on inputs added or dropped in this way is zero.

In this limit, we can set

$$\Delta \mathcal{X}_{i,t} = \underbrace{\left( \sum_{J \in \mathcal{J}_i} M_{iJ,t} \Omega_{iJ,t} \right)}_{\text{interm. input share of total variable cost}} \underbrace{\left( 1 - \frac{\sum_{j \in C_{i,t}} p_{j,t} x_{ij,t}}{\sum_k p_{k,t} x_{ik,t}} \right)}_{\text{interm. input share of separating suppliers}} \geq 0,$$

where  $C_{i,t}$  is the set of continuing suppliers for firm  $i$ :

$$C_{i,t} = \{j \in C_t : x_{ij,t} \times x_{ij,t+1} > 0\}.$$

That is  $\Delta \mathcal{X}_{i,t}$  is the share of firm  $i$ 's variable cost spent on suppliers that are lost between  $t$  and  $t + 1$ . Similarly, we can set

$$\Delta \mathcal{E}_{i,t} = \underbrace{\left( \sum_{J \in \mathcal{J}_i} M_{iJ,t} \Omega_{iJ,t} \right)}_{\text{interm. input share of total variable cost}} \underbrace{\left( 1 - \frac{\sum_{j \in C_{i,t}} p_{j,t+1} x_{ij,t+1}}{\sum_k p_{k,t+1} x_{ik,t+1}} \right)}_{\text{interm. input share of added suppliers}} \geq 0.$$

This is the share of firm  $i$ 's variable cost spent on suppliers that are added between  $t$  and  $t + 1$ .

**Calibrating  $\bar{\delta}_{i,t}^{\text{add}}$  and  $\bar{\delta}_{i,t}^{\text{sep}}$ .** We calibrate the average inframarginal surplus over additions and separations of suppliers per unit of expenditures using our microeconomic estimates from Section 3. We consider a few different cases: first, we set  $\bar{\delta}_{i,t}^{\text{add}} = \bar{\delta}_{i,t}^{\text{sep}} = 0$ , which ignores the role of supplier churn for growth. Second, we set  $\bar{\delta}_{i,t}^{\text{add}} = \bar{\delta}_{i,t}^{\text{sep}} = 0.3$ , which are broadly in line with our IV estimates in Tables 1 and 2.<sup>36</sup> Finally, we set  $\bar{\delta}_{i,t}^{\text{add}} = 0.33$  and  $\bar{\delta}_{i,t}^{\text{sep}} = 0.30$ , which are the benchmark point estimates, column (vi), in Table 1. We explore how the results vary away from these cases in Table 4.<sup>37</sup>

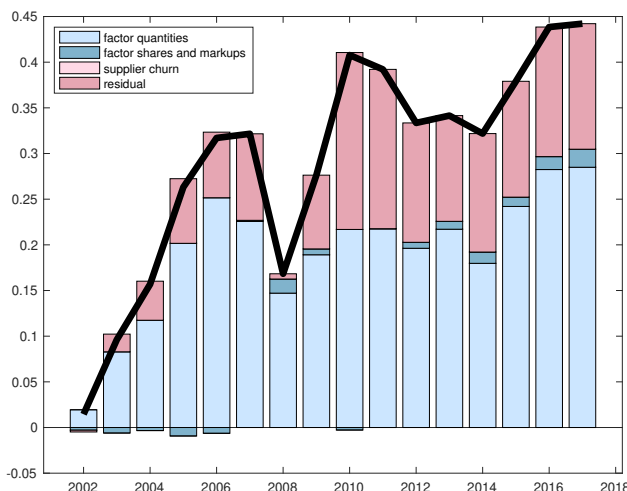
<sup>36</sup>For CES input demand, this corresponds to setting the elasticity of substitution equal to 4.3.

<sup>37</sup>Although we use all observed additions and separations to measure the addition and separation share in this section, we do not use the  $\bar{\delta}$  estimated from an OLS regression of all additions and separations on marginal cost due to the endogeneity concerns described in Section 3.2.

Table A4 in Appendix D reports information on the fraction of Belgian value-added in our sample and compares how aggregate growth rates in our sample compare to Belgian national accounts data. Table A5 in Appendix D reports basic statistics for the growth accounting sample of firms on the cost share of factors and intermediate inputs, the number of suppliers each firm has, and the separation and addition shares (relative to domestic material spending). Each firm has, on average, 68 suppliers (not reported in the table) while the sales-weighted average number of suppliers is 675. Table A5 also shows that addition shares are higher than separation shares.

## 5.2 Results

Figure 4:  $\bar{\delta}^{\text{add}} = \bar{\delta}^{\text{sep}} = 0$ .

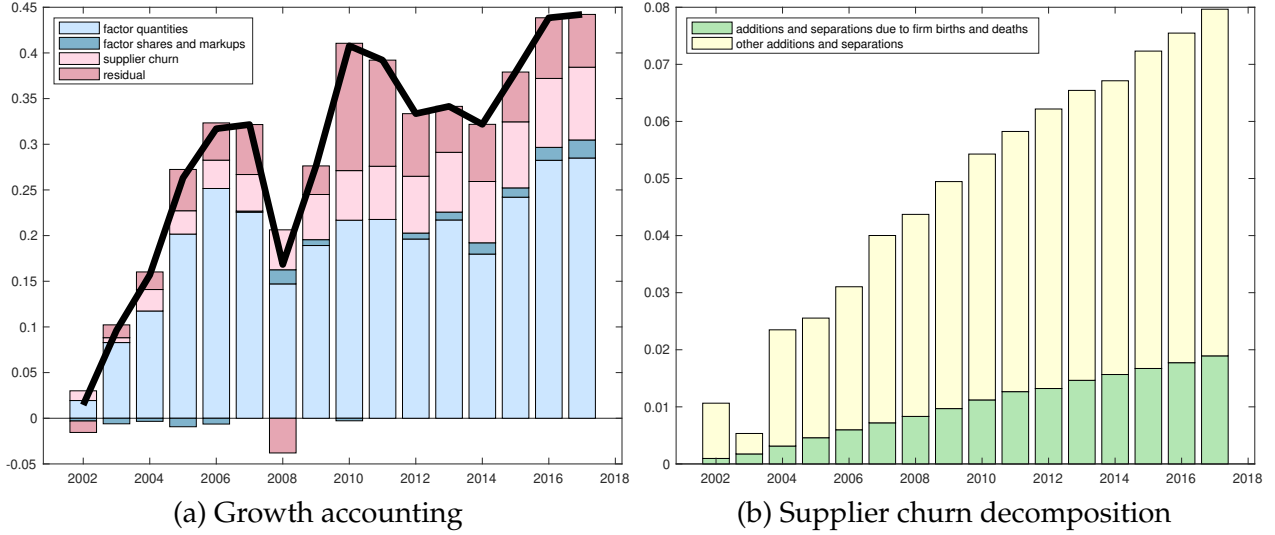


We start with a special case of Proposition 3 where the extensive margin is irrelevant,  $\bar{\delta}^{\text{add}} = \bar{\delta}^{\text{sep}} = 0$ . That is, Figure 4 implements a Baqaee and Farhi (2019b) style decomposition. This is a generalization of Solow-Hulten growth decompositions to an environment with markups. The markup and factor share terms, which capture reallocations (see Baqaee and Farhi, 2019b), do not play a large role in cumulative growth rates in this data set. The “unexplained” technology residual is large and accounts for about 14 log points of cumulative growth — roughly 1% per year.

Figure 5 sets  $\bar{\delta}^{\text{add}} = \bar{\delta}^{\text{sep}} = 0.3$ . The left panel shows that the extensive margin of supplier addition and separation accounts for about 8 log points out of a total of 14 log points of unexplained cumulative growth in the technology residual over the sample period. The extensive margin effect more than halves the size of the technology residual.<sup>38</sup> The

<sup>38</sup>This does not mean that in a counterfactual where firms cannot add or drop suppliers aggregate pro-

Figure 5:  $\bar{\delta}^{\text{entry}} = \bar{\delta}^{\text{exit}} = 0.30$



extensive margin effect is positive, even though  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$  are equal, because on balance additions are larger than separations (see Table A5). That is, the expenditure share on suppliers that continue from one year to the next declines on average. The right panel breaks down the extensive margin term into additions and separations associated with firm entry and exit (births and deaths) and the rest. Roughly one quarter of the extensive margin term is attributable to birth and death of firms, and the remaining three quarters is from additions and separations of firms that are continuing. Moreover, out of the 8 log points of the supplier churn term, 6 log points are accounted for by services-producing downstream firms and 2 log points by goods-producing downstream firms.

