

NBER WORKING PAPER SERIES

SUPPLIER CHURN AND GROWTH:
A MICRO-TO-MACRO ANALYSIS

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Working Paper 31231
<http://www.nber.org/papers/w31231>

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 2023, Revised December 2023

First version: June, 2022. We thank Andy Atkeson, Pablo Fajgelbaum, Kyle Herkenhoff, Jim Hamilton, Federico Huneus, Jozef Konings, Marc Melitz, Guido Menzio, Ezra Oberfield, Todd Schoellman, Felix Tintelnot, Gianluca Violante, Venky Venkateswaran, Jonathan Vogel, and Alwyn Young for comments. We acknowledge financial support from NSF grant No. 1947611 and the Alfred P. Sloan Foundation. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the National Bank of Belgium or the National Bureau of Economic Research.

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JEL No. E0,E10,O0,O4

ABSTRACT

It is widely believed that access to new suppliers leads to consumer surplus and that this surplus drives long-run growth and trade. Despite its importance, little direct empirical evidence exists on the strength of this force. We use detailed Belgian data to study this effect's impact on both micro- and macroeconomic outcomes. Instrumenting for supplier entry and exit, we find that the elasticity of downstream firms' marginal costs to the cost share of entering and exiting suppliers is around 0.3%. That is, marginal costs rise when suppliers are exogenously lost and they fall when suppliers are exogenously added. We show that this elasticity measures the area under the input demand curve relative to expenditures, and can be used to calibrate models with an extensive margin of inputs, such as expanding variety growth models. We develop a macroeconomic growth-accounting framework that quantifies the importance of supplier addition and separation for aggregate growth. Using firm-level production network data and estimated microeconomic elasticities, we show that supplier churn can plausibly account for more than half of aggregate productivity growth.

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1 Introduction

New producers generate surplus for their customers and this surplus can cause trade and fuel growth. However, despite its critical role, there is little direct empirical evidence that quantifies the size of surplus from new varieties. This study investigates the size of the surplus created for customers when firms form links with one another, and relates it to both microeconomic and macroeconomic outcomes.

In the microeconomic part of the paper, we define and estimate a statistic, the “infra-marginal surplus” ratio, which quantifies consumer surplus from additional suppliers per unit of expenditures. This notion of surplus, which we denote by δ , 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.¹ 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. We propose a strategy to estimate δ and implement this strategy using microeconomic data from Belgium.

In the macroeconomic part of the paper, we develop a growth accounting framework to assess the contribution of supplier churn 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, using the estimates of inframarginal surplus ratio 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. Demand estimation focuses on how quantities respond to prices. Using 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 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

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

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.

Our approach is different. 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 demand system. We estimate this elasticity using a detailed survey of manufacturing firms in Belgium called Prodcom. This survey contains sales and quantity information for manufacturing firms in Belgium. We merge this data with firm-to-firm input-output linkage information from VAT returns. Using this tax information, we observe at annual frequency almost all suppliers of the firms in Prodcom. We calculate a measure of marginal cost for Prodcom firms as the log change in average variable costs and regress it on supplier additions and separations. We show that, when this regression is consistently estimated, the coefficient should identify the inframarginal surplus ratio.

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%). For both entry and exit, the identification requirement is that addition and separation of suppliers caused by our instrument is 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 industry by year and firm fixed effects to allow for industry-level shocks and differential trends among firms.

We find significant 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, exit or enter, then this raises or lowers its marginal cost by around 0.3 percentage points. Our estimate of the area under the input demand curve implies that if demand for inputs is CES, the "love-of-variety" effect corresponds to an elasticity of substitution between 4 and 5. 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.

Our estimates of the integral of demand are related to the broader objective of measuring different derivatives of demand curves. Estimates of the first derivative of demand are common, since the first derivative of demand affects the price elasticity of demand (see, e.g., Berry and Haile, 2021 for a review of demand estimation). The second derivative of demand has also received considerable empirical attention, since it determines the pass-through of marginal cost into the price (see, e.g., Burstein and Gopinath, 2014 for a survey on exchange rate pass-through). Even the third derivative of demand is an important statistic, because it disciplines the rate at which pass-through changes along the demand curve (e.g. as in Amiti et al., 2019).

All these statistics can be estimated by considering small changes: the price elasticity is disciplined by how quantity responds to small price changes, the superelasticity by how prices respond to small changes in marginal costs, and the change in the super elasticity by how pass-through responds to small changes in marginal costs. In contrast, the area under the demand curve is more “global” in the sense that it depends on the entire shape of the demand curve, not just its properties around an observed point. The standard approach in the literature then is to estimate a fully parametric demand system and explicitly integrate demand curves to measure consumer surplus.

Our paper shows that, in a production context, this is not necessary and the area under the input demand curve can be estimated directly in response to small changes in supplier entry and exit without specifying the global demand system. However, as with the demand elasticity and the degree of pass-through, the inframarginal surplus ratio can be a complicated object that depends on where the perturbation occurs on the downstream firm’s cost function. With more parametric assumptions, one can use estimates of the inframarginal surplus ratio to pin down deeper parameters of the firm’s cost function.

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; Domar, 1961; Hulten, 1978; Basu and Fernald, 2002; Baqaee and Farhi, 2019b).² 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.

²By 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.

Our accounting framework does not require a fully spelled-out model of market structure, factor markets, or link formation but is consistent with many different structural models. Our growth accounting framework clarifies that the importance of supplier churn depends on the inframarginal surplus ratio, i.e. area under the input demand curve. We discipline the inframarginal surplus ratio in our growth accounting exercises to match what we estimate in the microeconomic regressions and find that over 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 estimates, to decompose aggregate growth in our data in Section 5. We conclude in Section 6.

Related literature. Our paper is related to three different literatures. First, as discussed above, our analysis contributes to models of growth with an extensive margin of inputs such as expanding-variety models. A key object of interest and source of welfare gains is the love for product variety. The love-of-variety effect is usually defined using an elasticity of the utility function.³ In this paper, we define love-of-variety using the area under the demand curve instead. Unlike the elasticity of the utility function, the area under the demand curve is, in principle, observable.

This definition also clarifies that love-of-variety captures the change in marginal cost resulting from significant (non-marginal) changes in input prices. If one is comfortable with the idea that small input price changes have effects on costs and welfare, then one should also be comfortable with the love-of-variety effect. Moreover, our definition, which is based on the area under the demand curve, can be applied to a much broader class of demand systems than standard definitions.

