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Multi Product Firms, Import Competition, and the Evolution of Firm-product Technical Efficiencies
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ABSTRACT

We study how increased import competition affects the evolution of firm-product technical efficiencies in the small open economy of Belgium. We observe quarterly firm-product data at the 8-digit level on quantities sold and firm-level labor, capital, and intermediate inputs from 1997 to 2007, a period marked by stark declines in tariffs applied to Chinese goods. Using Diewert (1973) and Lau (1976) we show how to estimate firm-product quarterly technical efficiencies using a multi-product production (MPP) function that avoids using single-product (SP) production function approximations to it. We find that a 0.01 increase in the import share leads to a 1.05% gain in technical efficiency. This elasticity translates into gains from com- petition over the sample period exceeding 1.2 billion euros, which is over 2.5% of the average annual value of manufacturing output in Belgium. Firms appear to be less technically efficient at producing goods the further they get from their ”core” good and firms respond to competition by focusing more on their core products. Instrumenting import share - while not important for the signs of the coefficients - is very important for the magnitudes as the effect of competition increases tenfold when one moves from OLS to IV. We close by testing the SP approximation to MPP and reject in eight of twelve industries.

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1 Introduction

Economists have shown in a variety of theoretical settings that product-market competition can provide firms with strong incentives to adopt cost-lowering production processes in order to remain profitable (see e.g. Holmes and Schmitz, 2010 for a recent review).[1] Several important contributions in the empirical productivity literature have established a strong positive relationship between firm-level total factor productivity growth and increased competition, where the former is given by total firm-level deflated revenue less its predicted value given input use (see e.g. Olley and Pakes, 1996; Pavcnik, 2002; Bloom, Draca and Van Reenen, 2016).

A well-known feature of micro-level production data is that most firms produce multiple products, which suggests the possibility that within-a-firm different products may be produced with different levels of technical efficiency.[2] We show existence of the multi-product production function using the seminal contributions of Diewert (1973) and Lau (1974). The standard single product production function gives the maximal output for any tuple of inputs (e.g. labor, capital, and intermediate inputs). A multi-product production function extends the single product setting by giving the maximal amount of output achievable of one of the goods the firm produces holding inputs *and* the levels of other goods produced constant.

We observe Belgian manufacturing data that records at the quarterly level firm-product quantities and production inputs. This existence result is critical for motivating our firm-product regression of output of one product on total input levels and the output quantities of all other products produced by the firm. We address the simultaneity of inputs and outputs with multiple unobserved technical efficiencies per firm by extending suggestions from Petropoulos (2001) and Ackerberg, Benkard, Berry, and Pakes (2007). We repeat these regressions with each firm-product treated separately as a dependent variable to get technical efficiency estimates for every product. A major strength of our theory is that it neither requires us to assume that multi-product production is a collection of single-product production functions nor does it require us allocate aggregate firm-level input measures across them.

Firm-product technical efficiencies allow for more direct identification of the impact of competition as changes in firm-product technical efficiencies can be directly related to changes in competitive conditions for that particular 8-digit product category. They also allow us explore implications of the recent theoretical models of Eckel and Neary

[1]For a more recent variant of the theory see Aghion and Howitt (1996).

[2]See e.g. Bernard, Redding and Schott (2010a,b), Bernard, Redding, and Scott (2011), and Goldberg, Khandewal, Pavcnik, and Topalova. (2010a,b).

(2010), Bernard, Redding and Schott (2010, 2011), and Mayer, Melitz and Ottaviano (2014). All of these models have - in equilibrium - higher revenue "core" products being produced more efficiently within multi-product firms. Recent extensions of these models by Dhingra (2013) and Eckel et al. (2015) show how firms respond to trade liberalization by undertaking R&D activities that lead to greater increases in technical efficiencies or improved quality depending on the nature orf the good or the initlial level of firm efficiency.

We explore all of these margins using the Census of Belgian manufacturing data from 1997 to 2007, a period of increased competition with China's 2001 entry into the World Trade Organization (WTO). We estimate multi-product production function for 12 industries separately. Consistent with our production theory the estimated coefficient on the other-goods-produced quantity index is the correct sign - negative - and significant for all 12 industries, implying that holding all input levels constant an increase in the firm's output index of other-goods-produced leads to a fall in the output of the good under consideration.

We calculate the implied estimates of quarterly firm-product technical efficiency and regress them on last period's import share while controlling for last period's technical efficiency, the product's "rank" in terms of revenue generated at the firm, interactions between the lagged import shares and product rankings, and 8-digit product- and quarter-specific fixed effects, We instrument for the share using European tariffs on Chinese imports and an estimate of world export supply (excluding Belgium), as suggested by Hummels et al. (2014). Consistent with the theory models we find that product rankings on average lines up one-to-one with the level of technical efficiency with which a good is produced, with the highest revenue good being produced most efficiently. We find that a 1% increase in the lagged import share is associated with a 1.05% percent increase in technical efficiency in the current period for the first and second ranked products, and a 0.65% increase in technical efficiency of all other products produced by the firm. Across 10 robustness checks our estimate of 1.05% ranges between 0.84% up to 1.17%. Without instruments we find only one-tenth the effect, which is consistent with lagged import penetration being higher in product markets where domestic innovations in technical efficiency are lower (and vice versa).

We calculate the long-run changes in the value of produced output due to a change in the previous period's input share by multiplying the log change in technical efficiency by the product's current revenue, and then scaling it up to account for future output gains arising due to the high persistence of the technical efficiency process as the AR(1) coefficient is estimated to be 0.9 across almost all specifications instrumented or not. Of the 65,242 positive and negative changes the average change is a little over 22 thousand euros, and while most changes are positive almost 35% of the realized changes are negative because import shares decrease in many cases. There is a tremendous amount of variation across industries in these changes with some of the biggest negative changes ranging from -1.8 to -2.5 million euros and the some of the biggest positive changes ranges between 2.2 and 2.5 million euros. Aggregating over the entire sample period the overall gain in the value of output due to increased import competition is on the order of 1.4 billion euros, almost 2.5% of average annual value of manufacturing output in Belgium over this period.

We investigate whether our findings change if we use the single-product (SP) production approximation with an input allocation rule based on the good's revenue share. We develop a test for whether we can reject the SP production approximation based on our production function theory and in eight of twelve cases we reject the SP approximation at the 1% level of significance. When we estimate the impact of competition on technical efficiency using the SP technical efficiency residuals we find with no other controls the coefficient is 0.71, not far off from our preferred estimate of 1.05. However, once the interaction terms are added between the import share and the product ranking, the coefficient on the import share drops to 0.45 and is no longer significant, and all of the interaction terms in this specification are close to zero and insignificant.

The closest empirical findings to ours are from De Loecker, Goldberg, Khandelwal, and Pavcnik (2016), who use manufacturing data on multi-product production from India to estimate the effect of trade liberalization on firm-product marginal costs. They assume multi-product production is a collection of single-product production functions and allocate inputs based on input optimization theory. Their setup has one firm technical efficiency firm common across all products but their model implies separate marginal costs for each firm-product. Similar to our findings they find that marginal costs are on average declining as the within-firm product revenue share increases and that increases in trade liberalization are associated with reductions in product-specific marginal costs.

The rest of the paper is structured as follows. Section 2 describes the detailed quarterly firm-product dataset that we build. In Section 3, we explain the methodology that we use to estimate the multi-product production functions. Section 4 formalizes and parameterizes the system of simultaneous production equations that comes out of the theory of Section 3. Section 5 addresses simultaneity, Section 6 presents our results, and Section 7 concludes.

2 Product Quantities, Prices, and Import Shares

We construct quarterly 8-digit firm-product observations on quantities sold, unit prices, and import shares from 1997–2007 using the Belgian PRODCOM survey and the Belgian data on international trade transactions. We construct quarterly measures of inputs used in production using the Value Added Tax (VAT) declarations, the National Social Security database, and data from the Belgian Central Balance Sheet Office.

2.1 The Belgian PRODCOM survey

The first data set is firm-product level production data (PRODCOM) collected by Statistics Belgium.[3] The survey is designed to cover at least 90% of production value in each NACE 4-digit industry by including all Belgium firms with a minimum of 10 employees or total revenue above 2.5 million Euros.[4] The sampled firms are required to disclose monthly product-specific revenues and quantities sold of all products at the PRODCOM 8 digit level (e.g. 15.96.10.00 for "Beer made from malt", 26.51.11.00 for "Cement clinker"). We keep only firms that are classified by NACE as have their principal business activities in manufacturing. We aggregate revenues and quantities to the quarterly level and calculate the associated quarterly unit price. We restrict our analysis to the period from 1995-2007 because it is the main period of trade liberalization and because in 2008 PRODCOM both significantly reduced its sample size and changed its classification system. For each firm within each 4-digit industry we compute the median ratios of total revenue over employment, capital over employment, total revenue over materials and wage bill over labor (average wage), and we exclude those observations more than five times the interquartile range below or above the median. Finally, we keep only firm-product observations where the share of the product's revenue in the firm's total revenue is at least 5%.

The Value Added Tax revenue data provides us with a separate check against the revenue numbers firms report to PRODCOM. Comparing the tax administrative data revenue numbers with the revenue numbers reported in the PRODCOM data, we find that between 85% and 90% of firms report similar values for both. We exclude firms if they do not report a total value of production to PRODCOM that is at least 90% of the revenue they report to the tax authorities.

Table 1 shows the average revenue share of products in firms' portfolios when they are producing a different number of products at two levels of aggregation (8-digit and 2-digit PRODCOM). We observe 137,453 firm-product observations between 1997-2007. As has been noted in other product-level data sets the majority of firms produce multiple products. [5] At the 8-digit level of disaggregation multi-product firms are responsible for

[3] See http://statbel.fgov.be/fr/statistiques/collecte_donnees/enquetes/prodcom/ and http://statbel.fgov.be/nl/statistieken/gegevensinzameling/enquetes/prodcom/ for more details in French and Dutch, or Eurostat in English (http://ec.europa.eu/eurostat/web/prodcom).

[4] NACE is a French acronym for the European Statistical Classification of Economic Activities.

[5] See e.g. Bernard et. al (2010) or Goldberg et. al (2010).