Whereas supplier churn is important for long-run growth in the period 2002-2018, it is not as important for explaining cyclical fluctuations. For example, the supplier churn term plays a small role for explaining the decline in aggregate output following the 2008 financial crisis. More formally, at annual frequency, the standard deviation of fluctuations in the residual is almost 9 times larger than that of the supplier churn term.

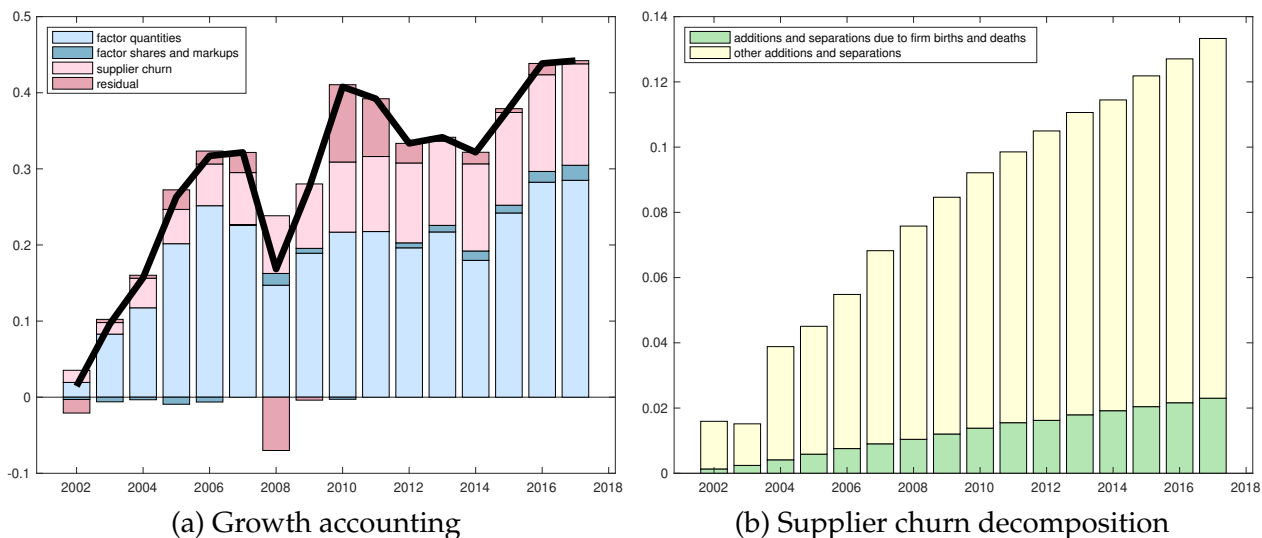
Figure 6 shows results using the point estimates from column (vi) of Table 1:  $\bar{\delta}^{\text{add}} = 0.33$  and  $\bar{\delta}^{\text{sep}} = 0.3$ . Since additions are more valuable than separations, this enlarges the extensive margin term so that it accounts for almost 13 log points of growth. This reduces the technology residual's cumulative role in growth over our 16 year sample to roughly

ductivity growth is 8 log points lower. In such a counterfactual, the remaining terms in Proposition 3 (the markup term, factor price changes, factor quantities, and the technology shocks) may all be different. The logic is similar to how in traditional growth accounting, shutting down productivity growth can affect, say, employment or capital accumulation. Instead, our growth accounting expression measures the technology residual given the observed patterns in the data and the calibrated values of  $\delta$ .



0.5 log points — essentially zero on an annual basis. The right panel breaks down the extensive margin effect into additions and separations due to firm birth and death, and the rest.

Figure 6:  $\bar{\delta}^{\text{entry}} = 0.33$  and  $\bar{\delta}^{\text{exit}} = 0.30$



Since the supplier churn term is not a residual, it is not affected by measurement error in the other terms in the growth accounting expression. The extensive margin term does however depend strongly on the value of  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$ . Table 4 provides the cumulative size of the supplier churn term over the sample for different values of  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$ . Our regression results cannot reject the hypothesis that  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$  are equal. These values are the diagonal elements of Table 4. Along this diagonal, the share of growth explained by the supplier churn term is between 7.7 and 8.8 log points.

The off-diagonal elements show that differences between  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$  are quantitatively very important. Our point estimates suggest that  $\bar{\delta}^{\text{add}}$  is slightly higher than  $\bar{\delta}^{\text{sep}}$ , which further boosts the role of supplier churn. On the flipside, if  $\bar{\delta}^{\text{add}}$  is less than  $\bar{\delta}^{\text{sep}}$ , then this can significantly reduce the importance of supplier churn since suppliers who disappear are, on balance, more valuable per unit of expenditures than suppliers who appear. Table 4 also shows the portion of supplier churn attributable to supplier births and deaths. These numbers are less sensitive to the precise values of  $\bar{\delta}^{\text{add}}$  and  $\bar{\delta}^{\text{sep}}$  and hover between 1.5 and 2.4 log points over the whole sample.

Of course, these results are speculative since they involve extrapolating estimates from the Prodcom manufacturing sample of firms to a much broader subset of Belgian firms (including ones outside the manufacturing sector). In practice, the inframarginal surplus ratio,  $\delta$ , is likely heterogeneous and varies by both the characteristics of the suppliers

Table 4: Cumulative supplier churn term under alternative values of  $\bar{\delta}^{add}$  and  $\bar{\delta}^{sep}$

		$\bar{\delta}^{sep}$				
		<b>0.29</b>	<b>0.3</b>	<b>0.31</b>	<b>0.32</b>	<b>0.33</b>
$\bar{\delta}^{add}$	<b>0.29</b>	0.077	0.062	0.047	0.031	0.016
	<b>0.30</b>	0.095	0.080	0.064	0.049	0.034
	<b>0.31</b>	0.113	0.098	0.082	0.067	0.052
	<b>0.32</b>	0.131	0.115	0.100	0.085	0.070
	<b>0.33</b>	0.149	0.133	0.118	0.103	0.088

(a) All separations and additions

		$\bar{\delta}^{sep}$				
		<b>0.29</b>	<b>0.3</b>	<b>0.31</b>	<b>0.32</b>	<b>0.33</b>
$\bar{\delta}^{add}$	<b>0.29</b>	0.018	0.018	0.017	0.016	0.015
	<b>0.30</b>	0.020	0.019	0.018	0.017	0.017
	<b>0.31</b>	0.021	0.020	0.020	0.019	0.018
	<b>0.32</b>	0.022	0.022	0.021	0.020	0.019
	<b>0.33</b>	0.024	0.023	0.022	0.022	0.021

(b) Firm births and deaths

being added or dropped. Investigating such heterogeneity is an important area for future research. However, with these caveats in mind, our aggregation exercise suggests that the extensive margin of supplier entry and exit is plausibly an important driver of aggregate productivity growth.

## 6 Conclusion

This paper analyzes and quantifies the microeconomic and macroeconomic importance of creation and destruction of supply linkages. Our analysis shows that downstream firms' marginal costs are significantly affected by supplier entry and exits, and this enables us to directly calculate the area under the input demand curve. The reduced form statistic we estimate shapes counterfactuals in many theories with an extensive margin. For example, it disciplines the welfare effect of changes in market size (e.g. Krugman, 1979), the gains from trade (e.g. Melitz, 2003), efficiency of the decentralized equilibrium with entry (e.g. Matsuyama and Ushchev, 2020b), and optimal innovation subsidies (e.g. Baqaee and Farhi, 2020).

Our growth accounting results demonstrate that supplier additions and separations

plausibly account for a large portion of the long-run aggregate productivity growth in a Solow (1957)-style growth accounting exercise. That is, inframarginal surplus associated with supplier churn can be an important channel through which aggregate productivity grows. These macroeconomic moments can be used as targeted moments for disciplining structural models of endogenous network formation and growth.