We 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 mea-

³The 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), amongst many others. The love-of-variety effect is sometimes viewed with suspicion since it is not easily measured and does not show up in conventional index number statistics. This may be exacerbated by the fact that in models where it plays a central role, it is often described using variables that are unobservable. For example, Vives (1999), Benassy (1996), Zhelobodko et al. (2012), and Dhingra and Morrow (2019) all use definitions that rely on the elasticity of the utility function with respect to quantity — an inherently unobservable object since utility is only defined up to monotone transformations.

sure 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).⁴

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 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), Barrot and Sauvagnat (2016), Carvalho et al. (2021), and Miyauchi et al. (2018) have shown that shocks and failures to one firm are transmitted across supply chains and affect the sales and employment of other firms in neighboring parts of the production network using reduced-form methods. Huneus (2018) and Arkolakis et al. (2021) use a fully-specified structural model to study adjustment costs in link-formation between firms and their aggregate consequences. Our paper is also related to Boehm and Oberfield (2020), who document that link formation is affected by institutional distortions and that this can reduce aggregate productivity. Our paper complements this large literature by providing direct estimates of the value of link formation at the microeconomic level and a growth accounting exercise that quantifies

⁴There 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.

the macroeconomic importance of supplier churn. Unlike this 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).⁵

Third, 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* growth.⁶ The macroeconomic and 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, or other types of mismeasurement, under a CES demand system. This CES methodology owes its popularity to its simplicity and non-demanding 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), Melitz and Redding (2014), Halpern et al. (2015), and Blaum et al. (2018) study the welfare gains from trade in intermediate inputs.⁷ 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

⁵In 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 costumers.

⁶There 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.

⁷The 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.

input demand curve directly through its effect on downstream marginal costs rather than via implicit or explicit integration of demand curves. This is 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.⁸

2 Microeconomic Value of Link Formation: 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.⁹ We allow the firm to have fixed costs of operation, but assume that variable production has constant returns to scale. We allow for the possibility that the price of some inputs is equal to infinity (i.e. some inputs are not available).^{10,11}

Assume that there is a continuum of inputs that can be grouped into types. The cost function is symmetric in input prices that belong to the same type but not necessarily sym-

⁸For 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.

⁹In this section, to simplify the notation, the vector of input prices \mathbf{p} includes intermediate input prices and factors (e.g. labor and capital). In Section 4 we introduce notation to distinguish intermediate inputs and factors.

¹⁰In 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.

¹¹The availability of varieties to i may be exogenous to i 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 directly model these decisions and consider the second-stage where i minimizes variable costs taking the availability of varieties as given.

metric across types. More formally, two inputs belong to the same group 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. We assume without loss of further generality that inputs of the same type also have the same initial price. We can do this by defining inputs with the same input demand function that have different initial prices to be different types. To simplify notation, we assume that there is a countable number of types.

Almost all popular production technologies used in the macroeconomics and trade literatures feature a notion of "types." For example, for CES, we say two inputs have the same type if they have the same share parameter and price. 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 paper focuses on the creation and destruction of buyer-supplier relationships. These events are typically discrete in the sense that when suppliers are added or dropped, expenditures change discontinuously.¹² Following Hicks (1940), to account for this phenomenon, we allow jumps in the price of inputs: when an input variety is dropped discontinuously, we say that its price jumped to infinity; when an input variety is added discontinuously, we say that its price became finite.

This price jump could be a literal jump in the price of the input variety, say due to entry or exit of a supplier into the market, or it could also represent a discontinuous change in the shadow price of that input. These discontinuous changes in shadow prices could be caused by changes in quality that are not reflected in market prices or by changes in the decision to pay fixed costs or changes in matching frictions associated with linking to some supplier. Empirically, we identify jumps in the data that can be attributed to exogenous supplier additions and separations.¹³

Define the *inframarginal surplus ratio* associated with a jump in the price of input of

¹²If expenditures on added and separated inputs do not change discontinuously, then additions and separations have no direct first-order effect on the downstream firms' marginal cost. We return to this point after stating Proposition 1.

¹³We do not investigate price jumps that may be occurring within continuing buyer-supplier relationships (caused by process or product innovation from continuing suppliers).

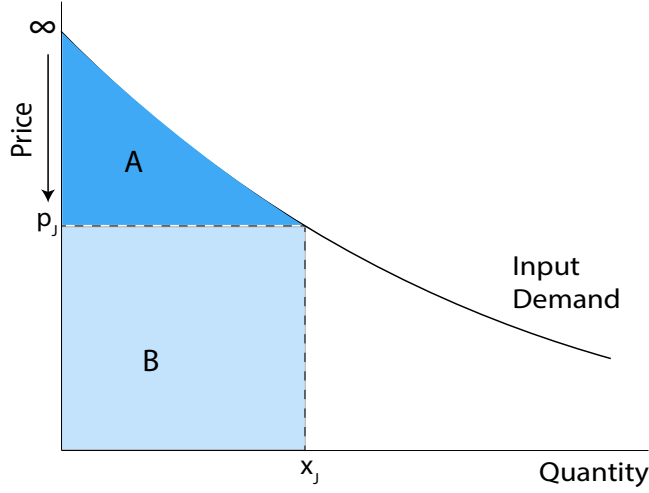


Figure 1: A Reduction in the Price of the Input

Figure 2: The inframarginal surplus ratio, δ , is the ratio of A to B .

type J (holding the price of all other inputs constant) to be:¹⁴

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

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

We show that when i adds or loses access to a supplier of type J , the consequences for i 's unit costs are given by surplus per unit of expenditures, δ_{iJ} , times expenditures $p_J x_{iJ}$. Let ΔM_{iJ}^{add} be the mass of inputs of type J that i gains access to, where the price jumps down from infinity to $p_J < \infty$, and ΔM_{iJ}^{sep} be the mass of inputs of type J that i loses access to, where the price jumps to infinity from p_J .¹⁵ Denote the input share of each type- J variety purchased by firm i to be Ω_{iJ} :

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

¹⁴In 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.

¹⁵If there is a choke price, then any price changes beyond the choke price are irrelevant.

The next proposition loglinearizes the downstream firm's marginal cost and shows that δ_{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 ΔM_i^{add} and ΔM_i^{sep} , and the technology parameter ΔA_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 δ_{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 δ_{ij} (the object we estimate) but the product of δ_{ij} and the expenditure share Ω_{iJ} (which is directly observable).

Additions and subtractions of suppliers that happen continuously, 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 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, in which the demand for an input variety of type j takes the form

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

where ω_{ij} and ω_{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

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

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. Suppose that a measure ΔM of producers of inputs of a certain type with quality-adjusted price p_j exit and are replaced by a measure ΔM 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

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

That is, the price of the downstream firm falls in accordance to the elasticity of substitution, σ , 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 this case, the change in marginal cost in (5) converges to $\Delta M \Omega_{ij} \log(p_{j+1}/p_j)$, 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.

Example 3 (Heterogenous Surplus Ratios). Consider a unit cost function defined by¹⁶

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

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.

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, we can show that the surplus produced by new varieties is maximized by the CES demand system.

Proposition 2 (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 $\sigma_{iJ}(\mathbf{p}) \geq 1$.

¹⁶See Matsuyama and Ushchev (2020a) who introduce and provide more information on this demand system.

Note that 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.¹⁷ Hence, under Marshall’s second law of demand and matching a given elasticity of demand, CES maximizes the inframarginal surplus ratio.

Example 3 shows that inframarginal surplus ratios can be type-dependent because each type has a different input demand curve. However, inframarginal surplus ratios can also vary even if all types face the same input demand curve if the input demand curve is not isoelastic. When Marshall’s second law holds, Corollary 1, which follows from Proposition 2, shows that the size of the inframarginal surplus ratio is increasing in the expenditure share of the input.

