Quantifying the Micro and Macro Effects of Variety Creation and Destruction

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Abstract

We study the consequences of the creation and destruction of varieties of inputs at both the micro- and macroeconomic levels. Using detailed data from Belgium, we show that the disappearance of inputs raises downstream marginal costs. Our regression results can be interpreted as a measure of the area under the input-demand curve and can be used to calibrate the value of additional suppliers in both expanding variety (“love-of-variety") and Schumpeterian (“step-size") growth models. At the macroeconomic level, we develop a growth-accounting formula that accounts for how churn in supply chains, driven by either creative destruction or expanding varieties, propagates through input-output connections to affect measured aggregate growth. We find that supplier churn can account for almost the entirety of the trend component of the Solow residual.

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[†] Emmanuel Farhi tragically passed away in July, 2020.

1 Introduction

This paper studies the consequences of supply link formation and destruction at both the microeconomic and macroeconomic levels. At the microeconomic level, we study how exogenous exits of suppliers affect the costs of production for downstream firms. At the macroeconomic level, we develop an accounting framework to quantify the role of churn in firm-to-firm linkages for measured aggregate output.

In many models of growth and trade, variety creation and destruction plays a pivotal role. In expanding variety models, consumer surplus from entry is the engine for generating long-run growth, as well as the reason why similar countries gain from trading with each other. A similarly important notion of surplus appears in Ricardian or Schumpeterian models of creative destruction, in which innovating firms improve upon the products of incumbent firms along a "quality ladder."[1] We provide a unified analysis showing that in both class of models the benefits of new suppliers for the buyer are summarized, locally, by the change in the area under the input demand curve relative to expenditures. We call this the *inframarginal surplus* ratio. In expanding variety models, the inframarginal surplus ratio captures the "love-of-variety", whereas in creative destruction models it is related to the innovation "step-size." This statistic is key for both positive and normative implications of these models, and we show how it can be identified in production with minimal parametric assumptions.

In many models, the welfare benefits of new entry accrue directly to households as higher utility. Since utility is unobservable, measuring and estimating these gains is challenging. In theory, measuring the consumer surplus generated from new suppliers requires knowing the global shape of the consumer demand system. Of course, eliciting the entire consumer preference relation is impracticable for many reasons. Therefore, researchers typically rely 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. However, as pointed out by Dixit and Stiglitz (1977), there is no reason to expect such a tight link between the benefits from new varieties and the local price elasticity of demand in general. Similarly, in Schumpete-

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[1] Expanding varieties models of growth and trade include Dixit and Stiglitz (1977), Krugman (1979), Romer (1987), and Melitz (2003). Ricardian models of growth and trade include Dornbusch et al. (1977), Aghion and Howitt (1992), and Eaton and Kortum (2002). For a synthesis of these models see Grossman and Helpman (1993), Acemoglu (2009), and Costinot and Rodriguez-Clare (2014). All of these models feature increasing returns to scale at the aggregate level — doubling the size of the market more than doubles total output. These models can be distinguished from models like Hopenhayn (1992) where firms have increasing returns to scale, at least up to a point, but the economy has constant returns to scale at the aggregate level.

rian models of creative destruction, researchers typically discipline the step-size between the best and second-best supplier 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). In general, researchers are forced to rely on these indirect methods because directly measuring the change in the marginal utility of income is impossible.

In this paper, we circumvent this problem by focusing on production rather than consumption. As pointed out by Ethier (1982), one can equally expect love-of-variety and quality-ladders to matter in the production of intermediate goods. Since the marginal cost of production is, at least in principle, observable (unlike the marginal utility of income), we can attempt to estimate the inframarginal surplus of a supplier by measuring how the exit of that supplier affects marginal cost. This approach does not require globally specifying, estimating, and integrating an input demand system.

To estimate the value of supplier churn, we use a detailed survey of manufacturing firms in Belgium called Prodcom. This survey contains sales and quantity information for most manufacturing firms in Belgium and is administered by the National Bank of Belgium. We merge this data with firm-to-firm input-output linkage information from value-added tax 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, and we regress marginal cost on supplier exits. We provide assumptions under which the estimated coefficient identifies the area under the exiting input's demand curve – that is, the surplus the exiting input generated for the buyer.

Consistent estimation requires an instrument for supplier exits. The instrument ensures that exits are caused by a negative shock to the supplier and not other drivers of the downstream firms' marginal cost. To instrument for supplier exits, we consider two alternative identification strategies. First, we predict exits using a Bartik-type instrument of upstream firms' sales to non-manufacturing industries. That is, a supplier is more likely to exit if sales in non-manufacturing industries they sell to decline. Our second instrument uses supplying firms' short-term debt obligations interacted with changes in aggregate interest rates. That is, a supplier is more likely to exit if they have taken on a large amount of short-term debt and the aggregate interest rate rises. In either case, the identification requirement is that exits predicted by our instrument are not correlated with other reasons why downstream firms' marginal costs change, such as a change in the firm's productivity or entry of better suppliers.

We find that if 1 percentage point of a firm's suppliers (in terms of the firm's cost share) exit, then this raises the firm's marginal cost by around 0.6 percentage points. In a CES expanding varieties model, this amount of love-of-variety corresponds to an elasticity of substitution of roughly 2.5. In a quality-ladder model with unitary elasticities between inputs, this corresponds to an innovation step-size of around 60 log points. In other words, at the microeconomic level, the creation and destruction of supply linkages have strong effects on downstream marginal costs.

Because inframarginal surplus from new suppliers affects the downstream firm's marginal cost, it is captured by real measures of economic activity like real GDP. This is unlike new consumer goods whose value to consumers is typically not captured by standard consumption deflators and is therefore missing from measured growth.

Moving from micro to macro, we develop an accounting framework for tracking how churn in firm-to-firm linkages affects measured aggregate output at the macroeconomic level. We extend growth accounting formulas (i.e. Solow, 1957; Domar, 1961; Hulten (1978), 1978; Basu and Fernald, 2002; Baqaee and Farhi, 2019) to include an extensive margin, in addition to misallocation due to markups, and allowing for input-output networks.

For this aggregation exercise, we compute how the entry and exit of suppliers affects the prices of downstream firms, and how these price changes are transmitted along existing supply chains from suppliers to customers, all the way down to final consumers. For this exercise, we assume a CES functional form in production between continuing and non-continuing suppliers. Our calculation requires knowing the firm-level input-output network of the Belgian economy and the elasticity of substitution in production between continuing and non-continuing suppliers. We obtain the former from VAT declarations, which track firm-to-firm transaction values for almost all firms in Belgium. We obtain the latter from a regression of instrumented changes in the share of continuing suppliers on changes in marginal cost, leveraging the well-known insight from Feenstra (1994). Given an estimated elasticity of roughly 3, we find that almost the entirety of the trend growth component in the aggregate Solow residual in Belgium can be accounted for via churn in the supply chain.

Related literature. Our paper is related to three different literatures. First, as discussed above our analysis informs expanding varieties models of entry and exit. In models of monopolistic competition with expanding varieties, following Dixit and Stiglitz (1977), a key object of interest and source of welfare gains is the love for product variety. This effect has been theoretically studied extensively by Zhelobodko et al. (2012), Dhingra and Morrow (2019), Matsuyama and Ushchev (2020), 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. In this paper, as in Baqaee et al. (2020), we instead prefer to think of love-of-variety as being related to the area under the demand curve. One reason to do this is that it demystifies the love-of-variety and makes clear that it simply corresponds to changes in marginal cost caused by large (inframarginal) 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. A second reason is that the area under the input demand curve is a more versatile concept that can be used in a broader set of contexts, including in more general specifications of demand and in quality-ladder models.

This paper contributes to both the expanding-varieties and quality-ladder literatures by directly estimating the size of the surplus generated for buyers when they lose access to suppliers. This can then be used to calibrate the strength of the love-of-variety effect or step-size between each rung of the quality-ladder in the aforementioned models using direct microeconomic evidence.[2]

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 Lim (2017), Tintelnot et al. (2018), Oberfield (2018), Acemoglu and Tahbaz-Salehi (2020), Elliott et al. (2020), Taschereau-Dumouchel (2020), Kopytov et al. (2022), and Bernard et al. (2018). 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. Huneeus (2018) and Arkolakis et al. (2021) study adjustment costs in link-formation between firms and their aggregate consequences using a structural model. Our paper complements this literature by providing direct estimates about the value of link formation at the microeconomic level and a growth accounting exercise that quantifies the importance

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[2] There is a large literature that provides reduced-form evidence of how changes in policies (e.g. import tariffs) impact firm outcomes such as productivity, markups, and firm product-scope. See, for example, Amiti and Konings (2007), Brandt et al. (2017), Goldberg et al. (2010), and De Loecker et al. (2016). Although this literature provides suggestive evidence that input variety matters for firm-level outcomes, it does not provide an estimate of how large these gains are.

of link formation.

Third, our paper is also related to a deep literature on correcting price indices to account for the entry and exit of goods. The macroeconomic and trade literatures on the importance of entry and exit, which traces its origins to Hicks (1940), has 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 nondemanding information requirements. 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.[3] Aghion et al. (2019) build on this methodology to correct aggregate growth rates for expanding varieties and unmeasured quality growth. Instead, our macroeconomic exercise quantifies the importance of supplier entry and exit for measured growth. Our results suggest that supplier entry and exit is much more important, quantitatively, than the entry and exit of varieties of consumer goods.

Outside of the CES literature, Hausman (1996), Feenstra and Weinstein (2017), and Foley (2022) have provided alternative price index corrections that rely on less heavily parameterized demand systems. A common theme in this literature is to estimate price elasticities of demand and infer the value of entering and exiting products by integrating demand curves under parametric restrictions (e.g. linear or translog demand). Our approach differs from this literature in that we attempt to identify the area under the input demand curve directly through its effect on downstream marginal costs rather than via implicit or explicit integration of demand curves. Of course, our methodology cannot be applied to household demand since marginal utility, unlike marginal cost, is not observable.