73% of total value of manufacturing output. Most firms produce between one and five products and these firms account for 75% of the value of manufacturing output. For firms producing two goods the core good accounts for 77.5% of revenue. Similarly for firms producing three goods 69.5% of revenue comes from the core product. Even for firms producing six or more goods the core good is responsible for 49.4% of revenue. At the 2-digit level of aggregation the fraction of manufacturing revenue coming from single product firms jumps to 78% and the fraction of manufacturing revenue from firms producing three or more goods falls to 3%, suggesting firms specialize by typically producing goods within the same 2-digit category.

2.2 Firm Input Measurements

Quarterly measurements of firms inputs from 1997 to 2007 are obtained from the VAT fiscal declarations of firm revenue, the National Social Security database, and the Central Balance Sheet Office database. For tax liability purposes Belgian firms have to report in their VAT fiscal declarations both their sales revenues and their input purchases. Using this information we construct quarterly measures for intermediate input use and investment in capital (purchases of durable goods). For measures of firm employment we use data from the National Social Security declarations where firms report on a quarterly basis their level of employment and their total wage bill. To construct a quarterly measure of capital we start with data from the Central Balance Sheet Office, which records annual measures of firm assets for all Belgian firms. For the first year a firm is in our data, we take the total fixed assets as reported in the annual account as their starting capital stock. We then use standard perpetual inventory methods to build out a capital stock for each firm-quarter.[6]

[6]In order to build the capital stock, we assume a constant depreciation rate of 8% per year for all firms. Real capital stock is computed using the quarterly deflator of fixed capital gross accumulation. The initial capital stock in $t = t_0$, where period t_0 represents the 4th quarter of the first year of observation of the firm, is given by

$$K_{t_0} = \frac{Total\ fixed\ assets_{first\ year\ of\ observation}}{P_{K;t_0}}$$

The capital stock in the subsequent periods is given by

$$K_t = (1 - 0.0194)\, K_{t-1} + \frac{I_t}{P_{K;t}}$$

We assume that the new investment is not readily available for production and that it takes one year from the time of investment for a new unit of capital to be fully operational.

2.3 The Increase in Import Shares: 1997-2007

The competitive environment in Europe changed significantly over the 1997-2007 period with the implementation of the Single Market Plan within the European Union in 1993 and with the entry in 2001 of China into the World Trade Organization. We construct two separate measures of import shares by combining information from the PRODCOM database with the Belgian international trade data, which contains the quarterly values and quantities of all imports and exports by Belgium firms at the 8-digit level.[7]

Let M_{ijt} denote the quantity of imports of firm i of good j at time t and let $M_{jt} = \sum_{i \in \text{Importers}} M_{ijt}$ be the total quantity of imports of product j at the 8-digit level. Let Q_{jt} denote the total domestic quantity sold of product j. Our first measure of import penetration is given as:

$$IS_{1jt} = \frac{M_{jt}}{Q_{jt} + M_{jt}}.$$

Belgium is a small open economy on the North Sea in Central Europe and a significant fraction of the products entering Belgium are subsequently re-exported to other countries.[8] To account for re-exporting we develop a second measure based on net imports. Continuing to work in quantity units we define net imports at the firm level as $Max\{M_{ijt} - E_{ijt}, 0\}$ where E_{ijt} is the physical quantity of exports of good j from firm i at time t. Our second import share measure is then given as

$$IS_{2jt} = \frac{\sum_{i \in \text{Importers}} Max\{M_{ijt} - E_{ijt}, 0\}}{Q_{jt} + \sum_{i \in \text{Importers}} Max\{M_{ijt} - E_{ijt}, 0\}}.$$

Table 2 shows the changes in import shares at the 8-digit product level between 1997 and 2007 using IS_{2jt}, the "export-corrected" measure of imports,, which is our preferred measure. The table shows the percentiles for all 8 digit-products pooled together and by 2-digit industries. The mean change across all products is an increase of 0.043. This mean hides the tremendous heterogeneity in the underlying changes with most changes positive but many changes negative. The 10th percentile change is -0.21 and the 90th percentile is 0.368. The 25th percentile is -0.04 and the 75th percentiles is 0.136. This pattern is reasonably robust across all of the 2-digit industries and across our two measures of import competition and it suggests that there is a role for increases *and decreases* in competition to both increase and decrease technical efficiencies.

[7] International trade data are recorded at the CN8 level while PRODCOM is recorded at the PRODCOM level. We use the concordance tables by Eurostat between nomenclatures and over time.

[8] For example, Duprez (2014) shows that 30% of Belgian exports in 2010 are re-exports of imported goods not processed in Belgium.

3 Multi-Product Production

Using Diewert (1973) and Lau (1976) we review the theoretical conditions under which single- and multi-product production functions exist and their testable implications. We then explore conditions under which multi-product production can be characterized by a collection of single product production functions, one for each good produced by the firm. Readers not interested in the details can jump directly to estimation in section 4.

3.1 Single Product Firms

The primitive of production analysis is the firm's production possibilities set T. In the single-product setting T lives in the non-negative orthant of R^{1+N} and contains all values of the single output q that can be produced by using N inputs $x = (x_1, x_2, \dots, x_N)$, so if $(\tilde{q_1}, \tilde{x}) \in T$, then $\tilde{q_1}$ is producible given $\tilde{x}$, The single-product production function $F(x)$ - the production frontier - is defined as:

$$q^* = F(x) \equiv max\{q \,|\, (q, x) \in T\}.$$

$F(x)$ admits some well-known testable properties. If inputs are *freely disposable* then an output level achieved with the vector of inputs x' can always be achieved with a vector of inputs x'' where $x'' \geq x'$. This implies the production function is weakly increasing in inputs (Diewert (1973)). The production function $F(x)$ should also be concave in the freely variable inputs holding fixed inputs constant and it should be quasi-concave in the fixed inputs holding the freely variable inputs constant (Lau (1976)).

3.2 Multi-Product Firms

With M outputs and N inputs the firm's production possibilities set T lives on the non-negative orthant of R^{M+N}. It contains all of the combinations of M non-negative outputs $q = (q_1, q_2, \dots, q_M)$ that can be produced by using N non-negative inputs $x = (x_1, x_2, \dots, x_N)$ so if $(\tilde{q}, \tilde{x}) \in T$ then $\tilde{q} = (\tilde{q_1}, \dots, \tilde{q_J})$ is achievable using $\tilde{x} = (\tilde{x_1}, \dots, \tilde{x_N})$. For good j produced by the firm let the output production of other goods be denoted by q_{-j}. For any (q_{-j}, x), if $max\{q_j \,|\, (q_j, q_{-j}, x) \in T$ is finite, then Diewert (1973) defines the multi-product production function as

$$q_j^* = F_j(q_{-j}, x) \equiv max\{q_j \,|\, (q_j, q_{-j}, x) \in T\}.$$

If no positive output of q_j is possible given (q_{-j}, x) then he assigns

$$F_j(q_{-j}, x) = -\infty.$$

We develop the properties of $F_j(q_{-j}, x)$ under a mix of assumptions from Diewert (1973) and Lau (1976).

We follow Lau (1976) and divide outputs and inputs (q_{-j}, x) into those that are variable v in the short-run and those that are not, denoted by K. We sometimes abuse notation by expressing (q_{-j}, x) as (v, K) and by writing $F_j(v, K)$.

We assume the production possibilities set T satisfies the following five *Conditions P*:

(i) P.1 T is a non-empty subset of the non-negative orthant of R^{M+N}

(ii) P.2 T is closed and bounded,

(iii) P.3 If $(q, x_k, x_{-k}) \in T$ then $(q, x'_k, x_{-k}) \in T\ \forall x'_k \geq x_k$.

(iv) P.4 If $(q_j, q_{-j}, x) \in T$ then $(q'_j, q_{-j}, x) \in T\ \forall q'_j$ such that $0 \leq q'_j \leq q_j$.

(v) P.5 The sets $T^K = \{v \,|\, (v, K) \in T\}$ are convex for every K; the sets $T^v = \{K \,|\, (v, K) \in T\}$ are convex in K for every v.

Conditions (i) and (ii) are weak regularity conditions on T that are not testable. Condition (iii) is the free disposal condition again but now on inputs conditional on outputs; it says if you can produce q_j given (q_{-j}, x) then you can produce q_j with any $x^{'} \geq x$. Condition (iv) is a similar free disposal condition on outputs that says if you can produce q_j given (q_{-j}, x) then you can produce any level of output $q_j^{'}$ of good j such that $0 \leq q_j^{'} \leq q_j$ given (q_{-j}, x). Diewert (1973) uses these free disposal conditions to prove that output is weakly increasing in any input holding all other inputs and outputs constant, and that output of good j is weakly decreasing in any other one output holding all other outputs and inputs constant.

Diewert (1973) shows if the production possibilities set T is convex the production function is concave in the inputs and the negative of outputs, ruling out the possibility of increasing returns to scale. Condition (v) (Lau (1976)) weakens full convexity on T to disjoint biconvexity, where convexity holds but only on two subsets of goods, the freely variable inputs v holding fixed inputs K constant, and the subset of fixed variables K holding freely variable inputs v constant. This setup allows for the possibility of overall increasing returns to scale - non-convexities in T - while allowing for decreasing marginal rates of substitution between inputs/outputs in v or inputs/outputs in K. Convexity in the flexible inputs/outputs v (conditional on any K) results in a production function that is concave in v holding K constant. For the fixed inputs/outputs K convexity in K given v results in the production function being quasi-concave in K given v.

The following theorem formalizes the above claims.

Theorem 3.1 (The Transformation Function) *Under P.1-P.5 the function $F_j(q_{-j}, x)$ is an extended real-valued function defined for each $(q_{-j}, x) \geq (0_{M-1}, 0_N)$ and is non-negative on the set where it is finite. $F_j(q_{-j}, x)$ is non-decreasing in x holding q_{-j} constant and non-increasing in q_{-j} holding x constant. $F_j(v, K)$ is concave in v for all K and quasi-concave in K for all v.*

See the Appendix. The existence result of the multi-product production function motivates its estimation, where one quantity is posited as a function of each of the total input levels used at the firm for all production and each of the other quantities of output produced by the firm. It also motivates several possible tests of the specification, including testing to see that inputs enter positively and outputs enter negatively in the production function.