Corollary 1 (Size-Dependent Inframarginal Surplus). *If Marshall’s second law of demand holds, then*

$$\frac{\partial \delta_J}{\partial p_J} < 0.$$

In this case, if spending per added supplier is higher than spending per separating supplier, then

$$\delta_J^{add} > \delta_J^{sep}.$$

3 Empirical Microeconomic Results

In this section, we consider regressions aimed at identifying the inframarginal surplus ratio associated with gaining access to a new supplier or losing access to existing suppliers. We first derive our baseline specification, motivated by the results in Section 2. We then describe the instruments and discuss the identification assumptions. Next, we describe our data and how we construct the main variables. Finally, we present our regression results.

3.1 From Theory to Baseline Regression

Define

$$\Delta M_{ij,t}^{add} = \sum_{j \in J} \mathbf{1}(\Omega_{iJ,t+1} > 0) \mathbf{1}(p_{ij,t} = \infty) \mathbf{1}(p_{ij,t+1} = p_{iJ,t+1}) \quad (7)$$

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,

¹⁷The proof 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.

define the mass of varieties that i loses access to be

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

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 .

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 σ , then $\bar{\delta}_{i,t}^{add} = \bar{\delta}_{i,t}^{sep} = 1/(\sigma - 1)$.

Given these definitions, we can rewrite Proposition 1 as

$$\Delta \log mc_{i,t} \approx -\bar{\delta}_{i,t}^{add} \sum_J \Omega_{ij,t+1} \Delta M_{ij,t}^{add} + \bar{\delta}_{i,t}^{sep} \sum_J \Omega_{ij,t} \Delta M_{ij,t}^{sep} + \sum_J \Omega_{ij,t} M_{ij,t} \Delta \log p_{J,t} + \mathcal{E}_{Ai,t} \Delta \log A_{i,t}, \quad (9)$$

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 (9) 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 . 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 (9). Unfortunately, we cannot perfectly observe any of the right-hand variables. The potential confounders in (9) 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 (9). 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 de-

mand curve, as in (7) and (8), 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 is 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. These additions and separations 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).

To allow for this possibility, we can enrich the model in Section 2 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. That is, in this section, we allow for the possibility that a shock discontinuously changes the input demand curve for some measure of the downstream firm's inputs. Doing this does not alter (9) except that the direct effect of the biased downstream technology shocks need to be included in the technology term: $\mathcal{E}_{A_{i,t}} \Delta \log A_{i,t}$.

Define the 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 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 (7) and (8), the addition and separation share 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 shifts of the input demand curve.

We consider a regression of the form

$$\Delta \log mc_{i,t} = -\hat{\delta}^{add} \underbrace{\sum_J \Omega_{ij,t+1} \Delta \tilde{M}_{ij,t}^{add}}_{\text{addition share}_{i,t}} + \hat{\delta}^{sep} \underbrace{\sum_J \Omega_{ij,t} \Delta \tilde{M}_{ij,t}^{sep}}_{\text{separation share}_{i,t}} + \hat{\gamma}' W_{i,t} + \varepsilon_{i,t}, \quad (10)$$

where $W_{i,t}$ are controls. The error term contains the same potential confounds as (9), 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 $S_{i,t}$ be the sales of firm i in period t . For each Prodcum firm i in year t , our first instrument is

$$Z_{i,t}^{separation} = \sum_j \Omega_{ij,t} \mathbf{1}(S_{j,t+1} = 0) \mathbf{1}(p_{j,t} x_{ij,t} / S_{j,t} < \text{cutoff}). \quad (11)$$

In words, we add up the expenditure share relative to variable costs, $\Omega_{ij,t}$, on suppliers of i who exit the market 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%).

Our second instrument is

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

In words, we add up the expenditure share relative to variable costs, $\Omega_{ij,t+1}$, on suppliers of i who enter the market between t and $t + 1$ and for whom i is a small customer (in our benchmark results, less than 5% of j 's sales).

The following proposition formalizes our identification strategy.

Proposition 3 (Identification). *Consider the regression in (10). 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 the price of competing inputs, and additions and separations that are not due to movements along 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 our instruments, Z_i . Under these conditions, the IV regression yields consistent and unbiased estimates of the average inframarginal surplus ratio for additions and separations.

We discuss our identification assumptions below. 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 the 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.¹⁸

We also include controls for prices of continuing suppliers (if we observe them), 6-digit industry by time fixed effects, 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 requires that, conditional on controls, the average inframarginal surplus ratio for each firm is independent of the instruments. This is automatic if δ is a constant (as in CES). We use the demand system in Example 3 and some Monte Carlo experiments to see how our regression performs when these assumptions are violated. 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 instrument, the bias in our estimates is quite small.

¹⁸Even 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).

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, (10). 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 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.¹⁹ 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 whose Prodcom sales are at least 30% of the firm’s total sales.²⁰ Our micro sample contains between roughly 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.²¹ 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 exceed sales.

¹⁹See 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) datasets.

²⁰Total 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.

²¹Page 81 in 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 measures sales using values reported in the annual accounts and, if the latter is missing, using values reported in the VAT returns.

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 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), the risk-free real rate (defined as the corresponding governmental 10 year-bonds nominal rate minus consumer price inflation at that time period), and 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 that a fraction ϕ of labor and capital costs are variable and the remaining fraction $1 - \phi$ are overhead costs. To calibrate ϕ , 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 ϕ is similar to that found by Dhyne et al. (2022).²² Given uncertainty over the extent of overhead costs, we redo our analysis under alternative assumptions. The results are quite robust to the value of ϕ . 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.²³ 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,

²²Dhyne et al. (2022) also show that ϕ is not correlated with firm size, which is consistent with our approach.

²³As 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).

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.

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.²⁴

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

$$\Delta \log mc = \Delta \log \text{total variable costs} - \Delta \log \text{total quantity}, \quad (13)$$

which is valid as long as the scale elasticity of the variable cost function is constant. Unfortunately, we 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 (13). This imputation is innocuous as long as the unobserved error term is uncorrelated with our instrument.

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 (10), we now discuss how we construct the right-hand side variables. Constructing the right-hand side

²⁴We 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

variables requires knowing the input shares of the downstream firms. For this purpose, we use the NBB B2B transactions data.

Intermediate input shares. We construct input shares of Prodcom 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 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 Prodcom 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 in which the separation share or the addition share is higher than 0.5, and perform sensitivity analysis to this cutoff.²⁵

Restricted exit and entry shares. We construct the instruments defined in (11) and (12) 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

²⁵Our 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.

the downstream firm accounts for less than 5% of the suppliers sales. We perform extensive sensitivity analysis to the value of this cutoff. We refer to the instruments as *restricted exit* and *restricted entry* shares.

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 A3 in Appendix C 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 exit and entry shares. Separation and addition shares driven by supplier's death or birth (and especially those for which the downstream firm is small) are much smaller than the overall separation and addition shares.