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[3] The methodology of Feenstra (1994) requires knowledge of the elasticity of substitution, which is typically estimated using data on expenditure switching. Blaum et al. (2018) instead uses changes in the buying firm's revenues (and parametric assumptions on the production function and demand for the buying firms' output) to estimate the elasticity of substitution between imports and domestic inputs. One of our regressions uses a similar approach, however we use quantity data to obtain a measure of marginal cost, so that we do not have to take a stance on the production function and the output demand elasticity when we estimate the elasticity of substitution between inputs. This is a key parameter in our growth accounting exercise.

2 Microeconomic Value of Link Formation: Theory

In this section, we derive expressions for how supplier entry-exit affects a downstream firm's marginal cost. The results in this section motivate our empirical strategy. We consider two approaches. The first approach imposes minimal assumptions on the demand system. We then compare this to the more traditional approach that imposes CES input demand.

Direct Approach Using Area Under Demand Curve. We start by considering the value of suppliers in partial equilibrium, taking the price of inputs as primitives. Consider a producer, called the *downstream* firm, whose variable cost function is

$$\mathcal{C}(\boldsymbol{p}, A, Y) = mc\left(\boldsymbol{p}, A\right) Y,$$

where $\boldsymbol{p}$ is the vector of (quality-adjusted) input prices, A indexes technology, and Y is the total quantity of output. We allow for the possibility that the price of some inputs is equal to infinity (i.e. some inputs are not available). For simplicity, we do not index variables by the downstream firm.

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 symmetric across types. This assumption implies that all varieties of a given type i face the same input demand curve by the downstream firm, $x_i(\boldsymbol{p}, A, Y)$, but it does not impose restrictions on own-type or cross-type price elasticities. Furthermore, without loss of generality, we assume that all inputs that belong to the same type have the same price. To simplify notation, we assume that there is a countable number of types. Let M_i denote the mass of inputs i.

Almost all popular production technologies used in macroeconomics and trade 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. More generally, 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.

In this paper, we are interested in 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. To capture such phenomena, for each i, assume there is the possibility that the price changes discontinuously. We call this a *jump* in the price of i and denote the size of the jump, or the *step-size*, by $z_i = \Delta \log p_i$.

We use jumps to represent the entry and exit of suppliers in both quality-ladder and expanding-variety models.[4] In a quality-ladder model, each input has a finite price and the price jumps to another finite price when one supplier is replaced by another. This represents a movement up or down the ladder depending on whether the initial price is greater or less than the new price. On the other hand, in models where product variety changes, a variety is dropped if the initial price is finite and the price jumps to infinity. On the other hand, a variety is added if the initial price is infinite but the new price is finite. That is, in expanding-variety models, the step-size is plus or minus infinity.

Holding the price of all other inputs constant, and suppressing dependence of the conditional input demand on its other arguments, define the *inframarginal surplus ratio* associated with a change in the price of input i from p_i to p_i' by

$$\delta_i - 1 = \frac{\int_{p_i}^{p_i'} x_i(\xi) d\xi}{p_i x_i(p_i)} \geq 0,$$

where with abuse of notation we define p_i to be the lower price and p_i' to be the higher of the two possible prices for input i. Since we define p_i to always be the lower of the two possible prices, $\delta_i - 1$ is always a non-negative number. As long as the demand curve is downward sloping, $\delta_i - 1$ is strictly positive.

The next proposition loglinearizes the downstream firm's marginal cost.

Proposition 1 (Downstream Price)**.** Consider a change in the price of inputs by type $\Delta \boldsymbol{p}$, the measure of inputs whose price jumps $\Delta \boldsymbol{M}$, and the technology parameter ΔA. To a first-order approximation, the change in the downstream firm's marginal cost is

$$\Delta \log mc \approx \underbrace{\sum_i s_i M_i \Delta \log p_i}_{\text{marginal changes}} + \underbrace{\sum_i s_i \Delta M_i (\delta_i - 1) \left[\mathbb{1}(z_i > 0) - \mathbb{1}(z_i < 0)\right]}_{\text{inframarginal jumps}} + \underbrace{\frac{\partial \log \mathcal{C}}{\partial \log A} \Delta \log A}_{\text{technology}}, \tag{1}$$

where $s_i \equiv x_i p_i / \mathcal{C}$ is the cost share of a type i variety.

Proposition 1 characterizes the change in the downstream firm's marginal cost. It motivates our empirical specifications where we seek to identify $\delta_i - 1$. The marginal cost of the downstream firm depends on the costs of its inputs, the first two summands, as well as its own technology. 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.

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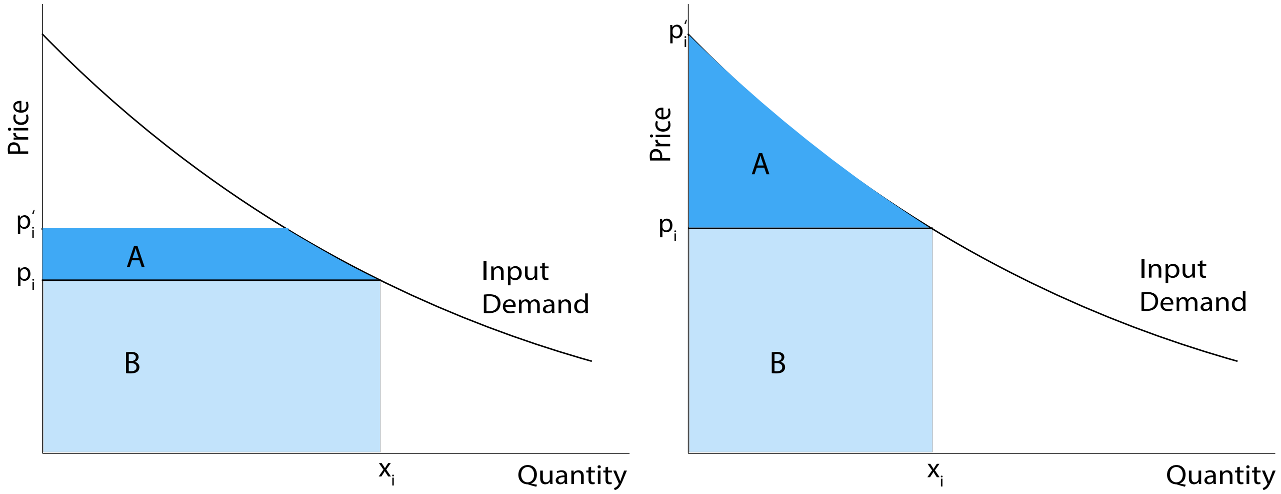
[4] We identify price jumps in the data from exogenous supplier exits. However, in principle, prices may also jump within continuing buyer-supplier relationships due to process innovation by continuing suppliers.

On the other hand, if input prices jump, then their effect on the downstream firm's marginal cost depends on the area under the input demand curve, which is captured by $\delta_i - 1$ and is depicted graphically in Figure 1. Intuitively, movements along the quality ladder and variety creation generate surplus for the downstream producer.

The left panel depicts a jump along the quality ladder where the price of the input rises from p_i to p_i' (so that $z_i > 0$). The right panel depicts the destruction of an existing variety whose price rises from p_i to infinity. In both cases, the inframarginal surplus ratio is given graphically by

$$\delta_i = \frac{A+B}{B} \geq 1.$$

Either way, this jump in input price raises the costs of production by an amount commensurate with $\delta_i - 1$, and this is weighted by the expenditures.



(a) Quality ladder

(b) Expanding variety

Figure 1: Graphical illustration of input price jump. In both figures, the inframarginal surplus ratio δ_i is $(A+B)/B$.

The proof of Proposition 1 is as follows. Use Shephard's lemma to get

$$d\mathcal{C} = \sum_i x_i dp_i M_i + \frac{\partial \mathcal{C}}{\partial A} dA + \frac{\partial \mathcal{C}}{\partial Y} dY.$$

Consider the change in costs due to a change in primitives. For any smooth path, indexed by $s \in [0,1]$, with end points given by $(\boldsymbol{p}^0, A^0, Y^0)$ and $(\boldsymbol{p}^1, A^1, Y^1)$ the change in costs is

$$\mathcal{C}(\boldsymbol{p}^1, A^1, Y^1) - \mathcal{C}(\boldsymbol{p}^0, A^0, Y^0) = \sum_i M_i \int_{p_i^0}^{p_i^1} x_i(\boldsymbol{p}(s), A(s), Y(s)) \frac{dp_i}{ds} ds + \int_0^1 \frac{\partial \mathcal{C}}{\partial A} \frac{dA}{ds} ds + \int_0^1 \frac{\partial \mathcal{C}}{\partial Y} \frac{dY}{ds} ds.$$

Given this exact representation of the cost function, we can now consider infinitesimal changes in the price of inputs by type dp, the mass of inputs of each type whose price jumps by a discrete amount dM, technology dA, and output dY. Omitting the dependence of conditional input, x_i, on its other arguments (which are held constant when we take the derivative), this results in the following expression

$$d\mathcal{C} = \sum_i M_i x_i dp_i + \sum_i \left(\int_{p_i^0}^{p_i^1} x_i(\xi) d\xi \right) dM_i + \frac{\partial C}{\partial A} dA + \frac{\partial \mathcal{C}}{\partial Y} dY.$$

This first-order approximation can be rewritten as

$$d \log \mathcal{C} = \sum_i M_i s_i d \log p_i + \frac{1}{\mathcal{C}} \sum_i \left(\int_{p_i^0}^{p_i^1} x_i(\xi) d\xi \right) dM_i + \frac{\partial \log C}{\partial \log A} d \log A + \frac{\partial \log \mathcal{C}}{\partial \log Y} d \log Y. \quad (2)$$

Next, by constant-returns, $\partial \log \mathcal{C} / \partial \log Y = 1$ and $d \log mc = d \log \mathcal{C} - d \log Y$. Hence, we can rewrite (2) as in (1) in Proposition 1 using the definition of δ_i, and noting that if $p_i^1 < p_i^0$, then $-\delta_i$ must be used.