3.3 Testing Single-product Production Approximations

We propose a test for whether multi-product production can be represented as a collection of single-product production functions. Total firm inputs used for all goods produced by any multi-product firm - what is reported in data - must be allocated across the single product production functions prior to estimation. Foster, Haltiwanger, and Syverson (2008) use product-output revenue shares to do so and De Loecker, Goldberg, Khandelwal, Pacvnik (2016) use input optimization. Definition 3.2 states the conditions under which SPPA holds in the settings of Foster et. al. (2008), De Loecker et. al. (2016), and any other setting where the input allocation rule *adds up* to the total input usage reported by the multi-product firm.

Definition 3.2 (Single-Product Production Approximation (SPPA)) *Multi-product production of M goods can be written as a series of M single-product production functions*

$$f_j : R^N \to R^1 \quad j = 1, \ldots, M$$

if

$$\forall\, (q_1, \ldots, q_M, x_1, \ldots, x_N) \in T$$

there exists input tuples $(x_{j1}, \ldots, x_{jN})_{j=1}^{M}$ satisfying

$$\sum_{j=1}^{M} x_{j1} = x_1, \ldots, \sum_{j=1}^{M} x_{jN} = x_N$$

and

$$q_j = f_j(x_{j1}, \ldots, x_{jN}) \quad j = 1, \ldots, M.$$

In contrast to the multi-product production function a necessary condition for Definition 3.2 to be satisfied is - conditional on the allocated inputs - (any function of) other own-firm instrumented outputs should not enter significantly in the single-product production function. We test the SPPA in our setting by including instrumented outputs in our single-product production specifications.

4 Functional Forms for Production

We describe simple Cobb-Douglas approximations first for the two-product case and then for the general multi-product case. Diewert (1973) argues for a trans-log specification and we add quadratic terns in our robustness section. We also revisit input and output indices.

4.1 2-Product Case

Dhyne, Petrin and Warzynski (2014) look at the bread and cakes industry in Belgium, where most firms that produce one also produce the other. With all variables in logs let q_{Bt} and q_{Ct} denote the output quantities of bread and cakes respectively, and let l_t, k_t, and m_t denote the three inputs labor, capital and materials. Tthe production function for bread is given as a function of inputs and cake production:

$$q_{Bt} = \beta_0 + \beta_l^b l_t + \beta_k^b k_t + \beta_m^b m_t + \gamma_C q_{Ct} + \varepsilon_{Bt} \tag{1}$$

with the production parameters $\beta^b = (\beta_l^b, \beta_k^b, \beta_m^b)$ denoting the percentage change in bread output due to a one percent change in any one input holding other inputs and cake output constant. γ_C is the percent change in bread output that results from increasing the output of cake by one percent holding overall input use constant. Similarly, the production function for cakes is given as

$$q_{Ct} = \beta_0 + \beta_l^c l_t + \beta_k^c k_t + \beta_m^c m_t + \gamma_B q_{Bt} + \varepsilon_{Ct} \tag{2}$$

with the production parameters $\beta^c = (\beta_l^c, \beta_k^c, \beta_m^c)$, and γ_B. Inputs and outputs are endogenous in this two equation system. Theorem 3.1 says that all six input coefficients should be positive and the two output coefficients should be negative.

4.2 M-Product Case

With all variables in logs the general M product system of production equations is given as:

$$q_{jt} = \beta_0^j + \beta_l^j l_t + \beta_k^j k_t + \beta_m^j m_t + \gamma_{-j}^j{}' q_{-jt} + \varepsilon_{jt} \quad j = 1 \cdots M \tag{3}$$

where q_{-jt} denotes the $M-1$ column vector of all other outputs excluding q_j and γ^j_{-j} denotes the $M-1$ row vector of output elasticities for all other products excluding j. The vector of input production parameters is given by $\beta^j = (\beta^j_l, \beta^j_k, \beta^j_m)$. Theorem 3.1 says the multi-product production function is only well-defined when $\beta^j > 0$ and $\gamma^j_{-j} < 0$. Again all inputs and outputs are simultaneously determined and will therefore need to be instrumented.

4.3 Input and Output Indices

Most firms produce output using only some of all available inputs recorded in disaggregated firm-level input data. An implication of Theorem 3.1 is different input tuples represent different production functions, but estimating separate production function parameters for each input tuple places prohibitively high demands on the data. In our data the same issue arises with multiple outputs as firms in our 2-digit industries produce only a small number of all possible goods in that 2-digit category.

In order to circumvent this "zeros" issue researchers have aggregated across inputs within firms to create a smaller number of non-zero input aggregates, like capital, intermediate inputs, or labor.[9] Suppose there are G goods over which to aggregate denoted $(m_1, \ldots, m_G)$ and let Q_{m_g} denote quantity used (or produced) of good m_g (we suppress the time index). The input index q^* that is almost universally used weights the quantity of the input by the input's price P_{m_g}:

$$q^* = log(\sum_{g=1}^{G} P_{m_g} Q_{m_g}).$$

In place of estimating the G unrestricted coefficients β_g $g = 1, \ldots, G$ on $log(Q_{m_g})$ $g = 1, \ldots, G$, only one coefficient β^G associated with the quantity index q^* is estimated. Letting $s_l = \frac{P_{m_g} Q_{m_l}}{\sum_{g=1}^{G} P_{m_g} Q_{m_g}}$ the index achieves this parsimony by restricting the elasticity of output with respect to input l (β_l) to be proportional to β^G:

$$\beta_l = s_l * \beta^G, \;\; l = 1, \ldots G.$$

so an input with twice the expenditure share of another input in the input category will have twice the output elasticity. We use this index for all of our inputs.

[9] Capital is an aggregate mix of the value of different kinds of machines, buildings, and/or vehicles used by the firm. The intermediate input aggregate sums across all kinds of different materials weighting by their price. Labor is also sometimes aggregated by weighting the different labor types with their wage to get the labor aggregate.

We construct two output aggregators for the production function for q_j. One is the analog to the input aggregator and is given by

$$q^*_{-j} = log(\sum_{g \neq j} P_{m_g} Q_{m_g}).$$

with the only difference being that it excludes good j. The second index sums all units of the goods and then takes logs:

$$q^*_{-j} = log(\sum_{g \neq j}^{G} Q_{m_g}),$$

where s_l is given as $s_l = \frac{Q_{m_l}}{\sum_{g=1}^{G} Q_{m_g}}$, The estimating equations become

$$q_{jt} = \beta_0^j + \beta_l^j l_t + \beta_k^j k_t + \beta_m^j m_t + \gamma_{-j}^j q^*_{-jt} + \varepsilon_{jt} \quad j = 1 \cdots M \tag{4}$$

where now there is only one coefficient γ_{-j}^j to estimate for each good j.

The output-side aggregation restriction is analogous to the input-side restriction. Consider a firm that produces good k and k' in addition to producing good j. If we use the first index then if good k generates twice as much of the firm's revenue as good k' then the (negative) elasticity of output of good j with respect to good k will be twice as large in absolute value as good k'.[10] If we use the index based only on quantities then to produce an extra unit of good k holding all other inputs and outputs constant the firm would have to give up twice as much unit-output of good j as it would if it had to produce another unit of k'.

5 Estimation

To address the issue of simultaneity (Marschak and Andrews (1944)) we extend the Wooldridge (2009) formulation of Olley and Pakes (1995) (OP) and Levinsohn and Petrin (2003) to the multi-product production setting by allowing for one technical efficiency shock for each product made by the firm.

5.1 Single-product production setting

In the single product case we have for q_t:

$$q_t = \beta_l l_t + \beta_k k_t + \beta_m m_t + \omega_t + \epsilon_t \tag{5}$$

[10] Roberts and Supina (2000) use a similar quantity index when they estimate cost functions.

where we have replaced the shock with its two components, i.e. $\varepsilon_t = \omega_t + \eta_t$. ϵ_t is assumed to be i.i.d. error upon which the firm does not act (like measurement error or specification error). ω_t is the technical efficiency shock, a state variable observed by the firm but unobserved to the econometrician. ω_t is assumed to be first-order Markov and is the source of the simultaneity problem as firm observe their shock before choosing their freely variable inputs l_t and m_t. k_t also responds to ω_t but with a lag as investments made in period $t-1$ come online in period t. This assumption allows k_t to be correlated with expected value of ω_t given ω_{t-1}. as ω_{t-1} - denoted $E[\omega_t|\omega_{t-1}]$ - but maintains that the innovation in the productivity shock $\xi_t = \omega_t - E[\omega_t|\omega_{t-1}]$ is unknown at the time the investment decision was made in $t-1$ and is therefore uncorrelated with current k_t.

The control function approaches of OP and LP both provide weak conditions under which there exists a proxy variable $h_t(k_t, \omega_t)$ that is a function of both state variables and that is monotonic in ω_t given k_t. The variables may include either investment (OP) or materials, fuels, electricity, or services (LP) (e.g.). Given the monotonocity there exists some function $g(\cdot)$,

$$\omega_t = g(k_t, h_t)$$

allowing ω_t to be written as a function of k_t and h_t. Wooldridge (2009) uses a single index restriction to approximate unobserved productivity, writing

$$\omega_t = g(k_t, h_t) = \mathbf{c}(k_t, h_t)'\beta_\omega$$

where $\mathbf{c}(k_t, h_t)$ is a known vector function of (k_t, h_t) chosen by researchers with parameter vector β_ω to be estimated. The conditional expectation $E[\omega_t|\omega_{t-1}]$ can then be written as

$$E[\omega_t|\omega_{t-1}] = f(\mathbf{c}(k_{t-1}, h_{t-1})'\beta_\omega)$$

for some unknown function $f(\cdot)$, which Wooldridge (2009) approximates using a polynomial.

Replacing ω_t with its expectation and innovation, the estimating equation becomes

$$q_t = \beta_l l_t + \beta_k k_t + \beta_m m_t + E[\omega_t|\omega_{,t-1}] + \xi_t + \epsilon_t \tag{6}$$

For expositional transparency we use only the first-order approximation term for $f(\cdot)$, which yields our error term

$$[\xi_t + \epsilon_t](\theta) = q_t - \beta_l l_t - \beta_k k_t - \beta_m m_t - \mathbf{c}(h_{t-1}, k_{t-1})'\beta_\omega \tag{7}$$

with the parameters to $\beta = (\beta_l, \beta_k, \beta_m, \beta_\omega)$.[11]

[11]The first-order approximation would add another parameter in front of $\mathbf{c}(h_{t-1}, k_{t-1})'\beta_\omega$ but this parameter is already subsumed in β_ω and is therefore not separately identified.