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## Proof of Proposition 1

*Proof.* Suppress the index  $i$  for the downstream firm throughout the proof. Use Shephard’s lemma to get

$$dC = \int_j x_j dp_j + \frac{\partial C}{\partial A} dA + \frac{\partial C}{\partial q} dq,$$

where  $j$ ’s are individual input varieties. Consider the change in costs due to a change in primitives. For any smooth path of prices and technology, with end points given by  $(\mathbf{p}^0, A^0, q^0)$  and  $(\mathbf{p}^1, A^1, q^1)$ , the change in costs is

$$C(\mathbf{p}^1, A^1, q^1) - C(\mathbf{p}^0, A^0, q^0) = \int_{p_j^0}^{p_j^1} x_j dp_j + \int_{A^0}^{A^1} \frac{\partial C}{\partial A} dA + \int_{q^0}^{q^1} \frac{\partial C}{\partial q} dq,$$

where we omit the dependence of conditional input,  $x_j$ , on its other arguments. Group the integrals into types to obtain

$$\begin{aligned} C(\mathbf{p}^1, A^1, q^1) - C(\mathbf{p}^0, A^0, q^0) &= \sum_J M_J \int_{p_j^0}^{p_j^1} x_j dp_j - \sum_J \Delta M_J \int_{p_j^0}^{\infty} x_j dp_j \\ &\quad + \int_{A^0}^{A^1} \frac{\partial C}{\partial A} dA + \int_{q^0}^{q^1} \frac{\partial C}{\partial q} dq. \end{aligned}$$

where  $p_j$  denotes the price of any available variety  $j$  of type  $J$ , the mass of non-jumping varieties of type  $J$  is  $M_J$ , and  $\Delta M_J = \Delta M_J^{add} - \Delta M_J^{sep}$ . Consider the total derivative of costs with respect to the new prices of each type  $p_j^1$ , the mass of suppliers of each type that become available  $\Delta M_J^{add}$  or that become unavailable  $\Delta M_J^{sep}$ , technology  $A$ , and quantity of output  $q$ . Denote by  $dM_J$  the infinitesimal measure of additions minus the infinitesimal

measure of separations of type  $J$ . This results in

$$d\mathcal{C} = \sum_J M_J x_J dp_J - \sum_J \left( \int_{p_J^0}^{\infty} x_J(p_J) dp_J \right) dM_J + \frac{\partial \mathcal{C}}{\partial A} dA + \frac{\partial \mathcal{C}}{\partial q} dq.$$

This first-order approximation can be rewritten as

$$d \log \mathcal{C} = \sum_J M_J \Omega_i d \log p_J - \frac{1}{\mathcal{C}} \sum_J \left( \int_{p_J^0}^{\infty} x_J(p_J) dp_J \right) dM_J + \frac{\partial \log \mathcal{C}}{\partial \log A} d \log A + \frac{\partial \log \mathcal{C}}{\partial \log q} d \log q.$$

Next, by constant-returns,  $\partial \log \mathcal{C} / \partial \log q = 1$  and  $d \log mc = d \log \mathcal{C} - d \log q$ . Hence, we can rewrite this as in (2) in Proposition 1 using the definition of  $\delta_j$ .

□

Online Appendix  
*Supplier Churn and Growth: a Micro-to-Macro Analysis*  
David Baqaee, Ariel Burstein, Cedric Duprez, and Emmanuel Farhi  
January 2024

<b>A Additional Proofs</b>	<b>A1</b>
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## Appendix A Additional Proofs

*Proof of Example 4.* To prove (6), once again, we suppress the index  $i$  for the downstream firm and other arguments in conditional input demand. Observe that

$$x_J(p_J) = \frac{\frac{\partial(p_J x_J(p_J))}{\partial p_J}}{1 - \sigma_J(p_J)}.$$

Substitute this into the definition of  $\delta_J$  to get

$$\delta_J = \frac{\int_{p_J}^{\infty} x_J(\xi) d\xi}{p_J x_J(p_J)} = \frac{\int_{p_J}^{\infty} \frac{\frac{\partial(\xi x_J(\xi))}{\partial \xi}}{1 - \sigma_J(\xi)} d\xi}{p_J x_J(p_J)}.$$

Marshall's second law implies that  $\sigma_J(\xi) > \sigma_J(p_J)$  if  $\xi > p_J$ , and the fundamental theorem of calculus implies  $\int_{p_J}^{\infty} \frac{\partial(\xi x_J(\xi))}{\partial \xi} d\xi = -p_J x_J(p_J)$ . We thus have

$$\delta_J < \frac{\int_{p_J}^{\infty} \frac{\partial(\xi x_J(\xi))}{\partial \xi} d\xi}{p_J x_J(p_J)(1 - \sigma_J(p_J))} = \frac{-p_J x_J(p_J)}{p_J x_J(p_J)(1 - \sigma_J(p_J))} = \frac{1}{\sigma_J(p_J) - 1}.$$



To prove (7), re-express the inframarginal surplus ratio as

$$\delta_J(p_J) = \frac{\int_{p_J}^{\infty} \frac{\frac{\partial(\xi x_J(\xi))}{\partial \xi}}{1 - \sigma_J(\xi)} d\xi}{p_J x_J(p_J)}.$$

Note that

$$\begin{aligned} \delta'_J(p_J) &= -\frac{\frac{\partial(p_J x_J(p_J))}{\partial p_J}}{p_J x_J(p_J)} - \frac{\int_{p_J}^{\infty} \frac{\frac{\partial(\xi x_J(\xi))}{\partial \xi}}{1 - \sigma_J(\xi)} d\xi}{p_J x_J(p_J)} \frac{\partial(p_J x_J(p_J))}{\partial p_J} \\ &= -\frac{\frac{\partial(p_J x_J(p_J))}{\partial p_J}}{p_J x_J(p_J)} \left[ \delta_J(p_J) - \frac{1}{\sigma_J(p_J) - 1} \right]. \end{aligned}$$

Hence,

$$\delta'_J(p_J) < 0$$

if

$$\frac{1}{\sigma_J(p_J) - 1} > \delta_J(p_J).$$

Note, from their definitions, that at the choke price,  $p_J^*$ , we must have  $\delta_J(p_J^*) = 1/(\sigma_J(p_J^*) - 1) = 0$ . For any  $p_J < p_J^*$ , Example 4 then guarantees that  $\delta_J(p_J) < \frac{1}{\sigma_J(p_J) - 1}$ . □

*Proof of Proposition 2.* According to Proposition 1, and re-introducing the downstream firm  $i$  index, we can write

$$\Delta \log mc_{i,t} = -\bar{\delta}_{i,t}^{add} X_{1i,t} + \bar{\delta}_{i,t}^{sep} X_{2i,t} + W'_{i,t} \gamma + \epsilon_{i,t} \quad (\text{A1})$$

where  $X_{1i,t}$  and  $X_{2i,t}$  are the addition and separation share due to price jumps for firm  $i$  at time  $t$  and  $W_{i,t}$  are other variables we control for, including fixed effects. The parameter  $\gamma$  is not necessarily a structural parameter and the error term  $\epsilon_{i,t}$  is uncorrelated with  $W_{i,t}$  by construction. Our first stage regression relates the addition and separation share to our instruments:

$$X_{1i,t} = \alpha_{11} Z_{1i,t} + \alpha_{12} Z_{2i,t} + W'_{i,t} \pi_1 + v_{1i,t},$$

$$X_{2i,t} = \alpha_{21} Z_{1i,t} + \alpha_{22} Z_{2i,t} + W'_{i,t} \pi_2 + v_{2i,t},$$

where  $Z_{1i,t}$  and  $Z_{2i,t}$  are the restricted birth and death instruments and  $v_{1i,t}$  and  $v_{2i,t}$  are residuals including other additions and separations due to price jumps and due to shifts in input demand. These first-stage residuals are orthogonal to the instruments by con-

struction.