Example 1 (CES with Quality Ladders)**.** Consider the CES special case, in which the demand for a variety of type i is

$$\frac{p_i x_i(\boldsymbol{p}, A, Y)}{\mathcal{C}(\boldsymbol{p}, A, Y)} = \frac{b_i p_i^{1-\sigma}}{\sum_j b_j p_j^{1-\sigma} M_j}.$$

Suppose that each time an input with price p' is creatively destroyed, it is replaced by a competitor whose quality-adjusted price is $p < p'$ (so that $z_i < 0$). The inframarginal surplus ratio is

$$\delta_i - 1 = \frac{\int_{p_i}^{p_i'} x_i(\xi) d\xi}{p_i x_i} = \left(1 - \left(\frac{p_i'}{p_i} \right)^{1-\sigma} \right) \frac{1}{\sigma - 1} \geq 0.$$

Hence, Proposition 1 implies that the change in the downstream firm's marginal cost in response to the creative destruction of a mass ΔM_i input i is

$$\Delta \log mc = -s_i \Delta M_i (\delta_i - 1) = -\frac{1}{\sigma - 1} s_i \Delta M_i \left(1 - \left(\frac{p_i'}{p_i} \right)^{1-\sigma} \right). \quad (3)$$

The negative sign in (3) is because $z_i = \log(p/p_i') < 0$ and so the change in marginal cost is proportional to $-(\delta_i - 1)$ given our convention that we always integrate from the low to the high price.

Example 2 (CES with Expanding Varieties)**.** If the variety is entering, then the initial price is infinity $p_i' = \infty$ in (3). Hence, in response to a change in the availability of some varieties of type i, the change in the downstream marginal cost is

$$\Delta \log mc = -s_i \Delta M_i (\delta_i - 1) = -\frac{1}{\sigma - 1} s_i \Delta M_i. \tag{4}$$

This is the so-called "love-of-variety" effect and is just the limiting case of quality-ladders when the step size is infinitely large.

Outside of the CES with expanding varieties case, the benefits of a new supplier are not given by just $1/(\sigma - 1)$. In fact, under some conditions, we can sign the difference between the surplus actually produced by new varieties, $\delta_i - 1$, versus what is implied by an isoelastic input demand curve calibrated to have the same price elasticity.

Proposition 2 (Love-of-Variety with Marshall's Second Law)**.** Denote the price elasticity of demand by

$$\sigma_i(\boldsymbol{p}) = -\frac{\partial \log x_i(\boldsymbol{p})}{\partial \log p_i} > 1.$$

Marshall's second law of demand holds if $\partial \sigma_i / \partial p_i > 0$. Under this condition,

$$\delta_i(\boldsymbol{p}) < \frac{\sigma_i(\boldsymbol{p})}{\sigma_i(\boldsymbol{p}) - 1}.$$

This proposition shows that a constant-price elasticity is the upper-bound for the surplus generated by entry as long as Marshall's second law holds.[5] The following is a concrete example.

Example 3 (Non-CES with expanding varieties)**.** Consider the HSA technology from Matsuyama and Ushchev (2017), and parameterize it in the following way. The expenditure share on each input type is given by

$$s_i = \max\left\{0, 1 - \frac{p_i}{D}\right\},$$

where D is a scalar that ensures the expenditure shares add up to one. As long as p_i is below its choke price (which is D), the price elasticity of demand is given by

$$\sigma_i = \frac{1}{1 - p_i/D} > 1.$$

Notice that the price elasticity of demand is increasing in the price. In the limit, as the price approaches the choke price, the price elasticity goes to infinity. On the other hand,

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[5] This result echoes similar results in Matsuyama and Ushchev (2020) and Grossman et al. (2021), though here, we do not impose any assumptions on separability of the input demand system.

the inframarginal surplus ratio from new varieties is

$$\delta_i - 1 = \frac{-\log(p_i/D)}{1 - p_i/D} - 1.$$

The inframarginal surplus ratio is decreasing in the price and goes to zero in the limit as the price approaches the choke price. That is, a new variety appearing at the choke price produces no inframarginal surplus.

We can re-express the inframarginal surplus ratio in terms of the price elasticity of demand at each point. This gives

$$\delta_i = -\sigma_i \log(1 - \frac{1}{\sigma_i}) < \frac{\sigma_i}{\sigma_i - 1}. \tag{5}$$

Hence, the price elasticity of demand at a point is not a sufficient statistic for the importance of new varieties. This inequality is a consequence of Proposition 2 but can also be derived as a consequence of the results established by Matsuyama and Ushchev (2020).

Indirect Approach Exploiting CES If we assume that technology is CES, then we can infer the value of supplier entry-exit using an alternative approach due to Feenstra (1994). We contrast this alternative approach with Proposition 1.

Proposition 3 (Feenstra, 1994)**.** *Suppose that the downstream firm has a CES technology with elasticity of substitution σ. Consider a change in the price of inputs by type $\Delta \boldsymbol{p}$, the measure of inputs whose price jumps $\Delta \boldsymbol{M}$, and the technology parameter ΔA. To a first-order approximation, the change in the downstream firm's marginal cost is*

$$\Delta \log mc \approx \sum_i s_i M_i \Delta \log p_i + \frac{1}{\sigma - 1} \sum_i s_i M_i \Delta \log s_i + \frac{\partial \log \mathcal{C}}{\partial \log A} \Delta \log A. \tag{6}$$

That is, as long as technology is CES, Proposition 3 allows us to infer the value of jumps by relying on the elasticity of substitution σ and the change in the share of non-jumping inputs.

Comparing (6) and (3) reveals the differences between the approaches in Propositions 1 and 3. In equation (6) the coefficient of the change in the share of non-jumping inputs is always $1/(\sigma - 1)$ regardless of the size of the price jumps. On the other hand, in equation (3) the coefficient of the share of jumping inputs is equal to the inframarginal surplus ratio, which under CES is shaped both by σ and the size of the price jump. The former uses the change in a share whereas the latter uses the level of a share. The difference between these becomes stark when we consider the Cobb-Douglas limit. In this case, the share of non-jumping inputs is constant. However, the share of jumping inputs can be high.

Both coefficients coincide only under expanding varieties (when the size of the jump is infinity). Furthermore, if the demand system is not CES, then Proposition 3 is no longer valid, whereas Proposition 1 continues to apply.

3 Empirical Microeconomic Results

Motivated by Propositions 1 and 3, we consider two different regressions aimed at identifying the benefits of inputs and the elasticity of substitution between continuing and non-continuing inputs.

3.1 Estimating Equations

Motivated by Proposition 1, we estimate the inframarginal surplus ratio, $\delta - 1$, by estimating the following regression

$$\Delta \log mc_{it} = \beta \times \text{exit share}_{it} + \text{controls}_{it} + \varepsilon_{it}, \tag{7}$$

where exit share_{it} is the expenditure share of a downstream firm i in period t on those suppliers who ceased to be suppliers to firm i in period $t+1$. Following Proposition 1, the estimated coefficient $\hat{\beta}$ should reflect an average of inframarginal surplus ratios if variation in the exit share is caused by jumps. Proposition 1 enumerates the threats to identification if we rely on an OLS regression. First, the error term includes changes in prices of continuing suppliers and own technology shocks. Any one of these could plausibly be correlated with the exit share. For example, it could be that exits are caused by changes in continuing suppliers' prices, the entry of new suppliers, or shocks to the downstream firm's technology. Second, unconditionally, we do not know if exit is due to an increase or a decrease in the input price. That is, a supplier could exit because the input price jumps up (i.e. the input becomes unavailable) or because the input price jumps down (i.e. the supplier is replaced by a better alternative). To identify $\delta_i - 1$, we need to use supplier exits that are associated with input price jumps of a common sign rather than pooling all exits together.

Similarly, if we impose the assumption that the downstream firms' technology is CES between continuing and non-continuing varieties, then following Proposition 3, we can identify the elasticity of substitution between continuing and non-continuing varieties by estimating the following regression:

$$\Delta \log mc_{it} = \beta \times \Delta \log \text{continuing share}_{it} + \text{controls}_{it} + \varepsilon_{it}. \tag{8}$$

Once again, the coefficient on the log change in continuing share should identify an average across downstream firms of $1/(\sigma - 1)$, where σ is the elasticity of substitution between inputs, as long as CES is a valid assumption and the error term is uncorrelated with the log change in the continuing share. Of course, as with (7), endogeneity is a major concern since changes in the continuing share could be caused by changes in the prices of continuing suppliers or shocks to the downstream firms' technology.

As explained in Section 2, regressions (7) and (8) estimate different objects even if one assumes CES technology. Furthermore, regression (7) is motivated by Proposition 1 which holds under quite general technology, whereas regression (8) requires assuming CES technology between continuing and non-continuing suppliers.

3.2 Data

Our empirical analysis makes use of a rich micro-level data structure on production networks of Belgian manufacturing 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 Central Balance Sheet Office (CBSO), which we refer to as the annual accounts; (ii) the Belgian Prodcom Survey; (iii) the National Bank of Belgium's B2B Transactions data; (iv) the International Trade data at the NBB; (v) the VAT declarations; and (vi) the Crossroads Bank of Enterprises (CBE). We now describe how we use these data to construct the different variables of interest.