Table A4 in Appendix C reports correlations between the number of suppliers, additions and separations, and our instruments, with the size (employment and sales) of the downstream firm. Larger firms are connected to a higher 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 share are lower for larger firms), but our instruments are not correlated with downstream firm size (restricted entry and exit 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.

3.4 Results

Having discussed how the terms in the baseline regression (10) 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 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 exit share raises marginal costs and an increase in the restricted entry share lowers marginal costs.

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

Columns (v) and (vi) are the IV regressions with and without controls. The point estimates are quite insensitive to the inclusion of the controls (other than fixed effects). 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, as in the case of CES input demand.²⁶

The final column, (vii), replaces the change in marginal cost on the left-hand side with the change in the price charged by the downstream firm.²⁷ The effect of separations and

²⁶Table A7 in the appendix reports results from a specification of (10) 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 exit has a small effect on additions and restricted entry has a small effect on separations. The fact that the point estimates in the univariate regression are smaller in magnitude can be rationalized via quality-ladders. Consider a quality ladder model where separations and additions are paired together. If input demand is CES, then the univariate regressions identify $\frac{1}{\sigma-1} \left(1 - (p'_j/p_j)^{1-\sigma}\right)$ (in the separation regression) and $\frac{1}{\sigma-1} \left((p'_j/p_j)^{1-\sigma} - 1\right)$ (in the addition regression) where p'_j/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.

²⁷More precisely, the unit value charged by the downstream firm, since our measure of price is total sales divided by total quantity.

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 1: Baseline estimates of δ

	(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 exit share		0.240*** (0.091)	0.929*** (0.052)	0.126** (0.062)			
Restricted entry 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 (10), 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, $Z_{i,t}^{separation}$ and $Z_{i,t}^{addition}$, defined by equations (11) and (12). 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.

Table 2 displays the results of the IV regression for different cut-off values of what constitutes a “small” customer in (11) and (12). 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, in magnitude, for both entry and exit of suppliers 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 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 δ 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 Suppliers	3 E&E	4 E&E	5 E&E	6 E&E	7 E&E	8 E&E	9 E&E	10 E&E	15 E&E	50 E&E	100 E&E	5 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 (labeled E&E in the table) when defining restricted exit and entry. The benchmark regressions use a value of 5%. Column (xii) uses all separations and additions with a 5% cutoff, rather than only E&E. 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 industry disaggregation in the industry by year fixed effects, considering 4 or 8 digit products 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.

Additional sensitivities are included in the appendix. 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 fixed and we use a produc-

Table 3: Estimates of δ 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 (10) 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.

tion function estimation approach to measure the change 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 magnitude of our point estimates.²⁸ 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.

Table A9 in the appendix considers how results change if we vary the sample of firms. 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 the estimated surplus ratio for separations increases but the one for additions stays similar. We also consider a more demanding formulation of the instruments where the downstream firm has to be a small customer for exiting sup-

²⁸We assume an iso-elastic cost function, $C_i(\mathbf{p}, A_i, q_i) = c_i(\mathbf{p}, A_i) q_i^{1.15}$. 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 (10). Similarly, our measures of marginal costs do not account for changes in the quality of the the downstream firm's output. If the downstream firm downgrades output quality in response to a positive jump in its input prices, we underestimate the rise in marginal cost because quality-adjusted quantity falls by more than measured quantity. Our inframarginal surplus ratio estimates would be downward biased in this case.

pliers 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. Column (v) weighs observations by employment and this raises our point estimate for separations to 0.42 but also raises the standard errors.²⁹ 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 Prodcum 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 A3). 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 investment. This 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 Value of Link Formation: Theory

In the previous section, we estimated the area under the input demand curve and found that input suppliers generate a considerable amount of inframarginal surplus 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.

²⁹To check if our estimates vary with the size of the downstream firm, we 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 each year. The estimated coefficient on this indicator is statistically insignificant from zero.

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 Definitions and 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.

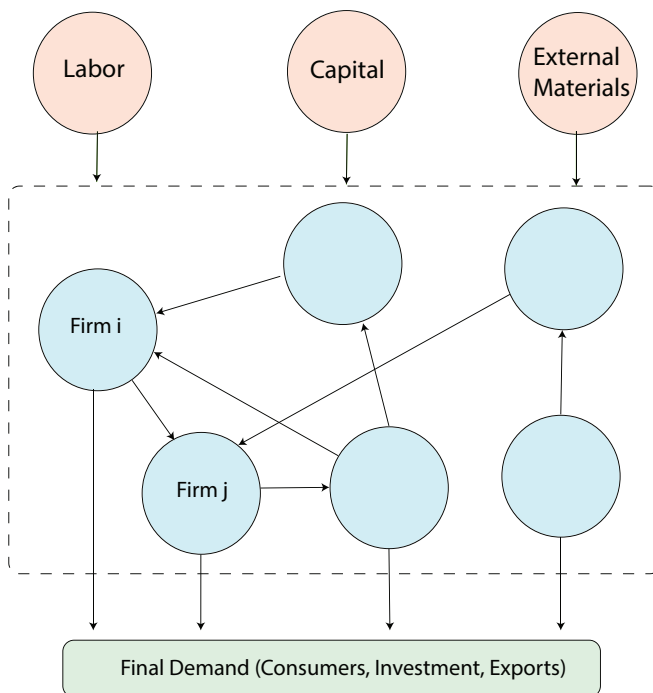


Figure 3: Graphical illustration of the economy. External inputs are red nodes and final output are green nodes. The set N is depicted by the dotted line.

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

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

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, but 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.

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 .

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:

$$\Delta \log Y_t = \Delta \log \left(\sum_{i \in C_t} p_{i,t} y_{i,t} \right) - \Delta \log P_t^Y. \quad (14)$$

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, as in a Tornqvist index, the weights are the average of shares in t and $t + 1$:

$$b_{i,t} = \frac{1}{2} \frac{p_{i,t} y_{i,t}}{\sum_{j \in C_t} p_{j,t} y_{j,t}} + \frac{1}{2} \frac{p_{i,t+1} y_{i,t+1}}{\sum_{j \in C_t} p_{j,t+1} y_{j,t+1}}.$$

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

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

This measure of aggregate growth is similar to, but is not the same, as GDP. 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).³⁰ 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 to have ij th element equal to:

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

³⁰If 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 wedges. See Baqaee and Farhi (2019a) for more details.

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

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

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

$$\Delta \log \mathbf{p}_t \approx \Psi_t \left[\Delta \log \boldsymbol{\mu}_t - \Delta \log \mathbf{A}_t + \Omega_t^F \Delta \log \mathbf{w}_t + \bar{\delta}_t^{\text{sep}} \Delta \mathcal{X}_t - \bar{\delta}_t^{\text{add}} \Delta \mathcal{E}_t \right], \quad (15)$$

where Ψ_t is the *cost-based continuing* Leontief inverse

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

Equation (15) shows that changes in the price of continuing goods depend on changes in markups, $\Delta \log \boldsymbol{\mu}_t$, productivity shifters, $\Delta \log \mathbf{A}_t$, prices of external inputs, $\Delta \log \mathbf{w}_t$, 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 Ψ_t .