Without loss of generality, we also assume that  $Z_{1,t}$  and  $Z_{2,t}$  have been orthogonalized. That is, let  $Z_{2i,t}$  be the residuals from a regression of the restricted death instrument on the restricted birth instrument so that they are uncorrelated by construction. Similarly, for each variable, say  $Q_{i,t}$ , let  $\tilde{Q}_{i,t}$  be residuals from a regression of  $Q_{i,t}$  on covariates  $W_{i,t}$ .

We first present some preliminary steps we use in the proof. Our assumption that the instruments are mutually independent of the error term in the second stage implies

$$\mathbb{E} [\tilde{Z}_{1i,t} \epsilon_{i,t}] = \mathbb{E} [\tilde{Z}_{1i,t}] \mathbb{E} [\epsilon_{i,t}] = 0, \quad (\text{A2})$$

where the second equality holds because  $\mathbb{E} [\tilde{Z}_{1i,t}] = 0$ . A similar equation holds for  $\tilde{Z}_{2i,t}$ . Our assumption that the instruments are mutually independent of the error terms in the first stage and also mutually independent of  $\bar{\delta}_i^{add}$  and  $\bar{\delta}_i^{sep}$  implies

$$\mathbb{E} [\bar{\delta}_{i,t}^{add} v_{1i,t} \tilde{Z}_{1i,t}] = \mathbb{E} [\bar{\delta}_{i,t}^{sep} v_{2i,t} \tilde{Z}_{1i,t}] = 0, \quad (\text{A3})$$

and similar for  $\tilde{Z}_{2i,t}$ .<sup>A39,A40</sup> Finally, our assumption that the instruments are mutually independent of  $\bar{\delta}_{i,t}^{sep}$  and  $\bar{\delta}_{i,t}^{add}$  implies that

$$\begin{aligned} \mathbb{E} [\tilde{Z}_{1i,t}^2 \bar{\delta}_{i,t}^{sep}] &= \mathbb{E} [\tilde{Z}_{1i,t}^2] \mathbb{E} [\bar{\delta}_{i,t}^{sep}] \\ \mathbb{E} [\tilde{Z}_{1i,t}^2 \bar{\delta}_{i,t}^{add}] &= \mathbb{E} [\tilde{Z}_{1i,t}^2] \mathbb{E} [\bar{\delta}_{i,t}^{add}], \end{aligned} \quad (\text{A4})$$

and similar for  $\tilde{Z}_{2i,t}^2$ .

The estimates  $\hat{\delta}^{add}$  and  $\hat{\delta}^{sep}$  satisfy the moment conditions

$$\mathbb{E} \left[ \left( \Delta \log mc_i + \hat{\delta}^{add} \tilde{X}_{1i} - \hat{\delta}^{sep} \tilde{X}_{2i} \right) \tilde{Z}_{1i} \right] = 0,$$

$$\mathbb{E} \left[ \left( \Delta \log mc_i + \hat{\delta}^{add} \tilde{X}_{1i} - \hat{\delta}^{sep} \tilde{X}_{2i} \right) \tilde{Z}_{2i} \right] = 0,$$

where we have suppressed the time subscript for simplicity. Substituting the first stage

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<sup>A39</sup>If  $\bar{\delta}_{i,t}^{add}$  and  $\bar{\delta}_{i,t}^{sep}$  are constant, then the first-stage regression implies  $\mathbb{E} [v_{1i,t} \tilde{Z}_{1i,t}] = \mathbb{E} [v_{2i,t} \tilde{Z}_{1i,t}] = 0$ , so (A3) does not require the assumption that the instruments are mutually independent of the error terms in the first stage.

<sup>A40</sup>Instead of assuming that the instruments  $Z$  are mutually independent of  $\bar{\delta}$  and the error in the first stage (conditional on the controls), we could alternatively assume that the instruments  $Z$  is independent of  $\bar{\delta}$  and uncorrelated with the product of  $\bar{\delta}$  and the error in the first stage (conditional on the controls). This is a weaker assumption.

into the second stage yields

$$\mathbb{E} \left[ \left( \Delta \log \tilde{m} c_i + \hat{\delta}^{add} (\alpha_{11} \tilde{Z}_{1i} + \alpha_{12} \tilde{Z}_{2i} + v_{1i}) - \hat{\delta}^{sep} (\alpha_{21} \tilde{Z}_{1i} + \alpha_{22} \tilde{Z}_{2i} + v_{2i}) \right) \tilde{Z}_{1i} \right] = 0.$$

Simplify this equation using  $\mathbb{E} [\tilde{Z}_{1i} \tilde{Z}_{2i}] = \mathbb{E} [\tilde{Z}_{1i} v_{1i}] = \mathbb{E} [\tilde{Z}_{1i} v_{2i}] = 0$  (where the two latter equalities are implied by the first-stage regression) to obtain

$$\mathbb{E} [\Delta \log \tilde{m} c_i \tilde{Z}_{1i}] + \hat{\delta}^{add} \alpha_{11} \mathbb{E} [\tilde{Z}_{1i}^2] - \hat{\delta}^{sep} \alpha_{21} \mathbb{E} [\tilde{Z}_{1i}^2] = 0.$$

Substitute the residualized version of (A1) for  $\Delta \log \tilde{m} c$  to get

$$\mathbb{E} \left[ \left[ -\bar{\delta}_i^{add} \tilde{X}_{1i} + \bar{\delta}_i^{sep} \tilde{X}_{2i} + \epsilon_i \right] \tilde{Z}_{1i} \right] + \hat{\delta}^{add} \alpha_{11} \mathbb{E} [\tilde{Z}_{1i}^2] - \hat{\delta}^{sep} \alpha_{21} \mathbb{E} [\tilde{Z}_{1i}^2] = 0.$$

Substitute the first stage and use (A2) to obtain

$$\begin{aligned} \mathbb{E} \left[ \left[ -\bar{\delta}_i^{add} (\alpha_{11} \tilde{Z}_{i1} + \alpha_{12} \tilde{Z}_{2i} + v_{1i}) + \bar{\delta}_i^{sep} (\alpha_{21} \tilde{Z}_{i1} + \alpha_{22} \tilde{Z}_{2i} + v_{2i}) \right] \tilde{Z}_{1i} \right] \\ + \hat{\delta}^{add} \alpha_{11} \mathbb{E} [\tilde{Z}_{1i}^2] - \hat{\delta}^{sep} \alpha_{21} \mathbb{E} [\tilde{Z}_{1i}^2] = 0. \end{aligned}$$

Using  $\mathbb{E} [\tilde{Z}_{1i} \tilde{Z}_{2i}] = 0$  and (A3) simplifies this expression to

$$-\alpha_{11} \mathbb{E} [\bar{\delta}_i^{add} \tilde{Z}_{i1}^2] + \alpha_{21} \mathbb{E} [\bar{\delta}_i^{sep} \tilde{Z}_{i1}^2] + \hat{\delta}^{add} \alpha_{11} \mathbb{E} [\tilde{Z}_{1i}^2] - \hat{\delta}^{sep} \alpha_{21} \mathbb{E} [\tilde{Z}_{1i}^2] = 0.$$

Using (A4) further simplifies this expression to

$$-\alpha_{11} \mathbb{E} [\bar{\delta}_i^{add}] + \alpha_{21} \mathbb{E} [\bar{\delta}_i^{sep}] = -\hat{\delta}^{add} \alpha_{11} + \hat{\delta}^{sep} \alpha_{21}.$$

Following similar steps, the second moment condition implies

$$\mathbb{E} [\Delta \log \tilde{m} c_i \tilde{Z}_{2i}] + \hat{\delta}^{add} \alpha_{21} \mathbb{E} [\tilde{Z}_{2i}^2] - \hat{\delta}^{sep} \alpha_{22} \mathbb{E} [\tilde{Z}_{2i}^2] = 0$$

which can be simplified to

$$-\alpha_{21} \mathbb{E} [\bar{\delta}_i^{add}] + \alpha_{22} \mathbb{E} [\bar{\delta}_i^{sep}] = -\hat{\delta}^{add} \alpha_{21} + \hat{\delta}^{sep} \alpha_{22}$$