Sample of firms for micro regressions. The Prodcom survey data covers firms that produce goods covered by the Prodcom classification and that have at least 20 employees or 3,928,137 euro turnover in the previous reference year. Our sample of "downstream" firms are firms in the Prodcom survey who file annual accounts and whose Prodcom sales are at least 50% of the firm's aggregate sales from the annual accounts (to ensure that Prodcom is representative of overall sales).

Sales. For each firm in Prodcom, we define firms' total sales as the sum of exports reported in the international trade dataset and sales to all domestic customers (both firms and non-firms customers) reported in the VAT declarations. We replace this measure of sales by the sum of intermediate input purchases (defined below) and value added if the latter exceeds the former.

Costs. Firms' variable input costs consist of purchases of intermediates, labor costs, and the user cost of capital. Purchases of intermediates are the sum of imports reported in the international trade dataset and domestic intermediates purchased from other Belgian firms reported in the B2B dataset. We do not include as part of intermediate consumption the goods purchased from other Belgian firms classified as capital goods providers, and we drop imported goods that are classified as capital goods in the Broad Economic Categories (BEC) classification (BEC codes 410 and 521), as these goods are not considered part of the variable intermediate inputs bundle. We replace the sum of imports and domestic purchases by total sales minus value added if the latter exceeds the former.

Labor costs are reported in the annual accounts. We add the cost of capital, $r \times K$, as an additional input, where K is the capital stock reported in the annual accounts and r is the user cost of capital. The user cost of capital 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 trim the data for firm-year observations in which either total costs (the sum of inputs, labor, and capital) or total sales rise or fall by at least a factor of 7.

Output prices. For each firm in Prodcom, we construct changes in output prices using sales and quantity data from Prodcom survey data. Products are identified at the 8-digit level of the Prodcom (PC) classification, which is common to all EU member states.[6] Sales values (in euro) and quantities are available at the firm-PC8-month level. Quantities are reported in one of several measurement units (over two thirds of observation are in kilograms; other units include liters, meters, square meters, kilowatt, and kg of active substance). We aggregate monthly observations to yearly values to match the other data sets. Changes in output prices are obtained as log differences in unit values from year $t - 1$ to t for all PC8 products. For multi-product firms (defined as Prodcom firms that produce multiple PC8 products), changes in output prices for individual products are aggregated to the firm-level using a Divisia index, with weights given by the revenue share of each product in the corresponding year. As output prices (and implied quantities) can be noisy, we trim the change in prices and quantities at the 5-95th percentile level.

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

Marginal cost and markups. To measure the log change in the marginal cost of Prodcom firms, we subtract changes in log changes in markups from changes in log output prices. We calculate the markup of each firm as the ratio of revenues to total variable costs. In sensitivity analysis, we measure markups as revenues relative to purchases of intermediate inputs divided by the output elasticity of intermediate inputs estimated as in Levinsohn and Petrin (2003).

Suppliers. We construct the network of domestic suppliers of Belgian firms using the NBB B2B Transactions data set. The confidential NBB B2B Transactions data set contains the values of yearly sales relationships among all non-financial private sector firms for the years 2002 to 2018, and is based on the VAT listings collected by the tax authorities. At the end of every calendar year, all non-financial private sector firms 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 euro 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 universal coverage of all businesses active in Belgium. We drop suppliers that produce capital goods, identified from the Main Industrial Groupings (MIG) Classification of the EU. To control for misreporting errors, we drop a transaction if its value is 10 times larger than the seller's aggregate sales (which is reported separately). To avoid any influence of this procedure on our entry/exit analysis, we also drop the transaction of the same supplier-buyer pair in year $t-1$.

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.[7] 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 (i) a VAT identifier that reports annual accounts, VAT declarations, and B2B transaction, and (ii) if multiple eligible VAT identifiers exist, 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

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[7] Another challenge is that VAT declarations 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.

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.

Input prices. We observe a subset of input prices for Prodcom firms (see Duprez and Magerman, 2018 and Cherchye et al., 2021), and we control for these input prices in our regression. To measure the price of labor, we divide total labor costs divided by total full time employed workers. We measure the user cost of capital as described above. We measure the price of imported inputs using a firm-level Divisia index of changes in unit values faced by firm *i* at the partner country - CN8 product level. As unit values can be noisy, we trim the change in unit values at the 5th-95th percentile.

3.3 Identification Strategy and Results

To identify δ and σ in (7) and (8), we use an instrumental variables identification strategy. To identify $\delta - 1$, the instrument must induce variation in the exit share, must be associated with an increase in the input price that jumps (otherwise the sign is flipped), and it must not be correlated with own technology shocks or the prices of continuing suppliers.

We instrument the endogenous variable in (7) and (8) using a Bartik-type demand shock to the suppliers. For each downstream firm *i* at time *t*, we use the instrument

$$\text{Suppliers' Demand}_{it} = \sum_j \sum_K \Omega_{ij,t} \times r_{jK,t} \times \Delta \log \text{sales}_{K,t+1}, \tag{9}$$

where $\Omega_{ij,t}$ is the share of *i*'s total variable costs spent on each supplier *j*, and $r_{jK,t}$ is the share of supplier *j*'s total sales to each non-manufacturing industry *K*, and $\Delta \log sales_{K,t+1}$ are the changes in total output of industry *K*. Intuitively, a reduction in the sales of *i*'s suppliers, triggered by shocks to non-manufacturing industries, makes it more likely that *i*'s suppliers shrink or shutdown operations (for example, due to the presence of overhead costs). This induces variation in the endogenous variable in equations (7) and (8) that is uncorrelated with technology shocks to *i* and continuing suppliers' prices.

The regression results are shown in Table 1. Column (ii) is the OLS showing that increases in the exit share lower marginal cost. Of course, the OLS is subject to severe omitted variable bias. For example, exiting suppliers could be replaced by better suppliers, as in models of creative destruction, flipping the sign on the coefficient in front of the exit share in Proposition 1. Or, a positive productivity shock to the downstream firm may induce the firm to switch suppliers or perform some operation in-house. For these reasons, we instrument changes in supplier exits.

Column (i) is an OLS regression showing that an increase in our instrument (increased demand for suppliers) predicts a decline in supplier death.[8] That is, when suppliers get favorable demand shocks, they are less likely to die. Column (iii) is the reduced-form regression showing that increased demand for a firms' suppliers reduces that firm's marginal cost. Columns (iv) and (v) run regression (7) using our suppliers' demand instrument, first without and then with controls. All regressions include 6 digit product code by year fixed effects. Column (vi) adds a firm fixed effects, allowing for the possibility of firm-level trends. Column (vii) weights observations by log sales. Column (viii) constructs the instrument using lagged sales. In all cases, the first-stage is strong and the second state estimates are positive and significant. The point estimates imply that $\delta - 1 \approx 0.6$. If technology is CES and there are expanding varieties, then $\delta - 1 = 0.6$ corresponds to a CES elasticity of substitution of a little higher than 2.5. On the other hand, in a typical quality ladders model with unitary elasticity across inputs, the implied step size is roughly 60 log points. Either way, marginal costs of downstream firms react very strongly to the exit of their suppliers.

Table 1: Estimating $\delta - 1$

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Supplier Death	$\Delta \log mc$						
Exit share		-0.134***		0.757***	0.694***	0.935***	0.629***	0.625**
		(0.012)		(0.257)	(0.255)	(0.321)	(0.241)	(0.263)
Supplier Demand	-1.981***		-0.996***					
	(0.126)		(0.331)					
F-stat				67	66	80	71	54
Specification	OLS	OLS	RF	IV	IV	IV	IV	IV
Controls	N	N	N	N	Y	Y	Y	Y
6 digit x year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	N	N	N	N	N	Y	N	N
Obs	35,458	35,458	35,458	35,458	35,458	34,661	35,458	35,458

Demand shock is the instrument in the IV regressions and is defined by (9). Supplier death is the expenditure-weighted share of the downstream firm's suppliers who ceased operations. Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms, changes in log wages, changes in the log user cost of capital, and a Bartik-type demand shock constructed for the downstream firm itself. All regressions are unweighted except (vii), which is weighted by log sales. Column (viii) uses lagged shares at $t-1$ instead of initial t shares in constructing the instrument. Standard errors are clustered at the firm-level.

As a robustness, we consider an alternative instrument. Rather than using suppliers' demand shocks, we construct an instrument that induces variation in suppliers' financial

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[8] Table 8 in Appendix A tabulates unconditional death rates for firms year by year in Belgium for small and large firms.

health. For each downstream firm i in period t, we construct the following variable

$$\text{Rate shock}_{it} = \sum_{j} \sum_{K} \Omega_{ij,t} \times d_{j,t} \times \Delta \mathrm{R}_{t+1}, \tag{10}$$

where $\Omega_{ij,t}$ are the expenditures of firm i on supplier j as a short of i's total costs, $d_{j,t}$ are the short-term debt obligations of j as a share of total assets (from the annual accounts), and ΔR_{t+1} is the change in the 1-month money market interest rate for the euro area. An increase in this variable indicates a negative financial shock to i's suppliers.

Table 2: Estimating $\delta - 1$ using alternative instrument

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Supplier Death	$\Delta \log mc$						
Exit share		-0.134***		0.846**	0.766**	0.805**	0.959*	-0.092
		(0.012)		(0.393)	(0.346)	(0.349)	(0.569)	(1.465)
Rate shock	0.102***		0.066***					
	(0.017)		(0.025)					
Sample	Full	Full	Full	Full	Full	Full	2008-2012	2003-2007
F-stat				15	18	18	14	2
Specification	OLS	OLS	RF	IV	IV	IV	IV	IV
Controls	N	N	N	N	Y	Y	Y	Y
Firm FE	N	N	N	N	N	Y	N	N
6 digit x year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	N	N	N	N	N	N	Y	Y
Obs	35,458	35,458	35,458	35,458	35,458	34,661	9,167	12,754

Rate shock is the instrument in the IV regressions and is defined by (10). Supplier death is the expenditure-weighted share of the downstream firm's suppliers who ceased operations. Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms, changes in log wages, changes in the log user cost of capital, and the firm's own short-term debt obligations interacted with interest rate changes. All regressions are unweighted except (vi), which is weighted by log sales. Standard errors are clustered at the firm-level.