We formulate the moment condition using materials m_t as the proxy but any other available proxy cited above could also be used here. The only change would be the set of conditioning variables. For the special case when m_t is the proxy a sufficient set of conditioning variables given as (e.g.) $x_t = (k_t, k_{t-1}, m_{t-1}, m_{t-2}, l_{t-1})$. Let θ_0 denote the true parameter value. Wooldridge shows that the conditional moment restriction

$$s(x_t;\theta) \equiv E[[\xi_t + \epsilon_t](\theta)|x_t] \text{ and } s(x_t;\theta_0) = 0$$

is sufficient for identification of β in the single product case (up to a rank condition on the instruments).[12] In equation (10) a function of m_{t-1} and k_{t-1} conditions out $E[\omega_t|\omega_{t-1}]$. ξ_t is not correlated with k_t, so k_t can serve as an instrument for itself. Lagged labor l_{t-1} and twice lagged materials m_{t-2} serve as instruments for l_t and m_t.

5.2 Multi-product production setting

In the multi-product case we have a system of M_t output equations:

$$q_{jt} = \beta_0^j + \beta_l^j l_t + \beta_k^j k_t + \beta_m^j m_t + \gamma_{-j}^j{}' q_{-jt} + \varepsilon_{jt} \quad j = 1 \cdots M \tag{8}$$

We denote the vector of technical efficiency shocks as $\omega_t = (\omega_{1t}, \omega_{2t}, \ldots, \omega_{M_t})$. Choices of inputs will now generally be based not only on ω_{jt} but also on all of the other technical efficiency shocks ω_{-jt}. This frustrates the "inverting out" of ω_t that allows one to express ω_t as a function of k_t and a single proxy h_t as is done in the single product case.

We adopt suggestions from Petropoulos (2001) and Ackerberg, Benkard, Berry, and Pakes (2007) to allow for multiple unobserved technical efficiency shocks. Suppose we observe (at least) one proxy variable for every technical efficiency shock. Let $\mathbf{h}_t = (h_{1t}, \ldots, h_{Lt})$ denote the $1XL$ vector of available proxies. Each of these variables will generally be a function of k_t and $(\omega_{1t}, \omega_{2t}, \ldots, \omega_{M_t})$ and we write $\mathbf{h}_t(k_t, \omega_t)$. If the multivariate function $\mathbf{h}_t(k_t, \omega_t)$ is a bijection in ω_t conditional on k_t - one-to-one and onto - then we can invert the proxy variables to get the $1XL$ vector of functions $\omega_t = \mathbf{g}(k_t, \mathbf{h}_t)$. Included in this vector of functions is

$$\omega_{jt} = g_j(k_t, \mathbf{h}_t), \quad j = 1 \cdots M$$

which then motivates including a function of (k_t, h_t) in the estimation to control for ω_{jt}.

The rest of the estimation proceeds in a manner similar to the single-product case. We use the same single index restriction to approximate unobserved productivity, so we have

$$\omega_{jt} = g_j(k_t, \mathbf{h}_t) = \mathbf{c}_j(k_t, \mathbf{h}_t)'\beta_{\omega_j}$$

[12] The Wooldridge formulation is robust to the Ackerberg, Caves, and Frazer (2015) criticism of OP/LP.

where $\mathbf{c}_j(k_t, \mathbf{h}_t)$ is a known vector function of $(k_t, \mathbf{h}_t)$ chosen by researchers. $E[\omega_{jt}|\omega_{t-1}]$ is now given as

$$E[\omega_{jt}|\omega_{t-1}] = f_j(\mathbf{c}_j(k_{t-1}, \mathbf{h}_{t-1})'\beta_{\omega_j})$$

for some unknown function $f_j(\cdot)$. Again we use only the first-order approximation term for $f_j(\cdot)$ to keep exposition to a minimum.

Re-expressing in terms of firm's expectations we have

$$q_{jt} = \beta_l^j l_t + \beta_k^j k_t + \beta_m^j m_t + \gamma_{-j}^j{\prime} q_{-jt} + E[\omega_{jt}|\omega_{t-1}] + \xi_{jt} + \epsilon_{jt} \tag{9}$$

with $\xi_{jt} = \omega_{jt} - E[\omega_{jt}|\omega_{t-1}]$. The error is

$$[\xi_{jt} + \epsilon_{jt}](\theta) = q_{jt} - \beta_l^j l_t - \beta_k^j k_t - \beta_m^j m_t - \gamma_{-j}^j{\prime} q_{-jt} - \mathbf{c}_j(k_{t-1}, \mathbf{h}_{t-1})'\beta_{\omega_j}$$

with the new parameters γ_{-j}^j added to $\beta^j = (\beta_l^j, \beta_k^j, \beta_m^j, \gamma_{-j}^j, \beta_{\omega_j})$.

An additional key difference from the single product case is the need for instruments for q_{-jt}, which might either be lagged values of q_{-jt} or inputs lagged even further back. Let the set of conditioning variables be given as (e.g.) $x_{jt} = (q_{-j,t-1}, k_t, k_{t-1}, \mathbf{h}_{t-1}, m_{t-1}, l_{t-1})$.[13] Let θ_0 denote the true parameter value. The conditional moment restriction

$$s(x_{jt};\theta) \quad \equiv \quad E[[\xi_{jt} + \epsilon_{jt}](\theta)|x_{jt}] \text{ and } s(x_{jt};\theta_0) = 0$$

continues to be sufficient for identification of β as long as a rank condition holds.

5.3 Example: Two product case

In the case of two-product production we have an equation for good 1

$$q_{1t} = \beta_l^1 l_t + \beta_k^1 k_t + \beta_m^1 m_t + \gamma^1 q_{2t} + \omega_{1t} + \epsilon_{1t} \tag{10}$$

and an equation for good 2

$$q_{2t} = \beta_l^2 l_t + \beta_k^2 k_t + \beta_m^2 m_t + \gamma^2 q_{1t} + \omega_{2t} + \epsilon_{2t}. \tag{11}$$

We use as our two proxies investment and materials, and we write these input demands as $i_t(k_t, \omega_{1t}, \omega_{2t})$ and $m_t = m(k_t, \omega_{1t}, \omega_{2t})$. If the bivariate function (i_t, m_t) is one-to-one and onto with $(\omega_{1t}, \omega_{2t})$ then this bivariate bijection can be inverted and there exist functions $g_1(\cdot)$ and $g_2(\cdot)$ such that $\omega_{1t} = g_1(k_t, i_t, m_t)$ and $\omega_{2t} = g_2(k_t, i_t, m_t)$. For either j we approximate

$$\omega_j = g_j(k_t, i_t, m_t) = \mathbf{c}_j(k_t, i_t, m_t)'\beta_{\omega_j}$$

[13]If h_t contains m_t (l_t) then one would add m_{t-2} (l_{t-2}) to the conditioning set.

where $\mathbf{c_j}(k_t, i_t, m_t)$ is a known vector function of (k_t, i_t, m_t) chosen by researchers. The nonparametric conditional mean function for either j is given as

$$E[\omega_{jt}|\omega_{t-1}] = f_j(\mathbf{c_j}(k_{t-1}, i_{t-1}, m_{t-1})'\beta_{\omega_j}) \quad j = 1, 2$$

for some unknown functions $f_1(\cdot)$ and $f_2(\cdot)$. The error now becomes

$$[\xi_{jt} + \epsilon_{jt}](\theta) = q_{jt} - \beta_l^j l_t - \beta_k^j k_t - \beta_m^j m_t - \gamma_{-j}^j q_{-jt} - f_j(\mathbf{c_j}(k_{t-1}, i_{t-1}, m_{t-1})'\beta_\omega) \quad j = 1, 2.$$

Let the set of conditioning variables be given as (e.g.) $x_{jt} = (q_{-j,t-1}, k_t, k_{t-1}, i_{t-1}, m_{t-1}, m_{t-2})$. Let θ_0 denote the true parameter value. The conditional moment restrictions for each equation are given as

$$s(x_{jt}; \theta) \quad \equiv \quad E[[\xi_{jt} + \epsilon_{jt}](\theta)|x_{jt}] \text{ and } s(x_{jt}; \theta_0) = 0 \quad j = 1, 2.$$

6 The link between technical efficiency improvements, import competition, and changes in gross output

We estimate three different specifications to investigate the relationship between technical efficiency andmport shares.. We use the import share net of re-exporting for our preferred results and show robustness of our results to our second import share index. We also discuss the mapping of changes import shares into the implied immediate long-term changes in the value of output due to these changes in competition.

In our first specification, we regress current firm-product technical efficiency on last quarter's technical efficiency and last quarter's import share, including 8-digit product indicator variables (ν_j), and year-quarter indicator variables (δ_t),

$$\omega_{ijt} = \rho\, \omega_{ij(t-1)} + \alpha_1 IS_{j(t-1)} + \nu_j + \delta_t + \eta_{ijt} \tag{12}$$

where η_{ijt} denotes the innovation in the firm-product technical efficiency conditional on last period's technical efficiency, import share, and the time and product fixed effects.

We map changes in import shares into changes in output as follows. Letting Δ denote the one period change operator. The units of the technical efficiency term are in the units of output, so the immediate short term impact on the growth rate of output induced by $\Delta IS_{j(t-1)} = IS_{j(t-1)} - IS_{j(t-2)}$ is given by $\Delta\omega_{ijt} = \alpha_1\, \Delta IS_{j(t-1)}$. An approximation to the short-term value of this change is then given by

$$PQ_{ijt} * \alpha_1\, \Delta\omega_{ijt},$$

where PQ_{ijt} denotes our approximation to the average revenue from period $t-1$ to t generated by the particular product. Alternative approximations might use last periods revenue or the simple average of this period's revenue and last period's revenue. Finally, if the AR(1) term ρ is greater than zero but less than one then this suggests approximating the long-term change in the value of output - denoted $\Delta Value_{ijt}$ - as

$$\Delta Value_{ijt} = \frac{PQ_{ijt} * \alpha_1 \, \Delta IS_{j(t-1)}}{(1-\rho)}. \tag{13}$$

Once we have estimates of α_1 and ρ we can compute this quantity for every firm-product in every time period.