So the two estimates  $\hat{\delta}^{add}$  and  $\hat{\delta}^{sep}$  satisfy the following two equations:

$$-\alpha_{11} \mathbb{E} [\bar{\delta}_i^{add}] + \alpha_{21} \mathbb{E} [\bar{\delta}_i^{sep}] = -\hat{\delta}^{add} \alpha_{11} + \hat{\delta}^{sep} \alpha_{21}$$

and

$$-\alpha_{21}\mathbb{E}[\bar{\delta}_i^{add}] + \alpha_{22}\mathbb{E}[\bar{\delta}_i^{sep}] = -\hat{\delta}^{add}\alpha_{21} + \hat{\delta}^{sep}\alpha_{22}.$$

This gives the desired result that  $\hat{\delta}^{add} = \mathbb{E}[\bar{\delta}_i^{add}]$  and  $\hat{\delta}^{sep} = \mathbb{E}[\bar{\delta}_i^{sep}]$  as long as the matrix of  $\alpha$ 's has full rank.  $\square$

*Proof of Proposition 3.* In the text we showed that, to a first-order approximation, the final output price deflator is given by

$$\Delta \log P_t^Y = \sum_{i \in C_t} \lambda_{i,t} \left[ \Delta \log \frac{\mu_{i,t}}{A_{i,t}} + \bar{\delta}_{i,t}^{sep} \Delta \mathcal{X}_{i,t} - \bar{\delta}_{i,t}^{add} \Delta \mathcal{E}_{i,t} \right] + \sum_{f \in F} \Lambda_{f,t} \Delta \log w_{f,t}.$$

Substitute this into

$$\Delta \log Y = \Delta \log \left( \sum_{i \in C_t} p_{i,t} y_{i,t} \right) - \Delta \log P_t^Y$$

and use the fact that  $\sum_{f \in F} \Lambda_{f,t} = 1$  and the fact that  $\Delta \log w_{f,t} = \Delta \log \check{\Lambda}_{f,t} - \Delta \log L_{f,t} + \Delta \log(\sum_{i \in C_t} p_{i,t} y_{i,t})$ , and we obtain the expression in the proposition.  $\square$

## Appendix B Monopsonistic Downstream Firms

In Section 2 we assumed that firms buy inputs at given prices. Here we generalize Proposition 1 to the case in which firm faces a price schedule for each input. Specifically, we assume that if the firm buys  $\mathbf{x}$  units of each input type, the per unit cost is given by  $\mathbf{p}(\mathbf{x})$ .

The cost minimization problem is

$$\mathcal{C}(\mathbf{p}(\cdot), A, q) = \min_{\mathbf{x}} \int_j p_j(\mathbf{x}) x_j, \text{ subject to } q = AF(\mathbf{x}).$$

Given  $A$  and  $q$ , this cost minimization problem implies a vector of input quantity choices with its implied input prices. We consider a shift in  $A$  from  $A^0$  to  $A^1$  and in the price schedule from  $\mathbf{p}^0(\cdot)$  to  $\mathbf{p}^1(\cdot)$ . We index a path between these schedules  $\mathbf{p}(\cdot, t)$  by  $t \in [0, 1]$ .

Let  $\mathbf{x}(t)$  be input quantities at  $t$ . Differentiating total costs with respect to  $t$  and applying the envelope theorem,

$$d\mathcal{C} = \int_j x_j \frac{\partial p_j}{\partial t} dt + \frac{\partial \mathcal{C}}{\partial A} \frac{\partial A}{\partial t} dt + \frac{\partial \mathcal{C}}{\partial q} \frac{\partial q}{\partial t} dq,$$

where all derivatives are evaluated at  $t$  and  $\frac{\partial p_j}{\partial t}$  is the derivative of the price schedule with respect to  $t$  evaluated at  $\mathbf{x}(t)$ .

We now follow similar steps to those in the proof of Proposition 1. The change in total costs is

$$\mathcal{C}(\mathbf{p}^1(\cdot), A^1, q^1) - \mathcal{C}(\mathbf{p}^0(\cdot), A^0, q^0) = \int_j \int_0^1 x_j(t) \frac{dp_j}{dt} dt + \int_0^1 \frac{\partial \mathcal{C}}{\partial A} \frac{dA}{dt} dt + \int_0^1 \frac{\partial \mathcal{C}}{\partial q} \frac{dq}{dt} dt.$$

For some measurable subset,  $\Delta M_J^{add}$ , of inputs of type  $j$ , we suppose that  $p(\cdot, 0) = \infty$  and  $p(\cdot, 1) < \infty$ . Similarly,  $\Delta M_J^{sep}$  is a subset where  $p(\cdot, 0) < \infty$  and  $p(\cdot, 1) = \infty$ . For the remaining set of inputs of type  $j$ , denoted by  $M_J$ , the price of the input changes from some finite  $p^0(\cdot)$  to some other finite  $p^1(\cdot)$ . Group the integrals so that

$$\begin{aligned} \mathcal{C}(\mathbf{p}^1(\cdot), A^1, q^1) - \mathcal{C}(\mathbf{p}^0(\cdot), A^0, q^0) = & \sum_J M_J \int_0^1 x_j(t) \frac{dp_j}{dt} dt + \sum_J \Delta M_J \int_0^1 x_j(t) \frac{dp_j}{dt} dt + \\ & \int_0^1 \frac{\partial \mathcal{C}}{\partial A} \frac{dA}{dt} dt + \int_0^1 \frac{\partial \mathcal{C}}{\partial q} \frac{dq}{dt} dt, \end{aligned}$$

where  $\Delta M_J = \Delta M_J^{sep} - \Delta M_J^{add}$ .

Consider the total derivative of costs with respect to the finite price schedule of each type  $p_J^1(\cdot)$ , the mass of inputs of each type whose price schedule jumps by an infinite amount  $\Delta M_J$  (and let  $dM_J$  denote the infinitesimal measure of jumpers of type  $J$ ), technology  $A$ , and quantity of output  $q$ . The log change in average cost is

$$\begin{aligned} d \log ac &= \log \mathcal{C} - d \log q \\ &= \sum_J M_J \Omega_J d \log p_J + \frac{1}{\mathcal{C}} \sum_J \left( \int_0^1 x_J(t) dt \right) dM_J + \frac{\partial \log \mathcal{C}}{\partial \log A} d \log A + \left( \frac{\partial \log \mathcal{C}}{\partial \log q} - 1 \right) d \log q. \end{aligned}$$

Here  $d \log p_J$  denotes a marginal change in the price schedule of type  $J$  inputs evaluated at initial input quantities, that is  $\frac{\partial \log p_J}{\partial t} dt$  evaluated at  $t = 0$ . Define the infra-marginal surplus ratio for input of type  $J$  to be

$$\delta_J = \frac{\int_0^1 x_J(t) dt}{p_J x_J},$$

which is the integral of input quantity demanded as the price schedule changes, relative to initial expenditures on this input. We can re-write the equation above as

$$d \log ac = \sum_J \Omega_J M_J d \log p_J + \sum_J \Omega_J \delta_J dM_J + \frac{\partial \log \mathcal{C}}{\partial \log A} d \log A + \left( \frac{\partial \log \mathcal{C}}{\partial \log q} - 1 \right) d \log q. \quad (\text{A5})$$

A special case of equation (A5) is when input prices do not depend on input quantities as in Proposition 1 and the intuition is very similar. However, constant-returns in the production function  $F$  does not imply  $\partial \log C / \partial \log q = 1$  since input prices respond to input quantities. To ensure  $\partial \log C / \partial \log q = 1$ , we require the additional assumption that  $p(x)$  is homogeneous of degree zero in input quantities. When  $\partial \log C / \partial \log q = 1$ ,  $d \log ac = d \log mc$ , and justifies the regression in (11).