The regression results are shown in Table 2. As before, Column (ii) is the OLS showing that increases in the exit share lower marginal cost. Column (i) shows that an increase in our instrument (financial shock to suppliers) predicts an increase in supplier death. That is, when suppliers get unfavorable financial shocks, they are more likely to die. Column (iii) is the reduced-form regression showing that worse financial conditions for suppliers predict an increase in the downstream firm's marginal cost. Column (iv) and (v) are the IV regressions (7) using the financial shock instrument, first without and then with controls. All regressions include 6 digit product code by year fixed effects. Column (vi) weights by log sales. The estimated coefficients in the IV regressions are similar to those in Table 1, suggesting that $\delta - 1 \approx 0.7$.

One concern with the financial shock instrument is the possibility that negative shocks to the downstream firm could be causing the downstream firms' suppliers to take on more debt. To assuage this concern, we take advantage of the fact that most of the variation in interest rates occurred between 2008 and 2009, after the great financial crisis (see Figure 6 in Appendix A). In columns (vii) and (viii) we conduct an event-study. We freeze the shares in (10) at their 2008 values and run the regression on $2008-2012$ and $2003-2007$. Since we include a firm fixed effect, we are now exploiting variation caused by the fact that at the onset of the financial crisis, some firms had suppliers who were more heavily reliant on short-term debt than others. Column (vii) shows that $\delta - 1$ is still positive and large, though less statistically significant. Column (viii) is the placebo test showing that before the large change in short-term interest rates, firms with high- and low- short-term debt-reliant suppliers did not have different marginal cost trends.

Table 3: Other outcomes

	(i)	(ii)	(iii)	(iv)
	$\Delta \log mc$ no K	$\Delta \log P$	$\Delta \log \mu$	$\Delta_2 \log mc$
Exit share	0.669***	-0.062	-0.706***	0.806***
	(0.246)	(0.058)	(0.238)	(0.312)
Specification	IV	IV	IV	IV
Controls	Yes	Yes	Yes	Yes
F-stat	71	71	71	58
6 digit x year FE	Y	Y	Y	Y

The instrument in the IV regressions is the suppliers' demand shock defined by (9). Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms, changes in log wages, changes in the log user cost of capital, and a Bartik-type demand shock constructed for the downstream firm itself. All regressions are unweighted. Standard errors are clustered at the firm-level.

Table 3 shows results for other left-hand-side variables using the Bartik supplier's demand instrument. Column (i) uses a measure of marginal cost which leaves out the user cost of capital, and shows that the results are very similar. Column (ii) replaces marginal cost with the output price and shows that the pass-through of these marginal cost shocks is close to zero in our context. This could be due either to strategic complementarities or sticky prices. Column (iii) shows that, predictably given the results in column (ii), it is the downstream firm's markup (defined as the ratio of price to marginal cost) that responds one-for-one to the marginal cost shock. Column (iv) uses two-year changes in marginal costs as the outcome and show that for the types of exits caused by our instrument, the effects are persistent.

Table 4 shows results for regression (8). Here, we instrument for the change in continuing share rather than the exit share, and the coefficient identifies $1/(\sigma-1)$ under the assumption that technology is CES. Columns (i) and (ii) use the suppliers' demand shock instrument in (9), whereas columns (iii) and (iv) use the financial shock instrument in (10). For columns (i) and (ii), the endogenous variable is the log change in the expenditure share of continuing suppliers. Column (i) has 6 digit product code by year fixed effects and column (ii) has 8 digit product code by year fixed effects. The point estimates are similar and suggest that $1/(\sigma-1) \approx 0.5$ or that $\sigma \approx 3$. In columns (iii) and (iv), the endogenous variable is the log change in the expenditure share of continuing suppliers who file annual accounts. Theoretically, any subset of continuing suppliers can be used to identify $1/(\sigma-1)$ and for columns (iii) and (iv) we focus on suppliers who file annual accounts since our financial shock instrument only applies to those suppliers who also file annual accounts. This is because if a supplier does not file annual accounts, then we do not know that suppliers' short-term debt obligations relative to total assets. The point estimates in columns (iii) and (iv) are slightly higher.

Table 4: Estimating $1/(\sigma-1)$

	(i)	(ii)	(iii)	(iv)
	$\Delta \log mc$			
Continuing share	0.675**	0.547**		
	(0.292)	(0.254)		
Continuing share filing annual accounts			0.760**	0.718*
			(0.378)	(0.431)
Instrument	Demand	Demand	Rate	Rate
F-stat	27	33	14	11
Controls	Y	Y	Y	Y
FE	6 digit x year	8 digit x year	6 digit x year	8 digit x year
Obs	27,406	32,878	13,888	10,623

Demand and rate are the instruments defined by (9) and (10). Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms, changes in log wages, changes in the log user cost of capital, a Bartik-type demand shock constructed for the downstream firm itself, and the firm's own short-term debt obligations interacted with interest rate changes. Standard errors are clustered at the firm-level.

In the appendix (to be added) we report the following sensitivity checks of our baseline results. First, we vary the product disaggregation in the product × year fixed effects, considering 4 or 8 digit products rather than 6 digits. With more stringent fixed effects, estimates are fairly robust but point estimates are a bit smaller. Second, we drop downstream firms that switch between years the set of 8-digit products they produce.[9] Second, when constructing the suppliers' demand instrument according to (9), we redefine $r_{jK,t}$ to be the share of supplier j's *non-manufacturing sales* to each non-manufacturing industry K (these share add up to one) multiplied by the average ratio of supplier j's non-manufacturing sales to total sales. Third, we drop suppliers that are either in the utilities sector or in the wholesale/retail sector. This increases point estimates slightly. Fourth, we measure markups using the alternative measure of markups that relies on production function estimation. Fifth, we change our sample selection by varying the trimming of price, quantity, and cost changes and by altering the minimum threshold in the ratio of a firm's Prodcom sales to the firm's aggregate sales from the annual accounts.

4 Macroeconomic Value of Link Formation: Theory

In the previous section, we estimated the inframarginal surplus ratio, $\delta - 1$, associated with new input varieties, as well as the elasticity of substitution between continuing and non-continuing varieties. We found that input suppliers generate a considerable amount of inframarginal surplus for their downstream customers.

In this section, we generalize growth accounting to account for churn in firm-to-firm linkages. Our micro results only apply to a relatively small subset of firms in the Belgian economy: manufacturing firms in Prodcom for whom we can observe prices. In the rest of the paper, we conduct an aggregate growth accounting exercise informed by the microeconomic point estimates that applies to almost all private sector Belgian firms. Our accounting exercise explicitly takes into account the fact that changes in one firm's marginal cost due to entry and exit of its suppliers spills over across the firm's network. This allows us to decompose the fraction of aggregate productivity growth that can be accounted for by churn in the supply chain. We describe the economic environment in Section 4.1 and then show how to decompose aggregate output growth in Section 4.2.

4.1 Environment and Notation

Consider an economy consisting of a set of producers N. Each producer is assigned to a unique industry and the set of industries is denoted by $\mathcal{I}$. There is a set of primary inputs denoted by $\mathcal{F}$. A primary input is an input used by producers in N that those producers do not themselves produce. In practice, the set $\mathcal{F}$ includes labor, capital, and imported intermediate inputs. With some abuse of terminology, we refer to elements of $\mathcal{F}$

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[9] We also consider another sensitivity in which we measure price using the downstream firm's largest 8-digit product (rather than averaging across all products).

as factors.[10] A stylized representation is given in Figure 2 showing the flow of goods and services.

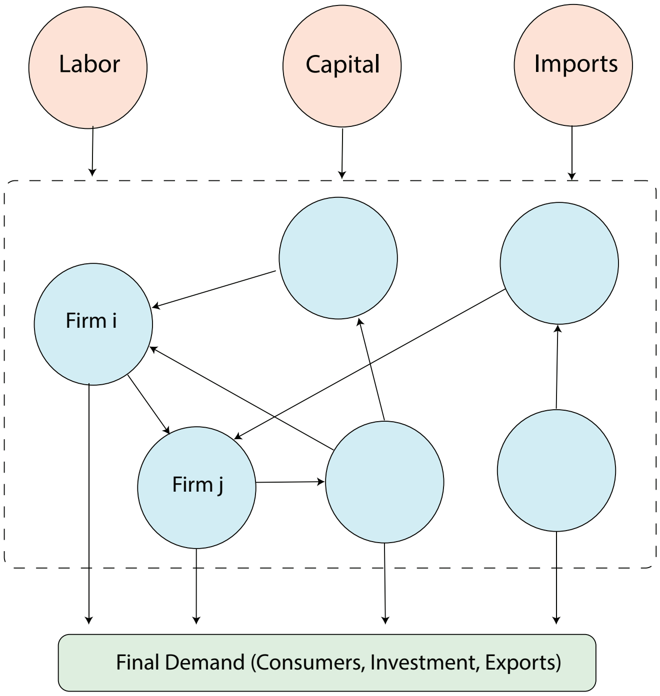

Figure 2: Graphical illustration of the economy

Technology and Prices. Producer $i \in N$ has a constant returns to scale production technology in period t given by

$$y_{i,t} = F_{i,t}\left(\left\{X_{iJ,t}\right\}_{J\in\mathcal{I}}, \left\{l_{if,t}\right\}_{f\in\mathcal{F}}\right).$$

In principle, we can capture non-constant-returns-to-scale on the margin at the producer level using producer-specific fixed factors. In addition, there may be fixed costs that must be paid in addition to the variable production technology defined above, but we do not need to take stance on these fixed costs. We assume that each producer minimizes costs and the markup μ_i charged by each producer i is defined to be the ratio of its price and marginal cost.