Define the *revenue-based Domar weight* of $i \in C_t$ and $f \in F$ to be

$$\lambda_{i,t} = \frac{p_{i,t} q_{i,t}}{\sum_{j \in C_t} p_{j,t} y_{j,t}}, \quad \text{and} \quad \Lambda_{f,t} = \frac{\sum_{i \in C_t} w_{f,t} l_{f,t}}{\sum_{j \in C_t} p_{j,t} y_{j,t}},$$

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

$$\tilde{\lambda}_{i,t} = \sum_{j \in C_t} b_{j,t} \Psi_{ji,t}, \quad \text{and} \quad \tilde{\Lambda}_{f,t} = \sum_{j \in C_t} \tilde{\lambda}_{j,t} \Omega_{f,t}^F.$$

The cost-based and revenue-based Domar weights are the same when there are no markups and the extensive margin is inactive. The cost-based continuing Domar weight $\tilde{\lambda}_{i,t}$ mea-

asures 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 (15) into the definition of the final output price deflator yields the following first order approximation for the change in the output price deflator

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

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

Plugging this into the definition of real final output in equation (14) yields the following decomposition.

Proposition 4 (Growth-Accounting with Entry-Exit). *The change in real final output is given, to a first-order, by*

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

Aggregate output growth can be broken down into different components. We describe the different terms in sequence starting with the first line. The first term is exogenous productivity growth weighted by cost-based Domar weights. This accounts for how exogenous improvements in technology affect output, accounting for 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.³¹

³¹For counterfactuals, we need to be able to solve for changes in factor shares $d \log \Lambda$. This requires modelling the details of fixed costs and entry decisions. However, conditional on changes in factor shares,

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 Domar weight Λ_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.

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 $\tilde{\lambda}_i \bar{\delta}^{add}$ and $\tilde{\lambda}_i \bar{\delta}^{sep}$. 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. As in standard growth accounting, the results cannot be used to make counterfactual statements since, just like capital, supplier churn is endogenous.

5 Empirical Macroeconomic Results

In this section, we apply Proposition 4 to decompose aggregate growth for a large subset of the Belgian economy.³² In the first part of this section, we describe how we map the data to the terms in Proposition 4. In the second part of this section, we show the results.

5.1 Mapping to Data

Proposition 4 is exact in continuous time if the primitive shocks are smooth functions of time. Following standard practice in the growth accounting literature (Hulten, 1978), we

we do not need to specify these details.

³²When we apply Proposition 4 to decompose output growth, we use a Tornqvist second-order adjustment. That is, although Proposition 4 is a first order approximation, when we average the t and $t + 1$ coefficients on each shock, it provides a second order approximation (see Theil, 1967). For example, we weigh $\Delta \log L_{f,t}$, the change in factor quantity f between t and $t + 1$, using the average of $\hat{\Lambda}_{f,t}$ and $\hat{\Lambda}_{f,t+1}$.

map our model to data using a discrete-time approximation of the continuous time limit. To apply Proposition 4, we need to define the set of continuing firms C_t , the average inframarginal surplus parameters $\bar{\delta}_{i,t}^{\text{add}}$ and $\bar{\delta}_{i,t}^{\text{sep}}$, the share of additions and separations due to price jumps, $\Delta\mathcal{E}_t$ and $\Delta\mathcal{X}_t$, the matrices Ω_t and Ω_t^F for all continuing firms in Belgium, markups $\mu_{i,t}$, the growth in external input quantities (labor, capital, and external materials), and the growth in final real output. We discuss these in turn.

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 continuing, non-financial domestic Belgian corporations. We exclude firms that are in self-employed and financial activities (NACE codes 64-66) and non-market services including government entities (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.³³ Even though we exclude from N self-employed, government, and financial entities, 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 A2). Crucially, our output measure is much broader than the Prodcom sample that we used in Section 3. Whereas our Prodcom 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

³³We exclude self-employed because of data-privacy considerations. Non-markets services, such as government entities, education, 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).

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).³⁴ 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 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 $\phi = 0.50$). Any other expenditures the firm incurs are treated as overhead costs.³⁵

Calibrating final output. Final output is defined to be the sales of 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 .³⁶ 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.

³⁴We 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.

³⁵For 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.

³⁶Given 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 $b_i = (p_i q_i - \sum_{j \in C_t} \Omega_{ji}^s p_j q_j) / E$.

Calibrating the addition and separation share. To apply Proposition 4, 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 separations 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 $t + 1$.

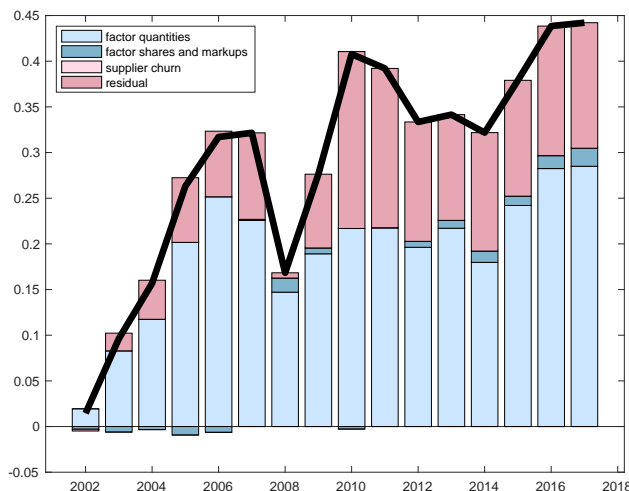
Calibrating $\bar{\delta}_{i,t}^{\text{add}}$ and $\bar{\delta}_{i,t}^{\text{sep}}$. We calibrate the average inframarginal surplus over additions and separations of suppliers per unit of expenditures using our microeconomic estimates from Section 3. We consider a few different cases: first, we set $\bar{\delta}_{i,t}^{\text{add}} = \bar{\delta}_{i,t}^{\text{sep}} = 0$, 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. 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 4.³⁷

Table A2 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 A2 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 same 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 while the sales-weighted average number of suppliers is 658. Therefore, the number of suppliers rises with the size of the firm. Furthermore, addition shares are higher than separation shares, both for all supplier churn and also for supplier entry and exit.

5.2 Results

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



We start with a special case of Proposition 4 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 captures changes in markups and factor prices, does not play a large role in cumulative growth rates in this dataset.

³⁷Although 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.

The “unexplained” technology residual is large and accounts for about 14 log points of cumulative growth — roughly 1% per year.