**Lemma 1.** *Suppose that  $F(x)$  has constant returns to scale in  $x$ , and  $p(x)$  is homogeneous of degree zero in  $x$ . Then,  $\partial \log C / \partial \log q = 1$ .*

*Proof.* Under the assumption above, we have that:

$$\begin{aligned}
C(p(\cdot), q) &= \min_x \{p(x) \cdot x : q = F(x)\} \\
&= \min_x \{q(p(x/q) \cdot x/q) : q = F(x/q)q\} \\
&= \min_z \{q(p(z) \cdot z) : q = F(z)q\} \\
&= \min_z \{q(p(z) \cdot z) : 1 = F(z)\} \\
&= q \min_z \{(p(z) \cdot z) : 1 = F(z)\} \\
&= qC(p(\cdot), 1).
\end{aligned}$$

That is, the cost function is linear in quantity. □

## Appendix C Additional Data Details

**Mergers and acquisitions.** One challenge with using data recorded at the level of the VAT identifier is the case of mergers and acquisitions, since this might blur our entry/exit analysis of suppliers.<sup>A41</sup> When a firm stops its business, it reports to the Crossroads Bank of Enterprises (CBE) the reason for ceasing activities, one of which is merger and acquisition. In such cases, we use the financial links also reported in the Crossroads Bank of Enterprises (CBE) to identify the absorbing VAT identifier and we group the two (or more) VAT identifiers into a unique firm. We choose the VAT identifier with the largest total assets. We use this head VAT identifier as the identifier of the firm. Having determined the head VAT identifier, we aggregate all the variables up to the firm level.

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<sup>A41</sup>Another challenge is that VAT returns are made at the unit level, which in some instances group more than one VAT identifier. In this case, we group the two (or more) VAT identifiers into a unique firm.

For variables such as total sales and inputs, we adjust the aggregated variables with the amount of B2B trade that occurred within the firm, correcting for double counting. For other non-numeric variables such as firms' primary sector, we take the value of its head VAT identifier. It is important to emphasize that we group VAT identifiers only for the year of the M&A and thereafter, and not over the whole panel period.

**Estimating share of variable costs in labor and capital costs** To estimate the share of labor and capital costs that are variable inputs,  $\phi$ , we consider the following regression:

$$\Delta \log (\text{labor} + \text{capital})_{i,t} = \phi \times \Delta \log (\text{intermediate inputs})_{i,t} + \text{controls}_{i,t} + \varepsilon_{i,t}. \quad (\text{A6})$$

The variable  $(\text{labor} + \text{capital})_{i,t}$  denotes the sum of labor and capital costs of firm  $i$  in period  $t$ , and  $\text{intermediate purchases}_{i,t}$  denotes intermediate input purchases of firm  $i$  in period  $t$ . Assuming that the variable component of labor and capital costs move one-to-one with intermediate input purchases (which we assume are fully variable) in response to firm-level demand shocks that keep technologies and relative factor prices unchanged,  $\phi$  captures the fraction of variable labor and capital costs.

We instrument changes in intermediate purchases using a Bartik-type demand shock. For each firm  $i$  at time  $t$ , we define the instrument:

$$\text{Firm's Demand}_{i,t} = \sum_j \sum_K \Omega_{iK,t} \times \Delta \log \text{sales}_{K,t+1}, \quad (\text{A7})$$

where  $\Omega_{iK,t}$  is the share of  $i$ 's sales to other domestic firms in each industry  $K$  (leaving out the firm's own industry) and  $\Delta \log \text{sales}_{K,t+1}$  is the change in total sales of industry  $K$  between  $t$  and  $t + 1$ .

All regressions include 4 digit NACE industry by year fixed effects, which is the most disaggregated classification we can consider for the sample of manufacturing firms. Controls include a non-manufacturing input-price deflator (calculated by weighing disaggregated industry-level deflators from Eurostat using firm-level sales shares across industries) and a variant of the instrument defined in (A7) where  $\Omega_{iK,t}$  is the share of  $i$ 's variable costs spent on industry  $K$ .

Table A1 displays the results. Columns (i) and (ii) report OLS results, which shows a positive but low estimate of  $\phi$ . However, OLS is subject to omitted variable bias because changes in intermediate purchases can result from shocks to firms' costs, such as changes in the price of intermediates or factor-biased technical change.

Columns (iii)-(vii) show the 2SLS results for different samples of firms (manufactur-

ing, goods producing firms, all firms, and the smaller Prodcum sample) and controls. In all cases (except for the Prodcum sample) the first-stage is strong (demand shocks help predict changes in intermediate input purchases). The point estimate of  $\phi$  is between 0.4 and 0.6, and the controls have a small impact on the estimates. In our baseline, we set  $\phi = 0.5$ , which is also the fraction of variable inputs in labor costs estimated by Dhyne et al. (2022) using an export-demand instrument in the Belgian data. We consider alternative values for  $\phi$  in sensitivity analysis.

Table A1: Elasticity of labor and capital costs with respect to intermediate purchases

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
	$\Delta \log(\text{labor} + \text{capital})$						
$\Delta \log(\text{interm. inputs})$	0.268*** (0.006)	0.269*** (0.006)	0.576*** (0.169)	0.575*** (0.175)	0.668 (0.458)	0.481*** (0.157)	0.400*** (0.054)
Specification	OLS	OLS	IV	IV	IV	IV	IV
F-stat			62	58	3	57	654
Sample of firms	Manufact.	Manufact.	Manufact.	Manufact.	Prodcum	Goods	All
Input prices control	N	Y	N	Y	Y	Y	Y
Bartik control	N	Y	N	Y	Y	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y
Obs.	305,158	304,421	219,992	219,892	39,149	295,916	3,105,547

*Notes:* This table displays estimates of regression (A6) for different samples of firms. The instrument is the firms' demand shock defined in (A7). The first control is an input price deflator, and the second control is a variant of the instrument defined in (A7) using purchases from (rather than sales to) other industries. Industry fixed effects at the 4-digit NACE level. Regressions are unweighted, and standard errors are clustered at the firm-level.



## Appendix D Additional Tables and Sensitivity Analysis

Table A2: Descriptive statistics: Prodcom sample

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)	(xi)	(xii)
	Share in variable costs			Import	Service	Numb.	Share in variable costs					
	labor	capital	interm.	interm. share	interm. share	suppl.	separations	additions	deaths	births	deaths restricted	births restricted
mean	0.136	0.009	0.854	0.269	0.654	227	0.057	0.068	0.003	0.005	0.001	0.002
p25	0.071	0.003	0.805	0.000	0.522	112	0.022	0.026	0.000	0.000	0.000	0.000
p50	0.120	0.006	0.870	0.221	0.692	168	0.040	0.049	0.000	0.001	0.000	0.000
p75	0.184	0.012	0.922	0.469	0.815	257	0.073	0.087	0.002	0.003	0.001	0.001
count	41,980	41,980	41,980	41,980	41,980	41,980	41,980	41,980	41,980	41,980	41,980	41,980

*Notes:* The sample of firms used in this table are those used in the micro regressions in Section 3 based on the Prodcom sample. Service suppliers are those in NACE code sections F-T. Summary statistics are unweighted.

Table A3: Correlation of addition and separations with downstream firm size

	(i)	(ii)	(iii)	(iv)	(v)
	log number suppliers	separation share	addition share	restricted death share	restricted birth share
log employment	0.78	-0.23	-0.22	-0.04	-0.04
log sales	0.80	-0.30	-0.30	-0.07	-0.06

*Notes:* The sample of firms used in this table are those used in the micro regressions in Section 3 based on the Prodcom sample. All shares are calculated relative to variable costs of the downstream firm.

Table A4: Coverage of growth accounting sample of firms

	(i)	(ii)	(iii)	(iv)	(v)
year	count	value added	% of agg.	employment	% of agg.
2002	99,577	107,652	72%	1,574	67%
2003	102,716	114,520	74%	1,579	67%
2004	104,826	122,354	75%	1,588	67%
2005	106,476	125,755	74%	1,595	66%
2006	108,461	134,770	75%	1,636	67%
2007	109,761	142,913	75%	1,710	68%
2008	110,700	143,835	73%	1,727	67%
2009	109,413	137,080	73%	1,653	64%
2010	109,026	146,411	74%	1,640	63%
2011	110,216	150,341	73%	1,684	64%
2012	110,983	152,705	73%	1,696	64%
2013	110,168	153,660	72%	1,693	64%
2014	110,415	151,948	70%	1,633	62%
2015	106,344	155,171	69%	1,621	61%
2016	105,992	174,552	75%	1,776	65%
2017	105,948	180,709	75%	1,818	66%
avg. growth (%)		3.5	3.3	1.0	1.1

*Notes:* The sample of firms used in this table are those used in the growth accounting exercise (continuing corporate non-financial firms) in Section 5. Employment is in thousands of people, and value added is in €million. “% agg.” is the share of value added and employment in the non-financial corporate sector reported in the national statistics calculated by the National Accounts Institute. The bottom row reports average annual growth rate for value added (in the sample and national statistics, respectively) and for employment.