In our second specification we include indicator variables that denote the revenue rank of the product in the firm's portfolio to investigate whether within-a-firm product rank and technical efficiency are correlated. The omitted variable is the core (highest revenue) product, $Rank^2_{ijt}$ is an indicator for the second product, $Rank^3_{ijt}$ is an indicator for the third product, and $Rank^4_{ijt}$ is an indicator that is equal to one for any product ranked lower than third. The estimation equation is

$$\omega_{ijt} = \rho \, \omega_{ij(t-1)} + \alpha_1 IS_{j(t-1)} + \sum_{k=2}^{4} \alpha_k Rank^k_{ijt} + \nu_j + \delta_t + \eta_{ijt} \tag{14}$$

Note that $\Delta Value_{ijt}$ in this setup is exactly the same as in the first setting above.

In our third specification we interact these rank indicators with the lagged product-level import shares in order to investigate whether the competitive effects vary by product rank. This will also allow for the $\Delta Value_{ijt}$ to vary by product rank holding the change in import share constant. The estimation equation is given as

$$\omega_{ijt} = \rho \, \omega_{ij(t-1)} + \alpha_1 IS_{j(t-1)} + \sum_{k=2}^{4} (\alpha_k + \alpha_{3+k} IS_{j(t-1)}) \, Rank^k_{ijt} + \nu_j + \delta_t + \eta_{ijt}. \tag{15}$$

For a product that ranks first the formulation for $\Delta Value_{ijt}$ remains as above but for a product that ranked (e.g.) second in revenues in a firm's portfolio the new expression for $\Delta Value_{ijt}$ is given as

$$\Delta Value_{ijt} = \frac{PQ_{ijt} * (\alpha_1 + \alpha_5) \, \Delta IS_{j(t-1)}}{(1-\rho)}, \tag{16}$$

and similarly for other lower ranking products.

We estimate these equations using ordinary least squares and using instrumental variables for the import share for a total of six primary specifications. As noted in De Loecker (2013), we could have estimated all of these parameters in one step along with the production function parameters to achieve possible efficiency gains. We did not do so because the one-step approach does not make apparent the quality of the instruments for the import share and we want the first stage F-statistic test for weak instruments to be very transparent. Also, in our results most of our production function estimates and our estimates from the equations above are fairly precise.

6.1 Instruments for Import Share

The import shares that enter into equations 7-9 are functions of the quantities of imports at the 8-digit level. If these quantities are correlated with the *innovations* in the firm-product technical efficiencies after controlling for last period's technical efficiency shock and time and 8-digit product-level fixed effects then we need instruments that are correlated with the shares but uncorrelated with the innovations. For example, if imports shares are increasing in 8-digit product categories in which domestic producers are becoming less technically efficient then import shares will be negatively correlated with the technical efficiency shocks, biasing the effect of import competition on technical efficiency down.

We use two different instruments. Our first instrument for the import share makes use of tariffs obtained from the World Bank WITS website.[14] Over our sample time period the "effectively applied tariffs" on Chinese goods applied by the European Union are significantly reduced for many goods as a result of China's entry into the World Trade Organization.[15] The World Bank aggregates tariffs to the HS6 level and we use this same HS6-level tariff for all 8-digit level goods in that category.[16] In the spirit of Hummels et. al. (2014) we focus more on HS6-level product categories where China has a significant pre-sample presence by weighting the HS6-level tariffs by the import share of China at the HS6 level in 1995.

Our second instrument is also based on Hummels et. al (2014). For each good j at time t we calculate the total world exports net of those coming from Belgium using the BACI database from CEPII.[17] This variable includes world-wide shocks to export supply for good j that vary over time and products. Positive shocks to world export supply for good j - like decreases in transportation costs for the good - should be positively correlated with the total import share of good j in Belgium. World export supply net of Belgium exports is a valid instrument for the import share if the world-wide supply shocks are uncorrelated with the *innovations* in firm-product technical efficiencies. This condition is a slightly weaker condition than required by Hummels et al (2014) where the *levels* of productivity must be uncorrelated with the world-wide shock holding other

[14]See *http://wits.worldbank.org/wits/wits/witshelp/Welcome.htm.*

[15]From the WITS website "WITS uses the concept of effectively applied tariff which is defined as the lowest available tariff. If a preferential tariff exists, it will be used as the effectively applied tariff. Otherwise, the MFN applied tariff will be used."

[16]We use conversion tables from Eurostat to identify the HS6-level product category to which each of our 8-digit level PRODCOM goods' belongs.

[17]BACI is the World trade database developed by the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). The original data is provided by the United Nations Statistical Division (COMTRADE database). BACI is constructed using a harmonization procedure that enables researchers to link import shares directly to HS 6-digit product disaggregation level.

controls constant.

7 Results

We report multi-product production function estimates and then relate the implied firm-product technical efficiencies to changes in import penetration. We then map realized changes in import shares to changes in aggregate manufacturing output. We compare our findings with what we would find if instead we used the single product production approximation to multi-output production.

7.1 Estimation at the firm-product level

Our baseline production functions specifications are Cobb-Douglas with parameters assumed constant at the 2-digit industry level. All of our estimates include both 8-digit product indicator variables and year-quarter indicator variables for all XX quarters from 2000 to 2007.[18] We allow for the possibility of two unobserved technical efficiency terms by using both investment and materials as proxies, and we refer to this estimator as the Wooldridge-OPLP estimator. The quantity aggregate used in our main specifications is the log of the (real) total revenues of all the other goods but we also experiment with the log of total quantities of all other goods.

Table 3 reports the results of our production function estimates for the 12 largest 2-digit product groups, which represents 1,655 different 8-digit products or 70% of all products made in Belgium. Our largest product group is food and beverages with 52,573 firm-product-quarter observations while our smallest product group is electrical machinery with 4,437 firm-product-quarter observations.[19] The quantity aggregate coefficient is the correct sign (negative) and significant for all 12 industries and ranges between -0.082 for paper and -0.145 for apparel. The interpretation for apparel is that - holding all input levels constant at their current levels - an increase in the firm's apparel output index of one percent comes at the expense on average of 0.14 percent of the good under consideration. On the input side 29 out of 36 coefficients are statistically significant, 35 of the 36 coefficients have the correct (non-negative) sign, and in the one case where capital is negative it is not significant.

In the multi-product setting returns to scale can be defined in a variety of ways depending upon what feature of production is of interest. If we hold the other outputs constant and increase all inputs by one percent we get a range for most industries of an

[18] We include the own-product price control suggested in De Loecker et al (2016). Later we show our main findings are robust to not including price.

[19] The 2-digit PRODCOM product categories are the same as the European industry codes (NACE).

increase in output of the good under consideration between 0.8 and 1, which is the sum of the coefficients on all three inputs. Above we report that "returns" to output of a good If we hold inputs constant and increase the other-output index by one percent ranges from -0.08 to -0.14. If we increase all inputs and the output index by one percent - the sum of all coefficients - then we get a range of increases that principally lie between 0.7 and 0.9. In the single-product case researchers frequently report returns to scale close to one but comparisons to the multi-product case are frustrated by the fact that they are different function, the latter of which holds other outputs constant and the former of which does not.

7.2 The link between technical efficiency and import competition

Table 4 presents results from the OLS and IV regressions of technical efficiency on import shares. All specifications include 8-digit product indicators and quarterly-time indicator variables. Our ten alternative estimates for α_1 range from 0.84 to 1.17 and are all statistically significant.

7.2.1 Non-instrumented Results

In column 1 we regress firm-product technical efficiency (in logs) on lagged firm-product technical efficiency (in logs) and lagged product import share. Changes in import share are positively correlated with technical efficiency but the magnitude is small; the estimated value of α_1 from equation (12) is estimated to be 0.10, implying an increase of 10% in the import share with a 1.0% increase in firm-product technical efficiency. Since the average change in shares is 4.7%, this OLS estimate suggests import competition has played a relatively minor role in promoting economic growth.

We find a high persistence in firm-product technical efficiency over time with a coefficient of 0.91 for lagged productivity that is statistically significant at 1%. This estimated value for ρ is approximately the same for all of the OLS and IV specifications we have estimated and it suggests changes in technical efficiency are long-lived.

In column 2, we investigate whether the technical efficiency associated with a product is related to the share of revenue that the product generates for the firm by including share-rank indicators. The left out good is the firm's "core" product, that is, the product that generates the most revenue for the firm. Products that generate less revenue are not produced in as technically efficient a manner, with the second ranking product's technical efficiency 9.3% less than the core product, the third ranking product 20.9% less, and the fourth and above ranked products 32.3% less. All rank indicator variables are statistically significant at 1%. While the exact magnitudes of these differences do vary across our OLS and IV specifications the finding of this ordering of technical efficiencies by share-rank is very robust.

Column 3 adds interactions between import share and the rank of the product to test whether the magnitude of the change in technical efficiency due to a change in import shares varies by share-rank. The lead coefficient α_1 is still small at 0.12 and significant at 1% and slightly higher than in the previous specifications, where it represented the average effect across all products. The interactions between import share and product rank are all negative, with -0.01 for the second product (but not statistically significant), -0.03 for the third product (significant at 1%) and -0.12 for products ranked more than 3 (significant at 1%). Thus the OLS results suggest changes in import shares impact the first, second, and third products similarly but do not affect products ranked higher than three.

7.2.2 Instrumented Results

Columns 4, 5, and 6 are the IV analogs to columns 1-3. They use the same price-weighted quantity index in the W-OPLP production function estimation. Our first-stage F-statistics from the regressions of import shares on our two instruments reject the hypothesis of weak instruments at the 1% level in all three IV regressions.

Column 4 shows estimates from the regression of technical efficiency on last period's technical efficiency and the lagged instrumented import share. Relative to column 1 the estimate of α_1 increases almost *ninefold* from 0.10 to 0.87 and is significant at the 10% level. When we add the share-rank indicators in column 5 the estimate of α_1 goes up to 0.99 and is significant at the 5% level. When we add the interactions of the share-rank indicators with the instrumented lagged import share in column 6 the estimate of α_1 climbs to 1.05 and remains significant at 5%. The increase from 0.12 to 1.05 when we move from OLS to IV is consistent with lagged import penetration being higher in product markets where domestic innovations in technical efficiency are lower (and vice versa).