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

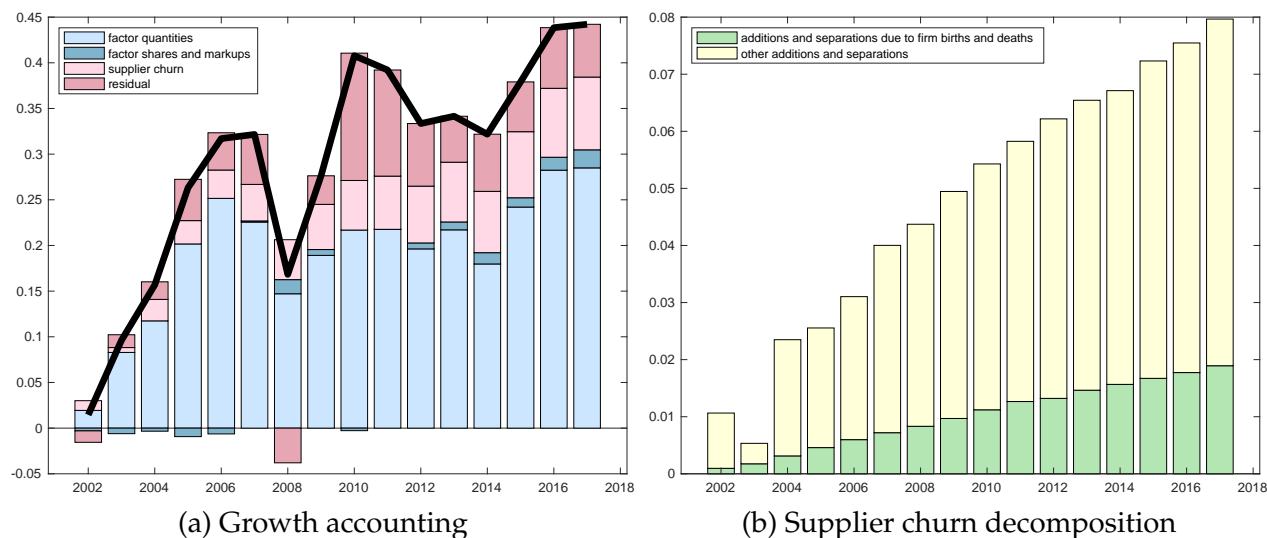


Figure 5 sets $\bar{\delta}^{\text{add}} = \bar{\delta}^{\text{sep}} = 0.3$.³⁸ The left panel shows that the extensive margin of supplier addition and separation accounts for about 8 log points out of a total of 14 log points of unexplained cumulative growth in the technology residual over the sample period. The extensive margin effect more than halves the size of the technology residual.³⁹ The 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 and the rest. Roughly one quarter of the extensive margin term is attributable to entry and exit 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.⁴⁰

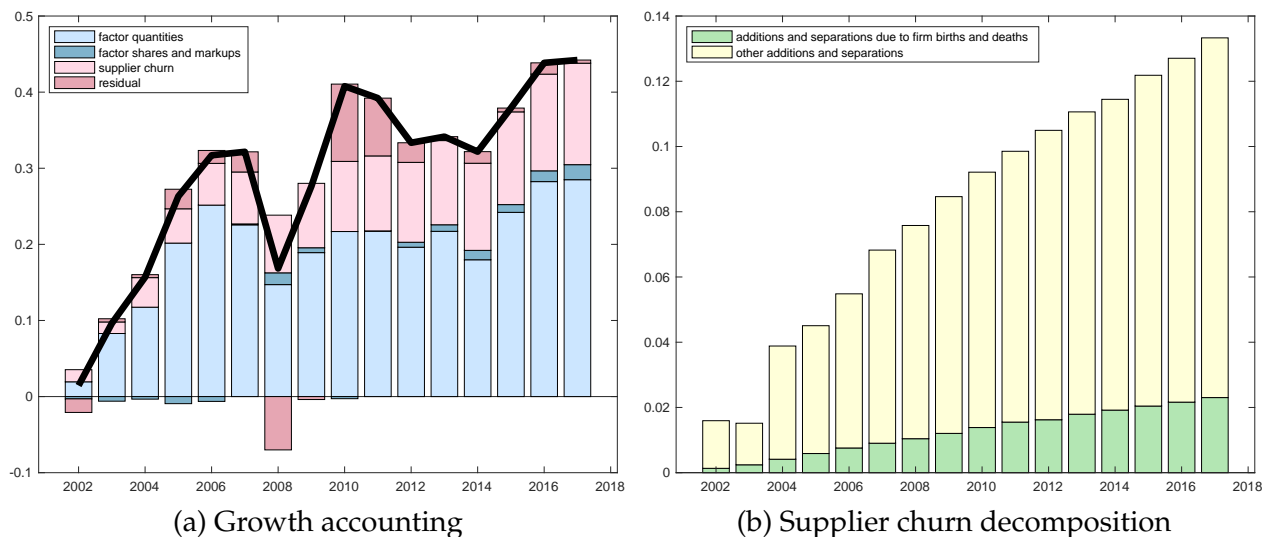
³⁸For CES input demand, this corresponds to setting the elasticity of substitution equal to 4.3.

³⁹This does not mean that in a counterfactual where firms cannot add or drop suppliers aggregate productivity growth is 8 log points lower. In such a counterfactual, the remaining terms in Proposition 4 (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 δ .

⁴⁰Whereas 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

Figure 6 shows results using the point estimates from column (vi) of Table 1: $\bar{\delta}^{add} = 0.33$ and $\bar{\delta}^{sep} = 0.3$. 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 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 entry and exit, and the rest.

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



Since the extensive margin 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 $\bar{\delta}^{add}$ and $\bar{\delta}^{sep}$. Table 4 provides the cumulative size of the supplier churn term over the sample for different values of $\bar{\delta}^{add}$ and $\bar{\delta}^{sep}$. Our regression results cannot reject the hypothesis that $\bar{\delta}^{add}$ and $\bar{\delta}^{sep}$ 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 $\bar{\delta}^{add}$ and $\bar{\delta}^{sep}$ are very quantitatively important. Our point estimates suggest that $\bar{\delta}^{add}$ is slightly higher than $\bar{\delta}^{sep}$, which further boosts the role of supplier churn. On the flipside, if $\bar{\delta}^{add}$ is less than $\bar{\delta}^{sep}$, 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 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 as large than that of the supplier churn term.

deaths. These numbers are less sensitive to the precise values of $\bar{\delta}^{add}$ and $\bar{\delta}^{sep}$ and hover between 1.5 and 2.4 log points over the whole sample.

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

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

(a) All separations and additions

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

(b) Firm births and deaths

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, δ , is likely heterogeneous and varies by both the characteristics of the suppliers 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, the gains from trade, optimality of entry, and optimal innovation subsidies. Furthermore, our micro estimates can be used as targeted moments for disciplining models of endogenous network formation.

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.