Table A5: Descriptive statistics: growth-accounting sample (sales-weighted)

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
	Share in variable costs			Import	Services	Numb.	Share in domestic intermediate spending			
	labor	capital	interm.	interm. share	interm. share	suppl.	separations	additions	deaths	births
mean	0.074	0.009	0.917	0.315	0.725	675	0.096	0.110	0.005	0.009
p25	0.009	0.001	0.896	0.000	0.55	123	0.022	0.027	0.000	0.000
p50	0.037	0.002	0.958	0.148	0.846	330	0.053	0.065	0.000	0.001
p75	0.093	0.006	0.989	0.645	0.973	853	0.116	0.138	0.002	0.006
count	1,721,022	1,721,022	1,721,022	1,716,375	1,715,958	1,717,426	1,715,958	1,717,124	1,715,958	1,717,124

*Notes:* The sample of firms used in this table are those used in growth accounting in Section 5. Service suppliers are those in NACE code sections F-T. Summary statistics are weighted by sales.

Table A6: Separations and additions from continuing suppliers on instruments

	(i)	(ii)	(iii)	(iv)
	Separations from continuing suppliers		Additions from continuing suppliers	
Restricted death share	-0.013 (0.050)	-0.029 (0.051)	0.150** (0.062)	0.153** (0.062)
Restricted birth share	0.141** (0.062)	0.142** (0.062)	0.030 (0.044)	0.029 (0.044)
Specification	OLS	OLS	OLS	OLS
Controls	N	Y	N	Y
Industry $\times$ year FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Observations	37,898	37,898	37,898	37,898

*Notes:* Columns (i) and (ii) regress the separation share from continuing suppliers (i.e. suppliers who separate but continue to operate) on our two instruments with and without controls. Columns (iii) and (iv) regress the addition share from continuing suppliers (i.e. suppliers who are added but operated in the previous year) on our two instruments with and without controls. Other controls are as in Table 1. Industry fixed effects are at the 6-digit product code level. All regressions are unweighted. Standard errors are clustered at the firm-level.

Table A7: Estimates of  $\delta$  when separations and additions are regressed separately

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)	(x)
	$\Delta \log mc$		First stage	$\Delta \log mc$		$\Delta \log mc$		First stage	$\Delta \log mc$	
Separation share	-0.001 (0.014)			0.263*** (0.099)	0.257*** (0.100)					
Additions share						0.037*** (0.013)			-0.277*** (0.083)	-0.284*** (0.082)
Restricted death share		0.239*** (0.091)	0.930*** (0.053)							
Restricted birth share							-0.287*** (0.083)	1.012*** (0.046)		
Specification	OLS	OLS	OLS	IV	IV	OLS	OLS	OLS	IV	IV
F-stat				325	308				490	491
Controls	Y	Y	Y	N	Y	Y	Y	Y	N	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	37,898	37,898	37,898	37,898	37,898	37,898	37,898	37,898	37,898	37,898

*Notes:* Columns (i)-(v) report estimates of regression (11) where addition share and its instrument are dropped. Columns (vi)-(x) report estimates of regression (11) where separation share and its instrument are dropped. Columns (iii) and (viii) display the first-stage for each regression. Other controls are as in Table 1. Industry fixed effects are at the 6-digit product code level. All regressions are unweighted. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

Table A8: Estimates of  $\delta$  for alternative measures of marginal costs

	(i)	(ii)	$\Delta \log mc$		(v)	(vi)	(vii)	(viii)
	Capital all overhead	60% overhead	40% overhead	0% overhead	Prod. fun. estimation	Decreasing returns	$\Delta_2 \log mc$	$\Delta_3 \log mc$
Separation share	0.307*** (0.106)	0.304*** (0.105)	0.372*** (0.125)	0.327*** (0.123)	0.337*** (0.130)	0.350*** (0.117)	0.360** (0.146)	0.363** (0.164)
Addition share	-0.343*** (0.090)	-0.339*** (0.089)	-0.353*** (0.093)	-0.294*** (0.093)	-0.381*** (0.111)	-0.328*** (0.097)	-0.318** (0.130)	-0.398*** (0.133)
Specification	IV	IV	IV	IV	IV	IV	IV	IV
F-stat	110	107	107	112	108	108	86	76
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Observ.	37,884	37,863	37,922	38,012	37,898	37,898	30,187	24,276

*Notes:* This table displays estimates of regression (11) for different measures of marginal cost, where we instrument separation and additions using restricted exit and entry shares defined by equations (12) and (13). Columns (i)-(iv) use measures of marginal costs under alternative assumptions on the share of overhead costs in capital and labor, column (v) uses marginal costs obtained from Levinsohn-Petrin production function estimates, column (vi) uses marginal costs assuming decreasing returns to scale in variable production, such that variable costs are  $C_i(\mathbf{p}, A_i, q_i) = c_i(\mathbf{p}, A_i) q_i^{1.15}$ . Columns (vii) and (viii) use two and three-year changes in marginal cost as outcomes. Controls are as in Table 1. All regressions are unweighted. Industry fixed effects are at the 6-digit product code level. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

Table A9: Estimates of  $\delta$  for alternative samples

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
	$\Delta \log mc$								
	Constant prod. mix	Single product	Two year cutoff	Three year cutoff	Employment weighted	Sep. & add. shares < 0.3	Sep. & add. shares < 1	Prodcom / total sales > 0.5	$ \Delta \log mc  < 1$
Separation share	0.278** (0.110)	0.482*** (0.144)	0.225** (0.108)	0.201 (0.127)	0.422** (0.172)	0.326*** (0.118)	0.369*** (0.120)	0.289*** (0.111)	0.295*** (0.106)
Addition share	-0.345*** (0.094)	-0.272* (0.142)	-0.288*** (0.093)	-0.289*** (0.098)	-0.248** (0.116)	-0.376*** (0.107)	-0.351*** (0.093)	-0.303*** (0.086)	-0.342*** (0.089)
Specification	IV	IV	IV	IV	IV	IV	IV	IV	IV
F-stat	103	49	95	72	97	139	69	99	108
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observ.	35,325	18,302	32,510	27,303	37,898	36,992	38,190	33,230	37,886

*Notes:* This table displays estimates of regression (11) for different measures of marginal cost, where we instrument separation and additions using restricted exit and entry shares defined by equations (12) and (13). Column (i) drops downstream firms that switch the set of 8-digit products between years, and column (ii) drops firms that produce more than one 8-digit products. Columns (iii) and (iv) restrict the set of suppliers in the instrument to those for which the downstream firm is a small customer for two or three years (rather than one year in the baseline) before exiting or entering. Column (v) weights observations by employment of the downstream firm. Columns (vi) and (vii) drop observations in which the separation or addition share are higher than 0.3 or 1 (rather than 0.5 in the baseline). Column (viii) restricts the sample to firms whose Prodcom sales are at least 50% of total sales, and column (ix) drops observations for which the absolute size of marginal costs changes exceeds 1. Controls are as in Table 1. Industry fixed effects are at the 6-digit product code level. All regressions are unweighted except for column (v). Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

Table A10: Estimates of  $\delta$  for alternative set of suppliers

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
	$\Delta \log mc$						
	Industry	Services	Exclude utilities	Exclude retail & wholesale	Incl. capital producers	Excl. finance	Excl. self-empl., finance, govt.
Separation share	0.135 (0.130)	0.467*** (0.139)	0.299*** (0.107)	0.250* (0.139)	0.300*** (0.103)	0.310*** (0.106)	0.258** (0.105)
Addition share	-0.289* (0.150)	-0.411*** (0.115)	-0.330*** (0.092)	-0.385*** (0.137)	-0.318*** (0.089)	-0.336*** (0.089)	-0.293*** (0.085)
Specification	IV	IV	IV	IV	IV	IV	IV
F-stat	93	88	103	74	106	115	115
Controls	Y	Y	Y	Y	Y	Y	Y
Industry $\times$ year FE	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y
Observ.	38,201	38,050	37,904	38,105	37,854	37,904	37,928