In column 6 the coefficients on the share-rank indicators decrease only a bit relative to OLS. However the coefficients on the interactions tell a different story from OLS as all products - regardless of the product revenue ranking - have technical efficiency increasing in response to increases in import competition. A 1% increase in the lagged import share is associated with a 1% percent increase in technical efficiency in the current period of both the first and second ranked products and a 0.65% increase in technical efficiency of all other products produced by the firm. All three coefficients are statistically significant at 1%. Recall that this impact is only the short-term effect because the estimated AR(1) coefficient is 0.89 and strongly significant.

Column 7 presents the first of ten robustness checks. We estimate the production function parameters with the W-OPLP estimator but using the unweighted quantity index instead of the price-weighted quantity index. The estimated coefficient on α_1 drops slightly to 1.01 and remains significant at the 5% level. The remaining point estimates are very similar to those from column 6. Table 5 and table A1 contain the other nine robustness checks. The estimates for α_1 range from 0.84 to 1.17 and seven of the nine are significant at the 5% level (the other two are significant at the 10% level). For the most part the other coefficients are very similar across these specifications. Readers not interested in these details can skip directly to Section 7.3.

For comparison Column 1 of table 5 reprints the results from our preferred specification (column 6 of table 4). All nine specifications use the price-weighted quantity index, and except for columns 2 and 3, all of these specifications estimate the production function parameters with the W-OPLP estimator. In column 2 we estimate the production function but address simultaneity using just materials as the proxy (the Wooldridge-LP estimator). We find an estimate of α_1 of 1.06. In column 3 we ignore simultaneity and use OLS to estimate the production function parameters. We find the estimated coefficient is 0.84, the lowest of all of our alternative estimates. Column 4 uses our alternative measure of the import share that does not adjust for re-export. For this specification we estimate a value of α_1 of 0.93. Column 5 does not include the product's output price in the estimation of the production functions and we find an estimate of 0.89 for α_1. Column 6 allows the price-weighted quantity index and its squared value to enter the production function during estimation, as argued by Diewert (1973), and the coefficient increases to 1.17, the largest estimate of α_1 across all eleven specifications.

We currently pool single and multi-product firms. Column 1 of table A1 reports results for only multi-product firms and Column 2 uses both single- and multi-product firms - the full sample - but includes an indicator variable for multi-product firms in the import share regression. The respective α_1's are 1.08 and 1.11 and both are significant at the 5% level.

Firms that are active in international markets may respond differently to increases in import competition relative to those that only sell in the domestic market. Column 3 of table A1 includes two indicator variables, one for whether the firm producing the product imports and one for whether they export. The estimate of α_1 is 1.02 and significant at the 5% level. Column 4 of table A1 includes two indicator variables, one for whether the firm imports goods in the same 8-digit category as the good it is producing and one for whether it exports that particular good. Both variables are lagged by one quarter. The estimate is 1.01 and again significant.[20]

7.3 Changes in the Value of Output due to Changes in Import Competition

Equation 16 shows how we translate changes in import shares into changes in the value of manufacturing output for any product j. The expected percentage change in technical efficiency in the current period due to a change in the lagged import share is given by multiplying our preferred estimate of α_1 of 1.05 by the change in the lagged import share for that 8-digit product category. We multiply this expected change in technical efficiency in the current period by the current revenue of the product to estimate the total expected change in product revenue this period. The AR(1) coefficient of 0.89 implies these changes are highly persistent and we account for future gains in technical efficiency by scaling up this estimated change in current revenue by $\frac{1}{1-0.89}$. By design the total lifetime change in revenues will be positive in years when the lagged import share increases and negative when the import share decreases.[21]

Table 6 reports the entire distribution of 65,242 changes in the long-run value of produced output due to changes in the previous period's input share from 1997-2007. There is a tremendous amount of dispersion in the changes in the value of output due to changes in import shares. Almost 35% of the realized changes are negative because import shares decrease in many cases (see Table 2). On average changes in prior year's input share leads to an increase in the long-run value of output of over 22 thousand euros. Across industries the largest average change is 96 thousand euros in Electrical Machinery followed by Apparel (75 thousand) and Basic Metals (71 thousand). The median changes in import shares are close to zero and this leads to the median changes in the value of output to be close to zero across all 11 2-digit industries. Both the positive and negative changes can be very large for products with the biggest revenues, as in industries like Machinery and Equipment, Basic Metals, and Electrical Machinery. Across these industries the 10th percentile of the distribution in these industries ranges between -1.8 to -2.5 million euros and the 90th percentile changes ranges between 2.2 and 2.5 million euros.

In table 7 we aggregate the positive and negative changes separately across industries in each year from 1997 to 2007. On average the value of increased output due to increases

[20] We also find two additional side results in line with previous papers in the literature. Firms that import appear to be slightly more efficient at making their goods (column 3), and exported goods appear to be produced slightly more efficiently as well (column 4).

[21] We did not have enough variation to allow for precise estimation of different coefficients on increases and decreases in import shares but we could not reject that they were significantly different from one another.

in import shares ranges from 1.1 to 1.4 billion euros in any given year and the decreases range from -1.1 to -1.4 billion euros. These numbers are not small relative to the overall average annual total value of real output in Belgian manufacturing of 55 billion euros. The net changes in every year are positive except for 1997 and most years range from between 100 and 300 million euros. Aggregating over the entire sample period the overall gain in the value of output due to increased import competition is on the order of 1.4 billion euros, almost 2.5% of average annual output.

7.4 Single-product production approximation to multi-product production

We investigate whether our findings change if we use the single-product (SP) production approximation. We allocate inputs to the SP production functions in proportion to the good's revenue share. We estimate the SP production functions with results reported in table A3. We then calculate the implied technical efficiencies and rerun our main import share regressions from table 4 and report these results in table 8.

If we think of the multi-product setting as generalizing the SP approximation, the SP approach will add measurement error to the estimates of technical efficiency. Our results are largely consistent with this hypothesis as many specifications have coefficients that appear to be attenuated towards zero relative to our preferred specifications in table 4. The coefficients on the lagged import share in the OLS specifications are about half of their magnitude at 0.05 and 0.06 down from 0.10 but continue to be statistically significant.. Almost all of higher-order product terms are close to zero and are not significant in any of the OLS specifications.

Columns four through six instrument the import share. In column four with no other controls and also in column five with only the product-rank indicator variables the coefficient is 0.71 and significant at the 10% level. So despite possible measurement-error attenuation in these two specifications the SP approach accounts for almost 70% of the changes we find with our preferred specification (that coefficient is 1.05). However, once the interaction terms are added between the import share and the product ranking, the coefficient on the import share drops to 0.45 and is no longer significant. All of the interaction terms in this specification are close to zero and insignificant.

We close by testing whether we can reject the SP production approximation using the test suggested in Section 3.3. We add the quantity index to the SP specification from table A3 to test for significance and report results in table A2. We find the point estimates across all twelve industries for labor, materials, and capital are virtually unchanged from table A3. However, in eight of twelve cases the instrumented quantity index enters significantly at the 1% level, rejecting the single product approximation.

8 Conclusion

We develop a new approach to estimate firm-product technical efficiencies for multi-product firms using detailed quarterly data on inputs and on the physical quantities of goods produced by firms. We use our estimates of 8-digit firm-product technical efficiencies to study the link between productivity and import competition. Our results show a strong positive relationship between firm-product technical efficiency and import competition, pointing towards the disciplinary effect of competition on efficiency. Over the sample period we find an aggregate effect on Belgian manufacturing of over $1.2 billion. Consistent with several theory models we find that firms are most technically efficient at the goods that generate them the most revenue. We also find that while all products' technical efficiencies benefit from increased competition, the "core" products experience the biggest increases in response to increased competition.

While our main finding is that increased import competition leads to higher productivity, we do not identify the exact channel through which firms generate these productivity gains. Therefore, our results as such provide indirect evidence in favor of recent extensions of multi product firms models that suggest that firms adapt their innovation strategy when facing trade liberalization (see e.g. Dhingra, 2013; Eckel et al., 2015). We leave this line of investigation for future research.

Appendix

The first two results are from Diewert (1973) and the last two results are from Lau (1976).

Proof of Theorem 3.1

Under P.1-P.5 $F_j(q{-}j, x)$ is

(1a) non-decreasing in x

Let $(q_{-g}, x) \geq (0_{M-1}, 0_N)$ and suppose $q_g^* = F(q_{-g}, x)$ is finite. Then $(q_g^*, q_{-g}, x') \in T \;\; \forall x' \geq x$ by free disposal. But $F(q_{-g}, x') \geq q_q^* = F(q_{-g}, x)$.

and

(1b) non-increasing in q_{-g}

Let $(q_{-g}, x) \geq (0_{M-1}, 0_N)$ and suppose $q_g^* = F(q_{-g}, x)$ is finite. Then $(q_g^*, q_{-g}, x) \in T$. Then $(q_g^*, q_{-g}^{'}, x) \in T \forall q_{-g}^{'} \leq q_{-g}$ by free disposal. Then $q_g^* \leq F(q_{-g}^{'}, x) \equiv max(q_g \,|\, (q_g, q_{-g}^{'}, x) \in T$. #

Under P.1-P.5 $F_j(v, , x)$ is

(2a) concave in $v \;\forall\; K$

Suppose $q_j^* = F(v_j, K) \;\; j = 1, 2$. Then $(q_j^*, v_j, K) \in T \;\; j = 1, 2$.

By convexity $(\lambda\, q_1^* + (1-\lambda) q_2^*, \lambda\, v_1 + (1-\lambda) v_2, K) \in T \;\; 0 < \lambda < 1$.

$$\begin{aligned} Then\ q^* &= F(\lambda\, v_1 + (1-\lambda) v_2, K) \\ &= max(q \,|\, (q, \lambda\, v_1 + (1-\lambda) v_2, K) \in T) \\ &\geq \lambda\, q_1^* + (1-\lambda) q_2^* \\ &= \lambda\, F(v_1, K) + (1-\lambda) F(v_2, K) \end{aligned}$$

(2b) quasi-concave in $K \;\forall\; v$

Suppose $q_j^* \equiv F(v, K_j)\ for\, j = 1, 2$. Then $(q_j^*, v, K_j) \in T\ for\, j = 1, 2$. Let $\tilde{q} = min(q_1^*, q_2^*)$. Then $(\tilde{q}, v, K_j) \in T\ for\, j = 1, 2$. Then convexity of T in $K \;\forall v$ implies $(\tilde{q}, v, \lambda K_1 + (1-\lambda) K_2) \in T\ for 0 < \lambda < 1$ With $K_\lambda \equiv \lambda K_1 + (1-\lambda) K_2$ we have

$$q_\lambda = F(v, K_\lambda) \geq \tilde{q} = min(F(v, K_1)\,,\, F(v, K_2).$$

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Table 1: Average share of a firm's revenue derived by its individual products, 1997 to 2007

Product ranking within a firm determined by its share of the firm's total revenue.