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Appendix A Proofs

Proof of Proposition 1. We suppress the index i for the downstream firm throughout the proof since all variables are indexed by the identity of the downstream firm. Use Shephard's lemma to get

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

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

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

where we omit the dependence of conditional input, x_j , on its other arguments. Group the integrals into types so that

$$\begin{aligned} \mathcal{C}(\mathbf{p}^1, A^1, q^1) - \mathcal{C}(\mathbf{p}^0, A^0, q^0) &= \sum_J M_J \int_{p_j^0}^{p_j^1} x_J dp_J + \sum_J \Delta M_J^{add} \int_{p_j^0}^{\infty} x_{iJ} dp_J \\ &\quad + \sum_J \Delta M_J^{sep} \int_{\infty}^{p_j^0} x_J dp_J + \int_{A^0}^{A^1} \frac{\partial \mathcal{C}}{\partial A} dA + \int_{q^0}^{q^1} \frac{\partial \mathcal{C}}{\partial q} dq, \end{aligned}$$

where p_j denotes the price of any available variety j of type J and M_J denotes the mass of non-jumping varieties of type J . Using the definition $\Delta M_J = \Delta M_J^{add} - \Delta M_J^{sep}$, we can re-write this expression as

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

Given this exact representation, 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 ΔM_J^{add} or that become unavailable ΔM_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 . Omitting again the dependence of conditional input, x_J , on its other arguments (which are held constant when we take the derivative), this results in

the following expression

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

This first-order approximation can be rewritten as

$$d \log \mathcal{C} = \sum_J M_J \Omega_i d \log p_J - \frac{1}{\mathcal{C}} \sum_J \left(\int_{p_J^0}^{\infty} x_J(p_J) dp_J \right) dM_J + \frac{\partial \log \mathcal{C}}{\partial \log A} d \log A + \frac{\partial \log \mathcal{C}}{\partial \log q} d \log q. \quad (\text{A1})$$

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 (A1) as in (2) in Proposition 1 using the definition of δ_j . □

Proof of Proposition 2. 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 δ_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

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

□

Proof of Corollary 1. Re-express the inframarginal surplus ratio as

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

Note that

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

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 $p_J < p_J^*$, Proposition 2 then guarantees that $\delta_J(p_J) < \frac{1}{\sigma_J(p_J) - 1}$. \square

Proof of Proposition 3. According to Proposition 1, and re-introducing the downstream firm i index, we can write

$$\Delta \log mc_{i,t} = -\bar{\delta}_{i,t}^{add} X_{1i,t} + \bar{\delta}_{i,t}^{sep} X_{2i,t} + W'_{i,t} \gamma + \epsilon_{i,t} \quad (\text{A2})$$

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 γ 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 construction.

Without loss of generality, we also assume that $Z_{1i,t}$ and $Z_{2i,t}$ 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

$$\mathbb{E} [\tilde{Z}_{1i,t} \epsilon_{i,t}] = \mathbb{E} [\tilde{Z}_{1i,t}] \mathbb{E} [\epsilon_{i,t}] = 0, \quad (\text{A3})$$

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

$$\mathbb{E} [\bar{\delta}_{i,t}^{add} v_{1i,t} \tilde{Z}_{1i,t}] = \mathbb{E} [\bar{\delta}_{i,t}^{sep} v_{2i,t} \tilde{Z}_{1i,t}] = 0, \quad (\text{A4})$$

and similar for $\tilde{Z}_{2i,t}$.^{A41, A42} Finally, our assumption that the instruments are mutually independent of $\bar{\delta}_{i,t}^{sep}$ and $\bar{\delta}_{i,t}^{add}$ implies that

$$\begin{aligned} \mathbb{E} [\tilde{Z}_{1i,t}^2 \bar{\delta}_{i,t}^{sep}] &= \mathbb{E} [\tilde{Z}_{1i,t}^2] \mathbb{E} [\bar{\delta}_{i,t}^{sep}] \\ \mathbb{E} [\tilde{Z}_{1i,t}^2 \bar{\delta}_{i,t}^{add}] &= \mathbb{E} [\tilde{Z}_{1i,t}^2] \mathbb{E} [\bar{\delta}_{i,t}^{add}], \end{aligned} \quad (\text{A5})$$

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 into the second stage yields

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

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

^{A41}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 (A4) does not require the assumption that the instruments are mutually independent of the error terms in the first stage.

^{A42}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.

latter equalities are implied by the first-stage regression) to obtain

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

Substitute the residualized version of (A2) for $\Delta \log \tilde{mc}$ to get

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

Substitute the first stage and use (A3) to obtain

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

Using $\mathbb{E} [\tilde{Z}_{1i} \tilde{Z}_{2i}] = 0$ and (A4) simplifies this expression to

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

Using (A5) 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

$$\mathbb{E} [\Delta \log \tilde{mc}_i \tilde{Z}_{2i}] + \hat{\delta}^{add} \alpha_{21} \mathbb{E} [\tilde{Z}_{2i}^2] - \hat{\delta}^{sep} \alpha_{22} \mathbb{E} [\tilde{Z}_{i1}^2] = 0$$

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 α 's has full rank. \square

Proof of Proposition 4. In the text we showed that, to a first-order approximation, the final output price deflator is given by

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

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 $\sum_{f \in F} \tilde{\Lambda}_{f,t} = 1$ and the fact that $\Delta \log w_{f,t} = \Delta \log \Lambda_{f,t} - \Delta \log L_{f,t} + \Delta \log (\sum_{i \in C_t} p_{i,t} y_{i,t})$, 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, ΔM_J^{add} , of inputs of type j , we suppose that $p(\cdot, 0) = \infty$ and $p(\cdot, 1) < \infty$. Similarly, ΔM_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

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

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 ΔM_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

$$d \log ac = \sum_J \Omega_J M_J d \log p_J + \sum_J \Omega_J \delta_J dM_J + \frac{\partial \log \mathcal{C}}{\partial \log A} d \log A + \left(\frac{\partial \log \mathcal{C}}{\partial \log q} - 1 \right) d \log q. \quad (\text{A6})$$

A special case of equation (A6) 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 $\partial \log \mathcal{C} / \partial \log q = 1$ since input prices respond to input quantities. To ensure $\partial \log \mathcal{C} / \partial \log q = 1$, we require the additional assumption that $p(x)$ is homogeneous of degree zero in input quantities. When $\partial \log \mathcal{C} / \partial \log q = 1$,

$d \log ac = d \log mc$, and justifies the regression in (10).

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

Proof. Under the assumption above, we have that:

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

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.^{A43} 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. 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 corresponding cross-section (the year of the M&A and after), and not over the whole panel period.

^{A43}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.

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

$$\Delta \log (\text{labor} + \text{capital})_{i,t} = \phi \times \Delta \log (\text{intermediate inputs})_{i,t} + \text{controls}_{i,t} + \varepsilon_{i,t}. \quad (\text{A7})$$

The variable $(\text{labor} + \text{capital})_{i,t}$ denotes the sum of labor and capital costs of firm i in period t , and 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, ϕ 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:

$$\text{Firm's Demand}_{i,t} = \sum_j \sum_K \Omega_{iK,t} \times \Delta \log \text{sales}_{K,t+1}, \quad (\text{A8})$$

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 (A8) 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 ϕ . 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 (manufacturing, goods producing firms, all firms, and the smaller Prodcom sample) and controls. In all cases (except for the Prodcom sample) the first-stage is strong (demand shocks help predict changes in intermediate input purchases). The point estimate of ϕ 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 alterna-

tive values for ϕ 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.	Prodcom	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 (A7) for different samples of firms. The instrument is the firms' demand shock defined in (A8). The first control is an input price deflator, and the second control is a variant of the instrument defined in (A8) using purchases from (rather than sales to) other industries. Regressions are unweighted, and standard errors are clustered at the firm-level.