In the expression above, $l_{if,t}$ is factor input f used by i and $X_{iJ,t}$ is a constant returns to scale bundle of intermediate goods from industry J used by i. We assume this bundle is a

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[10] Commonly, factors are labor and capital but not imported intermediates. This is because in national income accounting, imported intermediate inputs are subtracted from total value-added. We treat imported intermediates differently for reasons that will become clear later.

CES aggregator across varieties of different inputs from industry j

$$X_{iJ,t} = \left(\sum_{j \in J} \bar{x}_{ij,t}^{\frac{1}{\sigma_{iJ}}} x_{ij,t}^{\frac{\sigma_{iJ}-1}{\sigma_{iJ}}} \right)^{\frac{\sigma_{iJ}}{\sigma_{iJ}-1}},$$

where $x_{ij,t}$ is are inputs purchased by i from another producer j at time t. Here, $j \in J$ means that j belongs to industry J. The elasticity of substitution among J varieties purchased by i is $\sigma_{iJ} > 0$. We allow producer-pair-specific productivity shifters $\bar{x}_{ij,t}$ to change over time.[11] Given prices of each good $j \in J$, denoted by $p_{j,t}$, the shadow-value of the bundle of inputs from industry J used by firm i, denoted by $P_{iJ,t}$, satisfies

$$P_{iJ,t} X_{iJ,t} = \sum_{j \in J} p_{j,t} x_{j,t}.$$

Final output. Final output of good $i \in N$, denoted by $c_{i,t}$, is the quantity produced of i that is not used by any $j \in N$ and is either consumed by households, used for investment, or sold as exports. The nominal value of final output is $E_t \equiv \sum_{i \in N} p_{i,t} c_{i,t}$.

Growth in real final output as measured in the data is the change in nominal final output deflated by the average price change of continuing goods. We say that good i is a *continuing* good between t and $t+1$ if $y_{i,t} \times y_{i,t+1} > 0$ and denote by C_t the set of all goods who are continuing at time t. The change in real final output is defined by

$$d \log Y_t = d \log E_t - \sum_{i \in C_t} \frac{p_{i,t} c_{i,t}}{\sum_{j \in C_t} p_{j,t} c_{j,t}} d \log p_{i,t}. \tag{11}$$

To calculate growth in real final output between two time periods, we chain $d \log Y$ over time:

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

Additional Notation. For each continuing producer i, denote total variable cost of producer i in time t by

$$TVC_{i,t} = \sum_{J \in I} P_{iJ,t} X_{iJ,t} + \sum_{f \in \mathcal{F}} w_{f,t} l_{if,t},$$

---

[11] In general, we can think that for each customer-input pair ij, producer i can choose between alternative suppliers that produce perfect substitute versions of input j with different qualities in a quality ladder. The downstream firm i always purchases from the supplier with the lowest quality-adjusted price. In an expanding varieties model, the quality ladder consists of a single producer for each variety. We do not explicitly write down this additional nest to save on notation.

consisting of expenditures on factors and intermediate inputs. Then define the variable cost share of i on industry $J \in \mathcal{I}$ or factor $f \in \mathcal{F}$ to be

$$\Omega^V_{iJ,t} = \frac{P_{iJ,t} X_{iJ,t}}{TVC_{i,t}}, \quad \text{and} \quad \Omega^V_{if,t} = \frac{w_{f,t} l_{if,t}}{TVC_{i,t}}.$$

Divide inputs in industry J used by producer i into two sets: the subset of continuing suppliers of i in industry J between t and $t+1$ (i.e. $x_{ij,t} \times x_{ij,t+1} > 0$), denoted by $C_{iJ,t}$, and the rest. If the set $C_{iJ,t}$ is non-empty, denote the log change in the continuing goods' expenditure share between t and $t+1$ divided by $1/(\sigma_{iJ} - 1)$ by

$$d \log \mathcal{E}_{iJ,t} \equiv \frac{1}{\sigma_{iJ} - 1} \log \left(\frac{\sum_{j \in C_{iJ,t}} p_{j,t+1} x_{ij,t+1} / \sum_{k \in J} p_{k,t+1} x_{ik,t+1}}{\sum_{j \in C_{iJ,t}} p_{j,t} x_{ij,t} / \sum_{k \in J} p_{k,t} x_{ik,t}} \right),$$

and let the share-weighted average of $\mathcal{E}_{iJ,t}$ across all industries be

$$d \log \mathcal{E}_{i,t} = \sum_{J \in \mathcal{I}} \Omega^V_{iJ,t} d \log \mathcal{E}_{iJ,t}.$$

Define the matrix continuing input-output matrix W_t and factor shares W^F_t to be

$$W_{ij,t} = \mathbb{1}_{\{j \in C_{iJ,t}\}} \times \Omega^V_{iJ,t} \frac{p_{j,t} x_{ij,t}}{\sum_{k \in C_{iJ,t}} p_{k,t} x_{ik,t}}, \qquad W^F_{if,t} = \Omega^V_{if,t}.$$

Finally, define the cost-based continuing Domar weights of goods and primary inputs to be

$$\tilde{\lambda} = b'_t (I - W_t)^{-1}, \quad \tilde{\Lambda} = b'_t (I - W_t)^{-1} W^F_t,$$

where $b_{i,t} = p_{i,t} c_{i,t} / E_t$ is the share of good i in final expenditures. Revenue-based Domar weights of continuing goods and primary inputs are given by

$$\lambda_i = \frac{p_{i,t} y_{i,t}}{E_t}, \quad \Lambda_f = \frac{w_{f,t} L_{f,t}}{E_t},$$

where λ_i and Λ_f include all sales accruing to i and f, regardless of the use. That is, λ_i and Λ_f include expenditures on i and f that are used to satisfy fixed or variable input needs.

4.2 Decomposition

The following proposition is the main result of this section.

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

$$d\log Y_t = \underbrace{\sum_{i\in C_t} \tilde{\lambda}_{i,t} d\log A_{i,t}}_{\text{technology}} + \underbrace{\sum_{f\in\mathcal{F}} \tilde{\Lambda}_{f,t} d\log L_{f,t}}_{\text{factor quantities}} + \underbrace{\sum_{i\in C_t} \tilde{\lambda}_{i,t} d\log \mathcal{E}_{i,t}}_{\text{extensive-margin}} \\ - \underbrace{\sum_{i\in C_t} \tilde{\lambda}_{i,t} d\log \mu_{i,t}}_{\text{markups}} - \underbrace{\sum_{f\in\mathcal{F}} \tilde{\Lambda}_{f,t} d\log \Lambda_{f,t}}_{\text{factor shares}}.$$

Proposition 4 breaks down changes in aggregate output growth into different sources.[12] To derive Proposition 4, we note the change in the price of each continuing variety can be written as

$$d\log p_{i,t} = d\log \mu_{i,t} - d\log A_{i,t} + \sum_{f\in\mathcal{F}} \Omega^V_{if,t} d\log w_{f,t} \\ + \sum_{J\in\mathcal{I}} \Omega^V_{iJ,t} \sum_{j\in C_{iJ,t}} \frac{p_{j,t}x_{ij,t}}{\sum_{k\in C_{iJ,t}} p_{k,t}x_{ik,t}} d\log p_{j,t} + d\log \mathcal{E}_{i,t}.$$

That is, the change in the price of i depends on shocks to i's own markup and technology, changes in factor prices, changes in the prices of other continuing suppliers, and supplier churn. This equation is a linear system in the prices of continuing firms and can be inverted to express the price of every continuing firm in terms of primitive shocks to markups and technology, changes in factor prices, and changes in supplier churn. This solution can then be combined with the definition of real final output, (11) to yield Proposition 4.

To better understand the intuition for Proposition 4, it helps to consider some special cases. We use different special cases to isolate the different expressions in this formula.

Corollary 1 (Neoclassical Economy without Entry-Exit)**.** For an efficient economy with no markups and no entry-exit margin, the change in aggregate output is

$$d\log Y_t = \sum_{i\in N} \lambda_{i,t} d\log A_{i,t} + \sum_{f\in\mathcal{F}} \Lambda_{f,t} d\log L_{f,t}.$$

That is, output growth is the sum of technology and external input growth weighted by sales. This is the neoclassical case considered by Solow (1957), Domar (1961), and Hulten (1978). T

Corollary 2 (Markups without Entry-Exit)**.** For an economy with no entry-exit, the change

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[12] For 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, we do not need to specify these details.

in aggregate output is

$$d\log Y_t \;=\; \sum_{i\in N}\tilde{\lambda}_{i,t}d\log A_{i,t} + \sum_{f\in\mathcal{F}}\tilde{\Lambda}_{f,t}d\log L_{f,t} - \sum_{i\in N}\tilde{\lambda}_{i,t}d\log \mu_{i,t} - \sum_{f\in\mathcal{F}}\tilde{\Lambda}_{f,t}d\log \Lambda_{f,t}.$$

This is the environment considered by Baqaee and Farhi (2019). The first two terms measure the increase in output growth due to the increase in technology and inputs, holding fixed the allocation of resources, and the latter two terms measure the effect of changes in the allocation of resources. In an efficient economy, these reallocation effects have no effect on output due to the envelope theorem. Reallocations are beneficial if the reduction in factor prices, as measured by $-\sum_{f\in\mathcal{F}}\tilde{\Lambda}_{f,t}d\log\Lambda_{f,t}$, outpace the increases in prices caused by markups $\sum_{i\in N}\tilde{\lambda}_{i,t}d\log\mu_{i,t}$. Intuitively, beneficial reallocations, by making better use of scarce factors, make factors less scarce and boost overall production.