Number of products produced by the firm at the Prodcom 8-digit level

	1	2	3	4	5	More than 5	N
Product rank							
1	100	77.5	69.5	64.2	57.8	49.4	
2		22.5	23.0	23.5	23.6	22.4	
3			7.5	9.1	11.1	11.8	
4				3.2	5.3	6.7	
5					2.2	3.9	
6+						5.8	
Share of manufacturing output	26.4	19.0	12.8	11.7	4.1	26.0	100
# observations	59,510	33,955	15,078	9,246	4,906	12,119	134,814

Number of products produced by the firm at the Prodcom 2-digit level

	1	2	3	4	5	More than 5	N
Product rank							
1	100	82.1	74.4	74.1	63.8	65.4	
2		17.9	20.2	19.2	22.8	17.5	
3			5.4	5.1	7.9	9.3	
4				1.6	3.8	4.5	
5					1.6	3.1	
6+						0.2	
Share of manufacturing output	78.4	16.3	3.4	1.4	0.3	0.2	100
# observations	117,598	14,669	1,884	481	129	53	134,814

Note: For any product rank i each column j reports the average share (in %) of the i-th product in total output for firms producing j products.

Table 2: Changes in import share defined in terms of "re-export" corrected quantities (I_{2jt}) from 1997 to 2007 at the 8-digit product level

Distribution of changes reported for each 2-digit product category

Code	Product category	Mean	Mean (weighted)	10th	25th	Median	75th	90th	# products
24	Chemicals	0.027	0.073	-0.297	-0.098	0.002	0.140	0.381	240
15	Food and beverages	0.008	-0.015	-0.202	-0.096	0.004	0.098	0.228	215
28	Fabricated metal products	0.172	0.196	-0.176	0.001	0.122	0.389	0.575	103
29	Machinery and equipment	0.062	0.070	-0.290	-0.034	0.019	0.185	0.493	93
25	Rubber and plastic products	0.028	0.058	-0.284	-0.116	0.020	0.164	0.322	81
18	Apparel	0.114	0.194	-0.008	0.006	0.060	0.177	0.323	68
27	Basic metals	0.002	0.014	-0.303	-0.036	0.020	0.104	0.269	62
26	Non metallic mineral	0.090	0.038	-0.112	-0.007	0.047	0.193	0.347	49
21	Paper	0.047	-0.004	-0.270	-0.037	0.040	0.181	0.443	47
17	Textile	0.003	-0.030	-0.318	-0.186	0.002	0.112	0.372	45
31	Electrical machinery	0.064	0.022	-0.347	-0.062	0.028	0.193	0.478	29
	All products	0.051	0.043	-0.216	-0.040	0.020	0.164	0.409	1075

Note: The weighted means weight by the product's 8-digit revenue share of the total 2-digit industry revenue.

Table 3: Multi-product production function estimates at 2-digit Prodcom level

Dependent variable q_{ijt} is log of the quantity sold in physical units at the 8-digit product level of good j by firm i at time t
All specifications include quarter-year and product dummies and a constant term

	(1) Food & beverages 15	(2) Fab. metal 28	(3) Other manuf. 36	(4) Chemicals 24	(5) Non metallic mineral 26	(6) Rubber & plastic 25	(7) Machinery & equip. 29	(8) Textile 17	(9) Apparel 18	(10) Paper 21	(11) Basic metals 27	(12) Electrical machinery 31
$q_{(-j)}$	-0.107***	-0.097***	-0.110***	-0.100***	-0.086***	-0.096***	-0.107***	-0.097***	-0.145***	-0.082***	-0.113***	-0.085***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.005)	(0.001)	(0.002)	(0.003)
l	0.148***	0.388***	0.346***	0.037*	0.320***	0.043*	0.390***	0.179***	0.257***	0.305***	0.169***	0.475***
	(0.010)	(0.016)	(0.022)	(0.021)	(0.016)	(0.025)	(0.030)	(0.022)	(0.023)	(0.031)	(0.027)	(0.045)
m	0.443***	0.379***	0.658***	0.634***	0.439***	0.761***	0.178*	0.698***	0.507***	0.535***	0.629***	0.474***
	(0.049)	(0.062)	(0.077)	(0.071)	(0.074)	(0.098)	(0.102)	(0.105)	(0.059)	(0.116)	(0.114)	(0.128)
k	0.089**	0.115*	0.152*	0.085	0.109	0.132*	0.067	0.166*	-0.131	0.161	0.060	0.000
	(0.039)	(0.059)	(0.080)	(0.091)	(0.075)	(0.078)	(0.104)	(0.100)	(0.146)	(0.102)	(0.116)	(0.123)
# obs.	47,125	17,309	12,673	13,742	11,036	11,106	11,138	9,512	6,008	5,465	5,551	3,984

Note: Each column reports the estimated coefficients using a modified variant of the Wooldrige-Mixed OP-LP estimator. Explanatory variables are in logs and include firm-level labor, the standard real indices for materials and for capital - i.e. the dollar value of each - and a firm level index of the output of its other goods $q_{i(-j)t}$ given by the revenue of all other products produced by the firm. We include the product's price as an additional control (see Estimation section and see Appendix for results that do not include price). Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: The link between firm-product technical efficiency, import competition and product rank
Dependent variable is the estimated firm-product technical efficiency residual
Product ranking within a firm determined by its share of the firm's total revenue

	using price weighted quantity index						using unweighted quantity index
		OLS			IV		IV
Dep. var.: technical efficiency	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lagged import share	0.108***	0.101***	0.123***	0.878*	0.996**	1.055**	1.012**
	(0.013)	(0.013)	(0.014)	(0.501)	(0.494)	(0.460)	(0.474)
Second product		-0.093***	-0.090***		-0.094***	-0.089***	-0.110***
		(0.003)	(0.004)		(0.004)	(0.020)	(0.020)
Third product		-0.209***	-0.200***		-0.211***	-0.094***	-0.096***
		(0.004)	(0.005)		(0.005)	(0.025)	(0.026)
Product above rank 3		-0.323***	-0.287***		-0.325***	-0.195***	-0.194***
		(0.005)	(0.007)		(0.007)	(0.025)	(0.026)
Lagged import share x 2nd prod.			-0.014			-0.034	0.015
			(0.011)			(0.075)	(0.076)
Lagged import share x 3rd prod.			-0.039***			-0.398***	-0.384***
			(0.014)			(0.086)	(0.088)
Lagged import share x higher rank prod.			-0.122***			-0.422***	-0.410***
			(0.016)			(0.080)	(0.082)
Lagged technical efficiency	0.913***	0.889***	0.889***	0.915***	0.893***	0.894***	0.900***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)
First stage F-statistic				55.36***	55.73***	16.09***	15.89***
# obs.	165,800	165,800	165,800	106,243	106,243	106,243	106,243

Note: Import shares are computed controlling for re-export. The first three columns report OLS estimates. The next three columns show the estimates where import share is instrumented by Chinese tariffs weighted by the share of China in the pre-sample period and world export supply. Column (7) is similar to column (6) but uses the TFP estimates from a specification with an alternative unweighted quantity index. All specifications include quarter-year and product dummies and a constant term (not reported). Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: The link between firm-product technical efficiency, import competition and product rank
Robustness to production function estimators

Dep. var.: technical efficiency	(1) Wooldridge-OPLP	(2) Wooldridge-LP	(3) OLS	(4) Import share in quantity unadjusted for re-export	(5) without price control	(6) with quadratic term for $q_{(-j)}$
Lagged import share	1.055**	1.069**	0.849*	0.936**	0.894*	1.171**
	(0.460)	(0.459)	(0.472)	(0.420)	(0.477)	(0.547)
Second product	-0.089***	-0.088***	-0.096***	-0.091***	-0.090***	-0.074***
	(0.020)	(0.020)	(0.020)	(0.021)	(0.020)	(0.023)
Third product	-0.094***	-0.091***	-0.127***	-0.083***	-0.123***	-0.067**
	(0.025)	(0.025)	(0.026)	(0.029)	(0.026)	(0.030)
Product above rank 3	-0.195***	-0.197***	-0.235***	-0.177***	-0.216***	-0.182***
	(0.025)	(0.025)	(0.026)	(0.029)	(0.026)	(0.030)
Lagged import share x 2nd prod.	-0.034	-0.042	-0.069	-0.022	-0.070	0.071
	(0.075)	(0.075)	(0.075)	(0.070)	(0.076)	(0.089)
Lagged import share x 3rd prod.	-0.398***	-0.417***	-0.405***	-0.385***	-0.389***	-0.327***
	(0.086)	(0.086)	(0.087)	(0.085)	(0.088)	(0.103)
Lagged import share x higher rank prod.	-0.422***	-0.430***	-0.452***	-0.424***	-0.456***	-0.296***
	(0.080)	(0.080)	(0.081)	(0.080)	(0.082)	(0.095)
Lagged technical efficiency	0.894***	0.892***	0.870***	0.893***	0.878***	0.876***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
# obs.	106,243	106,243	106,243	106,243	106,243	106,243

Note: This table reports results for the estimates in column 6 of table 4 using four alternative methods of estimating the production function estimates and the implied technical efficiency residuals. As before all production function specifications include quarter-year and product dummies and a constant term (not reported). Column (1) uses the same specification as column 6 in table 4. Column (2) uses the TFP measure from the Wooldridge-Levinsohn&Petrin estimator with price control. Column (3) uses ordinary least squares estimates of TFP. The next four columns use the Wooldridge OPLP estimator used in table 4. Column (4) uses an import share measure in quantity and that does not control for reexport. Column (5) uses the TFP estimates from the Wooldridge-OPLP estimator that does *not* include the product's output price as an control. Column (6) includes a quadratic term for the revenues of the other goods produced by the firm when estimating the production function parameters. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: The distribution of estimated annual changes in the value of 8-digit firm-product output attributable to changes in import shares, 1997-2007
Thousands of Euros