Appendix D Additional Tables and Sensitivity Analysis

Table A2: Coverage of growth accounting sample of firms

	(i)	(ii)	(iii)	(iv)	(v)
year	count	value added	employment		
		% of agg.	% of agg.		
2002	99,577	107,652	1,574	72%	67%
2003	102,716	114,520	1,579	74%	67%
2004	104,826	122,354	1,588	75%	67%
2005	106,476	125,755	1,595	74%	66%
2006	108,461	134,770	1,636	75%	67%
2007	109,761	142,913	1,710	75%	68%
2008	110,700	143,835	1,727	73%	67%
2009	109,413	137,080	1,653	73%	64%
2010	109,026	146,411	1,640	74%	63%
2011	110,216	150,341	1,684	73%	64%
2012	110,983	152,705	1,696	73%	64%
2013	110,168	153,660	1,693	72%	64%
2014	110,415	151,948	1,633	70%	62%
2015	106,344	155,171	1,621	69%	61%
2016	105,992	174,552	1,776	75%	65%
2017	105,948	180,709	1,818	75%	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 A3: 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	exit	entry	exit	entry restricted
mean	0.136	0.009	0.854	0.269	0.683	227	0.057	0.068	0.003	0.005	0.001	0.002
p25	0.071	0.003	0.805	0.000	0.553	112	0.022	0.026	0.000	0.000	0.000	0.000
p50	0.120	0.006	0.870	0.221	0.729	168	0.040	0.049	0.000	0.001	0.000	0.000
p75	0.184	0.012	0.922	0.469	0.845	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. Summary statistics are unweighted.

Table A4: Correlation of addition and separations with downstream firm size

	(i)	(ii)	(iii)	(iv)	(v)
	log number suppliers	separation share	addition share	restricted exit share	restricted entry 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 Prodcum sample. All shares are calculated relative to variable costs of the downstream firm.

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	exit	entry
mean	0.074	0.009	0.917	0.315	0.807	675	0.096	0.110	0.005	0.009
p25	0.009	0.001	0.896	0.000	0.693	123	0.022	0.027	0.000	0.000
p50	0.037	0.002	0.958	0.148	0.924	330	0.053	0.065	0.000	0.001
p75	0.093	0.006	0.989	0.645	0.985	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. 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 exit share	-0.013 (0.050)	-0.029 (0.051)	0.150** (0.062)	0.153** (0.062)
Restricted entry 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. All regressions are unweighted. Standard errors are clustered at the firm-level.

Table A7: Estimates of δ 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			0.263***	0.257***					
	(0.014)			(0.099)	(0.100)					
Additions share						0.037***			-0.277***	-0.284***
						(0.013)			(0.083)	(0.082)
Restricted exit share		0.239***	0.930***							
		(0.091)	(0.053)							
Restricted entry share							-0.287***	1.012***		
							(0.083)	(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 (10) where addition share and its instrument are dropped. Columns (vi)-(x) report estimates of regression (10) 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. 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 δ for alternative measures of marginal costs

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	$\Delta \log mc$						$\Delta_2 \log mc$	$\Delta_3 \log mc$
	Capital all overhead	60% overhead	40% overhead	0% overhead	Prod. fun. estimation	Decreasing returns		
Separation share	0.307***	0.304***	0.372***	0.327***	0.348***	0.350***	0.360**	0.363**
	(0.106)	(0.105)	(0.125)	(0.123)	(0.133)	(0.117)	(0.146)	(0.164)
Addition share	-0.343***	-0.339***	-0.353***	-0.294***	-0.382***	-0.328***	-0.318**	-0.398***
	(0.090)	(0.089)	(0.093)	(0.093)	(0.111)	(0.097)	(0.130)	(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 (10) for different measures of marginal cost, where we instrument separations and additions using restricted exit and entry shares defined by equations (11) and (12). 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. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

Table A9: Estimates of δ 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 (0.101)	0.422** (0.127)	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*** (0.165)	-0.289*** (0.093)	-0.248** (0.098)	-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 (10) for different measures of marginal cost, where we instrument separation and additions using restricted exit and entry shares defined by equations (11) and (12). 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. All regressions are unweighted except for column (v). Industry fixed effects are at the 6-digit. Standard errors are clustered at the firm-level, and F-stat is the Kleibergen-Paap (KP) statistic.

Table A10: Estimates of δ for alternative set of suppliers

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
	$\Delta \log mc$						
	Goods	Services	Exclude utilities	Exclude retail & wholesale	Incl. capital producers	Excl. finance	Excl. self-empl., finance, govt.
Separation share	0.075 (0.142)	0.490*** (0.146)	0.293*** (0.107)	0.232* (0.14)	0.300*** (0.103)	0.308*** (0.106)	0.223** (0.108)
Addition share	-0.218 (0.144)	-0.426*** (0.122)	-0.328*** (0.091)	-0.379*** (0.138)	-0.318*** (0.089)	-0.331*** (0.090)	-0.266*** (0.102)
Specification	IV	IV	IV	IV	IV	IV	IV
F-stat	51	61	104	75	106	112	95
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.	37,898	37,898	37,898	37,120	37,854	37,915	37,952

Notes: This table displays estimates of regression (10) for different sets of suppliers. Controls are as in Table 1. All regressions are unweighted. Industry fixed effects are at the 6-digit. 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 (10) 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 ω_{ij} and σ_{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 σ_{ij} and ω_{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 ϵ_{kij} for $k = 1, 2, 3$ 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 σ_{ij} . If $\kappa < 0$, spending shares are negatively correlated with σ_{ij} .

Inputs $j = \{1, \dots, M/2\}$ are available in the first period, and each input has probability ρ^{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 ρ^{add} of being unavailable in the first period. Hence, ρ^{sep} and ρ^{add} control the fraction of separating inputs and the fraction of added inputs between the first and second period. All available inputs at the first period have price equal to one. Available inputs at the second period have log-normally distributed prices with standard deviation σ^p . For each firm, changes in Hicks-neutral productivity are log-normally distributed price with standard deviation σ^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 δ 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 upperbound of the uniform distribution r_1 so that the range of δ 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 δ and cost shares Ω 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 δ 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 σ^p and σ^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 (10) without instrumenting because additions and separations are exogenous in our simulations. Table A11 reports percentile estimates across the 100 simulations.

Motivated by Proposition 3, we first consider the case where average δ firm is uncorrelated with the addition and separation shares. Columns (i)-(iii) show that the estimated coefficients are very close to the true average δ 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 δ , violating one of the assumptions in Proposition 3, 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 δ, Ω		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
Addition share									
$\mathbb{E}[\bar{\delta}^{add}]$	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
Separation share									
$\mathbb{E}[\bar{\delta}^{sep}]$	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 δ 's for additions and separations. The estimates $\hat{\delta}^{add}$ and $\hat{\delta}^{sep}$ are for regression (10), with percentiles calculated across the 100 simulations. Details of the calibration are in the text.