Corollary 3 (Constant Non-Zero Markups and Zero Profits)**.** For an economy with constant markups, a single factor of production, and a zero-profit condition (variable profits are entirely dissipated by entry costs), we have

$$d\log Y_t = \sum_{i\in C_t}\tilde{\lambda}_{i,t}d\log A_{i,t} + \sum_{f\in\mathcal{F}}\tilde{\Lambda}_{f,t}d\log L_{f,t} + \sum_{i\in C_t}\tilde{\lambda}_{i,t}d\log \mathcal{E}_{i,t}.$$

The economy above mimics the structure in Melitz (2003) and nests the input-output model in Baqaee (2018). Mechanically, constant markups mean that $d\log\mu_i = 0$, and a zero-profit condition with a single factor implies that $d\log\Lambda_f = 0$. Substituting these into Proposition 4 yields the result. That is, similar to traditional neoclassical models, exogenous technology growth $d\log A$ and factor growth $d\log L$ can raise final output. However, there is new term involving churn in the supply chain.

The final term measures the importance of new varieties — if new varieties are introduced or destroyed in equilibrium in response to shocks, then these will affect marginal cost of downstream firms. These marginal cost shocks will then spill-over to other producers and the importance of these spill-overs is captured by the cost-based continuing Domar weight $\tilde{\lambda}_{it}$. Intuitively, supplier churn is especially powerful when the elasticity of substitution, σ_{iJ}, is low, and the cost-based Domar weight, $\tilde{\lambda}_{it}$, is large. This final term would be zero in a counterfactual in which the change in the price of inputs that enter or exit is equal to the change in the price of continuing inputs.

5 Empirical Macroeconomic Results

In this section, we combine the results of Sections 3 and 4 to decompose aggregate growth for the entire Belgian economy.

5.1 Data

To apply Proposition 4, we need the matrices W_t and W_t^F for all continuing firms in Belgium, the growth in factor quantities (labor, capital, and imported materials), the growth in final real output, and finally, the elasticity parameters $1/(\sigma_{iJ} - 1)$. Importantly, we do not need to observe all prices to be able to apply Proposition 4, hence, we can decompose aggregate growth for most firms in Belgium and not reduce our focus to just Prodcom firms. Below we describe how we map our model to the data.

As in Section 3, we construct the network of domestic suppliers of Belgian firms using the NBB B2B Transactions data set. As mentioned before, every firm in Belgium is required to report VAT on all sales of at least 250 euros, and the data has universal coverage of all businesses active in Belgium. We define the set of continuing firms C_t to be all continuing non-financial private sector firms (we exclude self-employed and government entities as well as the financial sector, NACE 2-digits 64 to 66, and non-market sectors, NACE 2-digits 84 to 99). We only include continuing firms, that is firms with both sales and intermediates purchases larger than 1000 euros in two consecutive years. Final output is defined to be the sales of these firms excluding sales 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 other non-financial private sector firms. The firms in our sample comprise roughly 80% of aggregate value-added in Belgium (see Table 6 in Appendix A for more information).

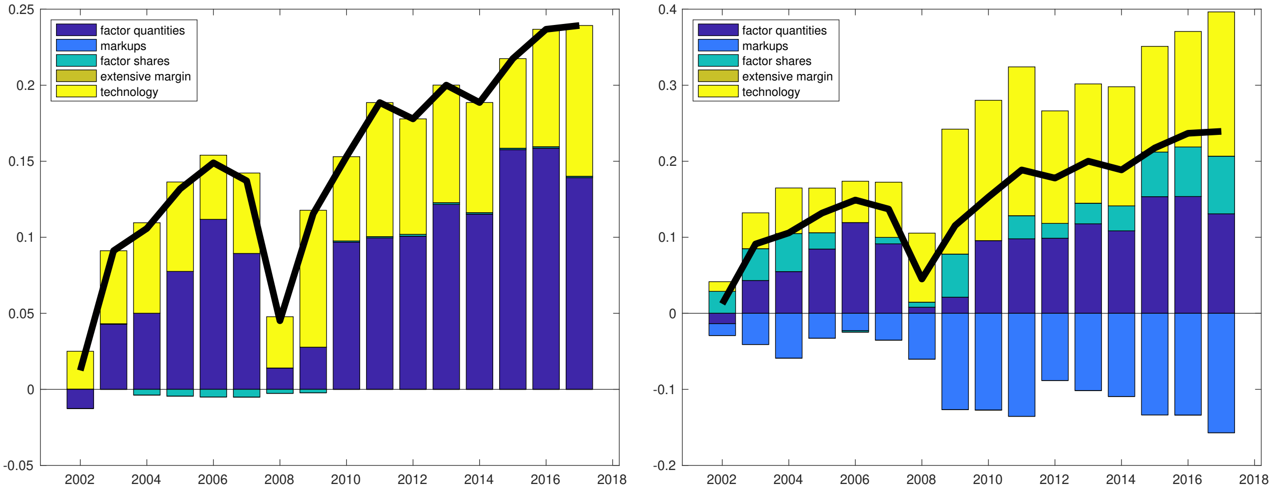
For the firms in C_t, we combine the B2B transactions with information from annual accounts and VAT declarations to construct the matrices W_t and W_t^F for each year in our sample. Similarly, we can construct the final goods shares vector b_t by combining total sales data with the B2B transactions data. We calculate firm level markups μ_t in each period as the ratio of total sales to total costs, as in Section 3. Since we do not need to observe prices to do this, we can construct this measure of markups for all firms in C_t.

We measure the growth in labor quantity using total full time employees for all firms in our sample. We measure the growth in the capital stock using the value of plants, property, equipment, and intellectual property deflated using the investment price deflator used for constructing the national accounts in 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. Finally, we measure real final output growth by deflating nominal growth in final output using a weighted average of the consumer price index and the export price deflator, both from Belgium's NIPA. The weights are given by total domestic final sales and total exports, respectively.

Finally, we assume that $\sigma_{iJ} = \sigma$ for all i and J, and we experiment with different values including the point estimates from Table 4.

5.2 Results

Table 6 in Appendix A 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 7 in Appendix A reports basic statistics about the level and changes in the continuing share of suppliers, as well as basic information on the number of suppliers each firm has, and the share of intermediate materials as a share of total costs for our sample.

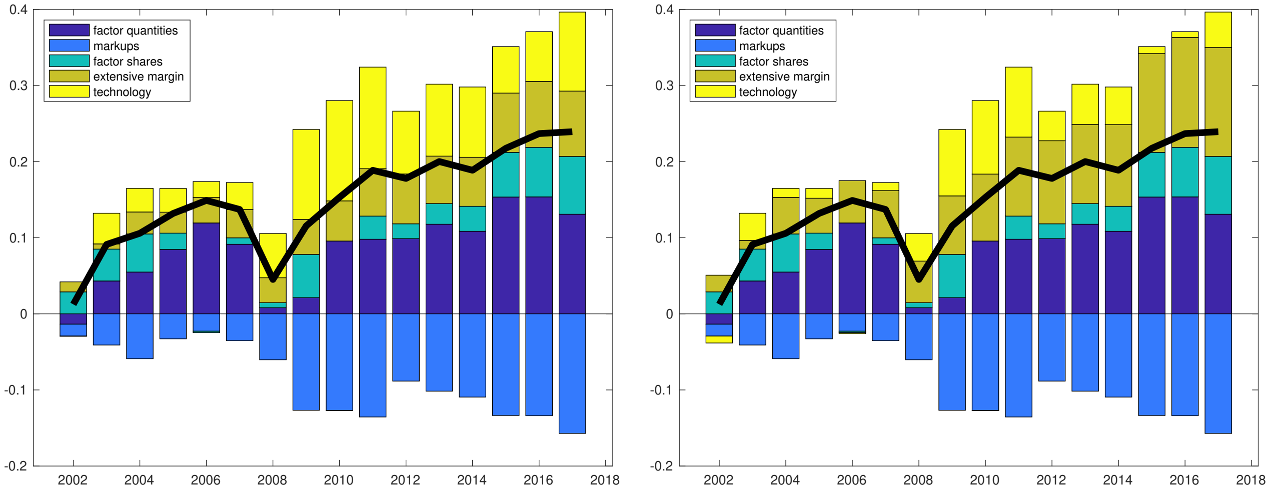


(a) No markups or entry

(b) $\beta = 0$

Figure 3: Growth accounting special cases

We start with two special cases in Figure 3. The first panel is a traditional Solow-Hulten decomposition, where we assume away entry-exit effects, setting $\sigma = \infty$, that is, supplier entry-exit (extensive margin) is irrelevant, and assuming that all prices are equal to marginal cost. This breaks down overall growth into growth due to an increase in the quantity of factors and a residual term capturing the technological residual. In these figures, a substantial portion of aggregate growth, slightly less than half, is driven by unexplained technological growth. The second panel allows for firm-level markups. This figure shows that markups on average have risen over the sample, and factor shares have fallen. However, the reduction in factor shares, which capture changes in factor prices, does not offset the increase markups. In other words, since markups on average have risen faster than factor shares have fallen, this suggests that there has been a reallocation away from high-markup firms. This dampens productivity growth, which means that we need a stronger unexplained technological residual to explain the observed growth in output.