*Notes:* This table displays estimates of regression (11) for different sets of suppliers. Industry suppliers are those in NACE code sections A-E, and service suppliers in sections F-T. Controls are as in Table 1. All regressions are unweighted. Industry fixed effects are at the 6-digit product code level. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

## Appendix E Monte Carlo Simulations

In this appendix we report results when we run regression (11) on artificial data. We use the cost function introduced in Example 3. The marginal cost for downstream firm  $i$  is  $mc_i = A_i^{-1} \tilde{m}c_i$ , where  $A_i$  is a Hicks neutral productivity shifter and  $\tilde{m}c_i$  solves

$$\sum_{j=1}^M \frac{\omega_{ij}}{\sigma_j - 1} \left( \frac{p_{ij}}{\tilde{m}c_i} \right)^{1-\sigma_{ij}} = \sum_{j=1}^M \frac{\omega_{ij}}{\sigma_{ij} - 1}.$$

The scalars  $\omega_{ij}$  and  $\sigma_{ij}$  are parameters of firm  $i$ 's cost function and  $M$  is the number of potential suppliers. Inputs that are unavailable to firm  $i$  have infinite price. The spending share on supplier  $j$  by firm  $i$  is

$$\Omega_{ij} = \frac{\omega_{ij} (p_{ij} / \tilde{m}c_i)^{1-\sigma_{ij}}}{\sum_k \omega_{ik} (p_k / \tilde{m}c_i)^{1-\sigma_{ik}}}.$$

We parameterize  $\sigma_{ij}$  and  $\omega_{ij}$  as follows so that we can control the correlation between spending shares on each input and the inframarginal surplus ratio of that input.

Firm  $i$  draws random variables  $\epsilon_{kij}$  for  $j = \{1, \dots, M\}$  and  $k = 1, 2, 3$  that are uniformly distributed in the interval  $[0, r_k]$ . We set  $\sigma_{ij} = \bar{\sigma}^{sep} + \epsilon_{1ij} + \epsilon_{2ij}$  for  $j = \{1, \dots, M/2\}$ , and  $\sigma_j = \bar{\sigma}^{add} + \epsilon_{1ij} + \epsilon_{2ij}$  for  $j = \{M/2 + 1, \dots, M\}$ . We set the parameters determining spending shares on each input as follows:  $\tilde{\omega}_{ij} = \epsilon_{3ij} + \kappa \epsilon_{2ij}$ ,  $\bar{\omega}_{ij} = \tilde{\omega}_{ij} / \sum_j \tilde{\omega}_{ij}$ , and  $\omega_{ij} = \bar{\omega}_{ij} (p_{ij} / \tilde{m}c_i)^{\sigma_{ij}-1}$ . If  $\kappa = 0$ , spending shares are uncorrelated with  $\sigma_{ij}$ . If  $\kappa < 0$ , spending shares are negatively correlated with  $\sigma_{ij}$ .

Inputs  $j = \{1, \dots, M/2\}$  are available in the first period, and each input has probability  $\rho^{sep}$  of becoming unavailable in the second period. All inputs  $j = \{M/2 + 1, \dots, M\}$  are available in period 2, and each input has probability  $\rho^{add}$  of being unavailable in the first period. Hence,  $\rho^{sep}$  and  $\rho^{add}$  control the fraction of separating inputs and the fraction of added inputs between the first and second period. All available inputs in the first period have price equal to one. Available inputs in the second period have log-normally distributed prices with standard deviation  $\sigma^p$ . For each firm, changes in Hicks-neutral productivity are log-normally distributed price with standard deviation  $\sigma^A$ .

In our simulations, we set  $M = 200$  which is close to number of suppliers for the average downstream firm. We set  $\bar{\sigma}^{sep}$  and  $\bar{\sigma}^{add}$  so that, conditional on the other parameters, the average  $\delta$  is 0.3 for separating suppliers and 0.33 for added suppliers (consistent with our baseline estimates). We set  $\rho^{sep} = 0.01$  and  $\rho^{add} = 0.01$  so that the average separation and addition shares are 0.005, which is similar to the variable cost share of entering and

exiting suppliers in the Prodcum sample. We set the upper bound of the uniform distribution  $r_1$  so that the range of  $\delta$  across inputs (within each of the addition and separation sets) is 0.1. We set  $r_2 = 1$  without loss since we rescale the input shifters  $\tilde{\omega}_{ij}$ . We set  $r_3 = 1$  so that the correlation between  $\delta$  and cost shares  $\Omega$  across inputs is 0.5 if  $\kappa = -1$  and  $-0.5$  if  $\kappa = 1$ . Across firms, the correlation between separation or addition share and average  $\delta$  for separating or added inputs is 0.28 if  $\kappa = -1$  or  $-0.28$  if  $\kappa = 1$ . We report results for three sets of values of  $\sigma^p$  and  $\sigma^A$ : (i)  $\sigma^p = \sigma^A = 0$ , (ii)  $\sigma^p = \sigma^A = 0.01$ , and (iii)  $\sigma^p = \sigma^A = 0.02$ . We consider 100 simulations, and for each simulations draw artificial data for 35,000 firms (roughly the number of observations in our regressions). We run regression (11) without instrumenting because additions and separations are exogenous in our simulations. Table A11 reports percentile estimates across the 100 simulations.

Motivated by Proposition 2, we first consider the case where average  $\delta$  firm is uncorrelated with the addition and separation shares. Columns (i)-(iii) show that the estimated coefficients are very close to the true average  $\delta$  for additions and separations. They are not exactly equal because of the small errors from the first-order approximation. As expected, the sampling uncertainty of the estimates is increasing when we increase the standard deviation of productivity and continuing price shocks. The remaining columns show that, when addition and separation shares are systematically correlated with average  $\delta$ , violating one of the assumptions in Proposition 2, the estimated coefficients are biased. However, for the median estimate the bias is quite small (it is of the same order as the variation induced by sampling uncertainty).

Table A11: Monte Carlo simulations

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Correlation $\delta, \Omega$		Zero			-0.5			+0.5	
Std. dev. $A, p$ shocks	0	0.01	0.02	0	0.01	0.02	0	0.01	0.02
<b>Addition share</b>									
$\mathbb{E}[\bar{\delta}^{add}]$	0.336	0.336	0.336	0.330	0.330	0.330	0.331	0.331	0.331
Median estimate $\hat{\delta}^{add}$	0.339	0.339	0.335	0.316	0.316	0.318	0.349	0.346	0.352
5th percentile estimate	0.339	0.324	0.303	0.316	0.301	0.281	0.348	0.333	0.311
95th percentile estimate	0.340	0.353	0.367	0.317	0.333	0.353	0.350	0.363	0.385
<b>Separation share</b>									
$\mathbb{E}[\bar{\delta}^{sep}]$	0.305	0.305	0.305	0.299	0.299	0.299	0.300	0.300	0.300
Median estimate of $\hat{\delta}^{sep}$	0.308	0.308	0.307	0.289	0.287	0.290	0.316	0.316	0.314
5th percentile estimate	0.308	0.291	0.278	0.289	0.277	0.259	0.315	0.300	0.281
95th percentile estimate	0.309	0.326	0.332	0.290	0.308	0.327	0.317	0.334	0.348

Notes: Table reports Monte Carlo statistics from 100 simulations with a sample of 35,000 firms in each simulation. The value of  $\mathbb{E}[\bar{\delta}^{add}]$  and  $\mathbb{E}[\bar{\delta}^{sep}]$  are unweighted averages of the true  $\delta$ 's for additions and separations. The estimates  $\hat{\delta}^{add}$  and  $\hat{\delta}^{sep}$  are for regression (11), with percentiles calculated across the 100 simulations. Details of the calibration are in the text.