Code	Product category	10th	25th	Median	75th	90th	# obs	Mean
24	Chemicals	-971.6	-53.3	0.0	55.2	936.4	10005.0	10.8
15	Food and beverages	-281.1	-30.5	-0.1	21.4	250.7	22186.0	-5.9
28	Fabricated metal products	-517.7	-100.6	0.1	137.1	691.2	6063.0	53.8
29	Machinery and equipment	-2536.6	-185.4	0.1	277.1	2241.2	2180.0	17.7
25	Rubber and plastic products	-953.8	-105.5	0.7	158.1	1070.3	4820.0	28.0
18	Apparel	-71.9	-3.1	1.4	52.1	308.7	4708.0	75.7
27	Basic metals	-1924.4	-154.0	0.2	282.2	2509.1	2113.0	71.2
26	Non metallic mineral	-343.7	-41.8	0.8	78.9	431.9	4091.0	23.6
21	Paper	-1165.2	-99.9	0.2	141.6	1156.4	2799.0	20.1
17	Textile	-879.0	-106.9	0.5	121.3	826.3	2741.0	9.8
31	Electrical machinery	-1878.8	-208.9	0.1	344.0	2589.4	656.0	96.5
	All products	-538.3	-46.7	0.1	63.6	625.9	65242.0	22.6

Note: The table uses the estimates in column 6 in table 4 along with the realized changes in import shares to calculate the estimated change in output value. The change in output value is calculated by first multiplying the change in firm-product technical efficiency by the coefficient on import share to get the change in the growth rate in output due to the change in the import share. In order to account for the time series persistence in technical efficiency implied by the AR(1) term we scale additional value in output by $\frac{1}{1-\hat{\rho}}$, where $\hat{\rho}$ is the estimated value of the AR(1) coefficient from column 6 of table 4.

Table 7: Aggregate manufacturing gains and losses from increases and decreases in import competition, 1997-2007
Millions of Euros

	Firm-product gains with increases in import share	Frm-product losses with decreases in import share	Total Change
	(1)	(2)	(1)+(2)
1997	1,122	-1,473	-351
1998	1,246	-1,105	141
1999	1,376	-1,237	138
2000	1,317	-1,245	72
2001	1,407	-1,369	38
2002	1,369	-1,095	273
2003	1,407	-1,191	216
2004	1,372	-1,002	370
2005	1,278	-1,033	245
2006	1,357	-1,140	217
2007	1,263	-1,147	116
Total	14,514	-13,038	1,476

Note: The table reports the sum of all estimated productivity gains, losses and net gains at the annual level across all 2-digit manufacturing industries reported in Table 5.

Table 8: The link between firm-product technical efficiency, import competition and product rank assuming multi-product production is a collection of single product production functions

	Ordinary Least Squares			Instrumental Variables		
Dep. var.: technical efficiency	(1)	(2)	(3)	(4)	(5)	(6)
Lagged import share	0.056***	0.056***	0.061***	0.715*	0.719*	0.456
	(0.010)	(0.010)	(0.011)	(0.413)	(0.413)	(0.381)
Second product		0.003	0.004		0.004	-0.008
		(0.002)	(0.003)		(0.004)	(0.016)
Third product		0.001	0.004		0.001	0.029
		(0.003)	(0.004)		(0.005)	(0.021)
Product above rank 3		-0.003	0.002		-0.001	0.007
		(0.004)	(0.006)		(0.005)	(0.021)
Lagged import share x 2nd prod.			-0.004			0.047
			(0.009)			(0.061)
Lagged import share x 3rd prod.			-0.010			-0.082
			(0.011)			(0.071)
Lagged import share x higher rank prod.			-0.019			-0.025
			(0.013)			(0.066)
Lagged technical efficiency	0.908***	0.908***	0.908***	0.915***	0.915***	0.913***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)
# obs.	165,800	165,800	165,800	106,243	106,243	106,243

Note: This table replicates Table 4 using firm-product technical efficiency computed under the assumption that multi-product production is just a collection of single product production functions. Inputs are allocated across products by revenue shares. Dependent variable in Table 7 is the estimated firm-product technical efficiency from the estimated single-product production function.

Table A1: The link between firm-product technical efficiency, import competition and product rank
Other checks on robustness to production function estimation and importing/exporting

Dep. var.: technical efficiency	(1) Only multi-product firms	(2) All firms pooled with multi-product indicator in production estimation	(3) Does the firm import or export ?	(4) Is the product imported or exported by the firm ?
Lagged import share	1.086**	1.114**	1.020**	1.012**
	(0.439)	(0.459)	(0.469)	(0.468)
Second product	-0.136***	-0.159***	-0.090***	-0.090***
	(0.020)	(0.020)	(0.020)	(0.020)
Third product	-0.140***	-0.170***	-0.095***	-0.094***
	(0.027)	(0.026)	(0.025)	(0.025)
Product above rank 3	-0.242***	-0.267***	-0.197***	-0.197***
	(0.027)	(0.026)	(0.025)	(0.025)
Lagged import share x 2nd prod.	-0.116	0.023	-0.030	-0.029
	(0.077)	(0.075)	(0.074)	(0.074)
Lagged import share x 3rd prod.	-0.512***	-0.332***	-0.397***	-0.398***
	(0.092)	(0.086)	(0.086)	(0.086)
Lagged import share x higher rank prod.	-0.565***	-0.376***	-0.419***	-0.419***
	(0.087)	(0.080)	(0.080)	(0.080)
Multi-product indicator		0.149***		
		(0.005)		
Lagged Importer indicator			0.017**	-0.004
			(0.007)	(0.005)
Lagged exporter indicator			0.006	0.025***
			(0.007)	(0.006)
Lagged technical efficiency	0.873***	0.885***	0.892***	0.892***
	(0.003)	(0.003)	(0.003)	(0.003)
# obs.	84,493	106,243	106,243	106,243

Note: Column (1) considers only multi-product firms. Column (2) considers all firms but adds an indicator variable for multi-product firms when estimating the production function parameters. Column (3) includes two indicator variables, one for whether the firm is an importer, the other for whether the firm is an exporter. In column (4), the import and export indicators are on if the firm is exporting or importing that specific product. All specifications include quarter-year and product dummies and a constant term (not reported). Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table A2: Testing for the existence of single-product production functions at the 2-digit Prodcom level

Significance of $q_{(-j)}$ *rejects existence*

Firm inputs allocated across products using firm-product revenue shares

Dependent variable q_{ijt} is log of the quantity sold in physical units at the 8-digit product level of good j by firm i at time t

All specifications include quarter-year and product dummies and a constant term

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	15	28	36	24	26	25	29	17	18	21	27	31
$q_{(-j)}$	0.004***	0.004***	0.006***	0.001	0.004***	-0.000	0.005***	0.007***	0.002	0.000	-0.005***	0.004***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)
l	0.166***	0.329***	0.300***	0.134***	0.275***	0.237***	0.400***	0.175***	0.183***	0.290***	0.221***	0.285***
	(0.004)	(0.008)	(0.010)	(0.009)	(0.008)	(0.010)	(0.021)	(0.008)	(0.012)	(0.013)	(0.012)	(0.022)
m	0.505***	0.599***	0.556***	0.648***	0.621***	0.745***	0.301***	0.948***	0.551***	0.652***	0.792***	0.647***
	(0.035)	(0.049)	(0.059)	(0.049)	(0.062)	(0.057)	(0.099)	(0.065)	(0.050)	(0.059)	(0.067)	(0.113)
k	0.260***	0.064	0.131***	0.177***	0.042	-0.005	0.308***	-0.109*	0.188***	0.059	-0.033	-0.000
	(0.031)	(0.043)	(0.049)	(0.044)	(0.052)	(0.047)	(0.084)	(0.058)	(0.049)	(0.049)	(0.059)	(0.099)
# obs.	49,572	17,999	13,863	13,917	11,828	11,470	10,853	10,606	7,926	5,823	5,634	4,108

Note: Each column reports the estimated coefficients of the production function for each 2-digit product category using a modified variant of the Wooldrige-LP estimator. The explanatory variables are all in logs and include firm-level labor, the standard indices for materials and for capital - i.e. the dollar value of each - and a firm level index of the output of its other goods $q_{i(-j)t}$ given by the revenue of all other products produced by the firm. All indices are in real terms. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A3: Production function estimates obtained by assuming multi-product production is collection of single-product 2-digit Prodcom production functions

Firm inputs allocated across products using firm-product revenue shares

Dependent variable q_{ijt} is log of the quantity sold in physical units at the 8-digit product level of good j by firm i at time t

All specifications include quarter-year and product dummies and a constant term

	(1) 15	(2) 28	(3) 36	(4) 24	(5) 26	(6) 25	(7) 29	(8) 17	(9) 18	(10) 21	(11) 27	(12) 31
l	0.163***	0.321***	0.290***	0.134***	0.269***	0.237***	0.394***	0.168***	0.181***	0.290***	0.222***	0.286***
	(0.004)	(0.008)	(0.010)	(0.009)	(0.007)	(0.010)	(0.021)	(0.008)	(0.011)	(0.013)	(0.012)	(0.022)
m	0.505***	0.588***	0.558***	0.648***	0.619***	0.745***	0.292***	0.938***	0.552***	0.653***	0.784***	0.633***
	(0.035)	(0.050)	(0.059)	(0.049)	(0.062)	(0.057)	(0.100)	(0.065)	(0.050)	(0.059)	(0.067)	(0.112)
k	0.262***	0.077*	0.135***	0.177***	0.047	-0.006	0.319***	-0.095	0.189***	0.059	-0.026	0.013
	(0.031)	(0.043)	(0.049)	(0.044)	(0.052)	(0.047)	(0.084)	(0.058)	(0.049)	(0.049)	(0.059)	(0.098)
# obs.	49,572	17,999	13,863	13,917	11,828	11,470	10,853	10,606	7,926	5,823	5,634	4,108

Note: Each column reports the estimated coefficients of the production function for each 2-digit product category using a modified variant of the Wooldrige-LP estimator. The explanatory variables are all in real terms and in logs and include firm-level labor and the standard indices for materials and for capital - i.e. the dollar value of each. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$