(a) $1/(\sigma - 1) = 0.3$ (b) $1/(\sigma - 1) = 0.5$

Figure 4: Growth accounting baseline results

Figure 4 allows for entry-exit. The first panel shows the results with $1/(\sigma - 1) = 0.3$, corresponding to an elasticity of substitution of 4, while the second panel shows $1/(\sigma - 1) = 0.5$, corresponding to an elasticity of substitution of 3. Both of these are conservative compared to our point estimates in Table 4 in the sense that they assign a slightly relatively smaller role to entry-exit than our point estimates suggest. Nevertheless, we find that the extensive margin of suppliers can explain a substantial fraction of the technology residual. Indeed, when $1/(\sigma - 1) = 0.5$, the role of the technology residual, intensive margin improvements for existing firms, has all but disappeared from the calculation, showing that almost the entirety can be attributed to the entry and exit of suppliers. Interestingly, the growth that can be explained by churn in the supply chain is long-run, and supplier-churn cannot explain cyclical movements in aggregate output like the recession following the 2008 financial crisis.

For comparison, Figure 5 calculates the missing growth in final demand, following Aghion et al. (2019), capturing the importance of entry-exit for final demand (which is unaccounted in GDP). In the baseline case we weight industries by employment (as in Aghion et al. (2019)) and in an alternative case by final sales. The numbers are much smaller when compared to the importance of entry-exit in supply chains as captured by Figure 4. This suggests that in comparative terms, most of the benefits of new varieties are already accounted for in the national accounts because they occur in production rather than consumption.

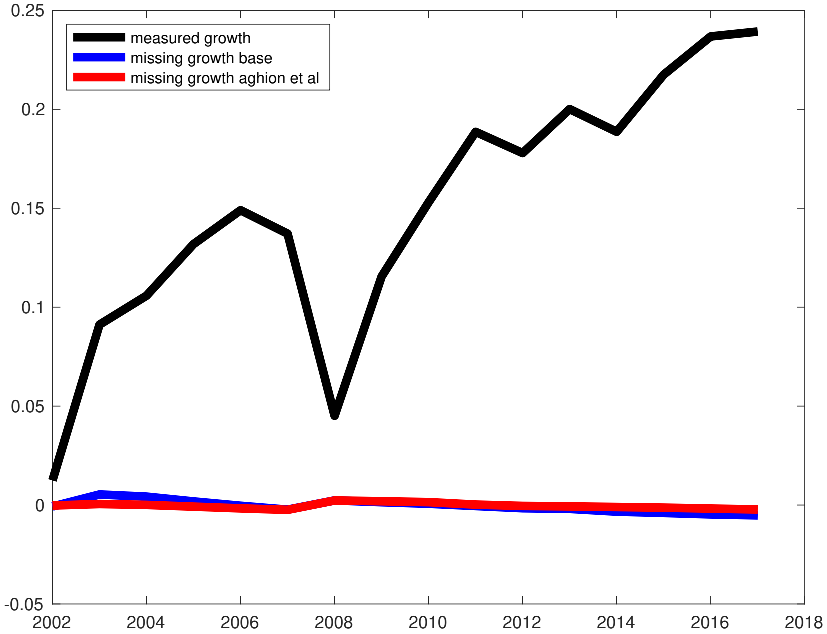


Figure 5: Unmeasured growth

6 Conclusion

This paper analyzes and quantifies the microeconomic and macroeconomic importance of creation and destruction of supply linkages. At the microeconomic level, we show that supplier exits have large effects on downstream firms' marginal costs and show that this can be used to directly calibrate the change in inframarginal surplus that a supplier exit triggers. In an expanding variety model, this captures the love-of-variety effect, whereas in a Schumpeterian model of creative destruction, this captures the innovation step-size. At the macroeconomic level, we show that supplier entry and exit can account for most of the growth component of the unexplained technological residual in a Solow (1957)-style growth accounting exercise. Our results suggest that supplier entry and exit has large and important consequences for growth.

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Appendix A Additional Tables and Figures

Table 8 provides the number of firms for every year t between 2002 and 2007, as well as the fraction of firms that exit rate between t and $t + 1$. The exit rate is much higher for small firms (those below the median size) and large firms.

Table 5: Identifying $\delta - 1$ with more stringent fixed effects

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Supplier Death	$\Delta \log mc$						
Exit share		-0.129***		0.580***	0.529**	0.858***	0.498**	0.483**
		(0.013)		(0.224)	(0.223)	(0.319)	(0.215)	(0.229)
Demand Shock	-2.083***		-0.862***					
	(0.136)		(0.331)					
F-stat				74	73	73	77	55
Specification	OLS	OLS	RF	IV	IV	IV	IV	IV
Controls	N	N	N	N	Y	Y	Y	Y
8 digit x year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	N	N	N	N	N	Y	N	N
Obs	31,788	31,788	31,788	31,788	31,788	30,959	31,788	31,788

Demand shock is the instrument in the IV regressions and is defined by (9). Supplier death is the expenditure-weighted share of the downstream firm's suppliers who ceased operations. Controls are log changes in the price of imported inputs, log changes in the price of inputs purchased from other Prodcom firms, changes in log wages, changes in the log user cost of capital, and a Bartik-type demand shock constructed for the downstream firm itself. All regressions are unweighted except (vii), which is weighted by log sales. Column (viii) uses lagged shares at $t-1$ instead of initial t shares in constructing the instrument. Standard errors are clustered at the firm-level.

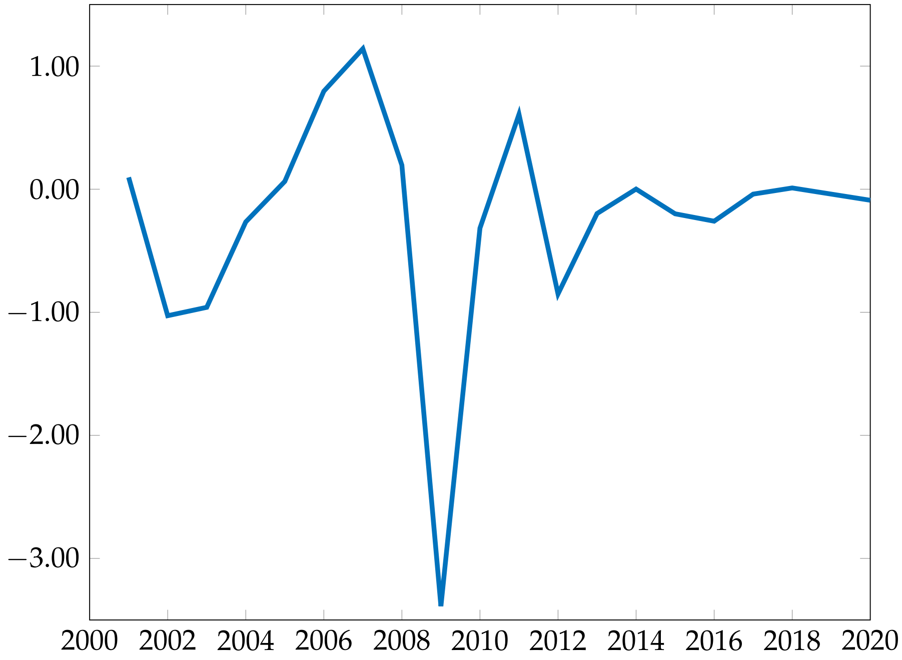

Figure 6: Changes in the short-term nominal interest rate in our sample.

Table 6: Coverage of growth accounting sample of firms

	(1)	(2)	(3)	(4)	(5)
year	count	value added		employment	
			% of agg.		% of agg.
2002	225293	117877	79%	1736	74%
2003	232834	130144	84%	1717	73%
2004	240997	141466	86%	1729	73%
2005	248600	141161	83%	1745	72%
2006	258480	141358	79%	1787	73%
2007	269570	141708	74%	1820	72%
2008	279497	142397	72%	1833	71%
2009	287599	145369	77%	1810	71%
2010	298497	169457	85%	1806	70%
2011	310392	149460	72%	1843	70%
2012	317164	171272	82%	1858	70%
2013	319764	168458	79%	1873	71%
2014	324552	174503	81%	1863	70%
2015	332470	179573	80%	1881	70%
2016	343110	185386	80%	1917	70%
2017	352457	195098	81%	1960	71%
avg. growth (%)		3.4	3.3	0.8	1.1

Notes: The sample of firms used in this table are those used in the growth accounting exercise (continuing corporate non-financial firms continuing firms). % agg. is the share of value added and employment in the non-financial corporate sector reported in the national statistics.

Table 7: Descriptive statistics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	continuing supplier share		intermediates share		short-term	number of suppliers	
	level	dlog	all	domestic	debt ratio	all	annual accts.
mean	0.56	0.01	0.86	0.59	0.27	686	625
p25	0.30	-0.14	0.81	0.34	0.00	69	62
p50	0.61	-0.01	0.92	0.62	0.07	247	228
p75	0.84	0.11	0.99	0.85	0.36	790	719
count	4627730	4519005	4628332	4628332	5529159	4628332	4628332

Notes: The sample of firms used in this table are those used in the growth accounting exercise (continuing corporate non-financial firms continuing firms) with at least one domestic supplier filling its annual account.

Table 8: Exit rates

	(1) Count	(2)	(3) Exit rate	(4)
	all	all	small	large
2002	226342	0.037	0.063	0.011
2003	237497	0.036	0.060	0.011
2004	247459	0.039	0.065	0.012
2005	252874	0.042	0.070	0.013
2006	261895	0.037	0.063	0.011
2007	270355	0.035	0.060	0.010
2008	279226	0.039	0.065	0.014
2009	287553	0.034	0.057	0.011
2010	291129	0.032	0.054	0.010
2011	299381	0.034	0.057	0.010
2012	309501	0.042	0.070	0.014
2013	307803	0.036	0.061	0.010
2014	315123	0.036	0.061	0.011
2015	317887	0.032	0.055	0.010
2016	326172	0.031	0.053	0.009
2017	333882	0.031	0.055	0.009

Notes: Number of continuing firms at t and fraction of firms that exit between t and $t+1$ Small and large firms are those below and above the median sales firm.