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 1995 to 2007, a period marked by stark declines in Chinese tariffs. Using Diewert (1973) and Lau (1976) we show how to estimate firm-product quarterly technical efficiency shocks allowing for interactions among the production processes for multi-product firms and without allocating firm-level inputs across the different products produced. 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 find import competition is strongly positively related to firm-product level productivity with a increase of 10% in the import share leading to a 10% gain in technical efficiency. Firms appear to be less technically efficient at producing goods the further they get from their core competence. Firms respond to competition by focusing more on their core products.

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1 Introduction

In this paper, we provide a new methodology to estimate technical efficiencies at the firm-product level. We then use this methodology to revisit the old question in economics of the link between productivity and competition, which is thought to be an important mechanism in promoting improvements in technical efficiency (see e.g. Aghion and Howitt, 1996 or the review in Holmes and Schmitz, 2010). Several important contributions in the productivity literature have established a clear positive relationship between firm-level productivity growth and increased competition (e.g. Olley and Pakes, 1996; Pavcnik, 2002; Bloom, Draca and Van Reenen, 2016). Once we generate firm-product technical efficiencies, we add to this literature by investigating how Belgian *firm-product* technical efficiencies responded over the period 1995-2007 to increased import competition induced by the general relaxation of trade restrictions and the fall in Chinese import tariffs in particular.

Our work is related to several recent theoretical contributions in international trade. Eckel and Neary (2010) develop a model of multi-product firms investing in the quality of their products and show in their setting firms invest more in products closer to firms' core competence, leading to those products having both lower costs of production and higher sales. In the model of Bernard, Redding and Schott, (2010, 2011) when firms switch up their line of products resources within the firm are reallocated towards a more efficient use. Mayer, Melitz and Ottaviano (2014) show in their setup that tougher competition in an export market induces firms to skew their export sales towards their most profitable products. In this paper we look at our estimates of firm-product technical efficiencies to investigate whether firms are more technically efficient at producing their most lucrative products. We also investigate how these technical efficiencies change over our sample period in response to the increase in import competition.

We observe quarterly firm-product observations at the 8-digit level on quantities sold and unit prices in the PRODCOM data from the period 1995Q1-2007Q4. Most production in our data is multi-product production in terms of value, a finding which is consistent with other papers that have looked at multi-product data.[1] We also observe firm level quarterly measures of labor, capital, and intermediate inputs. In the past, researchers using this kind of data have faced the challenge of how to model and estimate multi-product production. One approach has been to assume that the goods are similar enough such that their quantities can be added together and treated as a single output (see e.g. Dunne and Roberts, 1992 for a discussion). Another approach has been to assume multi-product production is a collection of single product production functions. In this

[1] See e.g. Bernard, Redding and Schott, 2010a,b; Bernard et al., 2012; Goldberg et al., 2010a,b

latter case, one must determine a rule for allocating the aggregated inputs across the single product production functions. Foster, Haltiwanger and Syverson (2008) use product revenue shares to allocate the inputs. More recently, De Loecker et. al (2016) suggest a novel algorithm where they endogenously derive the share of inputs allocated to each output using optimization.

We show how to estimate quarterly firm-product technical efficiency shocks without maintaining any of these assumptions. We use a combination of results from Diewert (1973) and Lau (1976) to generalize well-known single-product production function results - existence and testable restrictions - to multi-product settings. The single product production function gives the maximal output for any set of inputs of aggregate labor, capital, and intermediate measures of inputs constant. The multi-product production function gives the maximal amount of one output achievable holding the set of inputs of aggregate labor, capital, and intermediate measures of inputs constant, and holding all other output levels constant. The existence result is critical for motivating the regression of output of one product on total input levels and quantities of all other products produced by the firm. We then show how to address the simultaneity of both inputs and outputs using a slight extension of Olley and Pakes (1996) or Levinsohn and Petrin (2003).

A key empirical challenge for our approach is that the theory applies only to particular production tuples. In Belgium, for many production tuples, the number of observations is small (although this may not be a limiting factor for large data sets like manufacturing in China, India, or the United States) and we need to adapt our approach to this reality. Aggregation is standard over inputs like capital, intermediates, and sometimes labor. We follow a similar logic and construct an output index over all outputs except the output that is being explained. This allows us to "add back" many of the firm-product observations that would otherwise be lost due to a lack of observations on production tuples. Alternatively, parts of the approach of De Loecker et. al (2016) could be combined with our moment conditions in a hybrid estimator that could address paucity of data. In this sense our work is highly complementary.

The firm-product technical efficiency shocks that come out of this estimation become the dependent variables in our import penetration regressions. We construct quarterly 8-digit product-specific import penetration rates using the international trade data hosted at the National Bank of Belgium (NBB) coupled with the PRODCOM data. From the World Bank, we obtain information on the evolution of European tariffs on Chinese imports, which we use as instruments for these import shares. From the BACI database from CEPII, we also build a world export supply (excluding Belgium) instrument at the 8-digit level, as suggested by Hummels et al. (2014). We relate these quarterly firm-product technical efficiency shocks to last-period's - last quarter's - technical efficiency shock, 8-digit product- and quarter-specific fixed effects, last period's instrumented import shares, the product's "rank" in terms of revenue generated at the firm, and interactions between the instrumented lagged import shares and product rankings.

When we treat the import share as exogenous, we find that firms' technical efficiencies do appear to respond to an increase in competition. Consistent with the theoretical models cited above we find that firms appear to be more technically efficient at producing goods that account for a higher share of their revenue. We also find technical efficiency gains for core products arising from increased competition are significantly larger than for non-core products. When we instrument the import share, our coefficient increases *tenfold*. We find using IV that a 1% increase in import share leads to a 1% increases in technical efficiency. Given the large swings - both positive and negative - in import shares over the time period, this suggests there may have been large gains in some product categories and large losses in others. We suspect that market equilibration may explain some of this stark attenuation. If the 8-digit products categories where import shares are highest are also those where domestic firms have technical efficiency innovations that are largely negative, this would induce a negative correlation between the error in the equation and the import share.

We perform several robustness checks on the type of estimation method used, the sample definition, the number of controls added, various choices of quantity aggregate measures and the way we compute import shares. All our robustness checks rely on our most complete specification, using instrumental variables for import competition.

The closest paper to our findings is De Loecker et. al. (2016). Their method delivers one technical efficiency term for each firm but different marginal cost measures for every firm-product. They find that trade liberalization primarily affected markets by causing firms to find ways to reduce marginal costs, as opposed to causing output prices to fall. Consistent with our findings, their results show that marginal costs are on average declining as the within-firm product revenue share increases.

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-level Quantities and Unit Prices in Belgian Manufacturing

We observe a variety of different data sets on Belgian firms that allow us to construct quarterly firm-product observations on quantities sold, unit prices, and inputs used from the period 1995Q1-2007Q4 period. The data sets include the Belgian PRODCOM survey, the Value Added Tax (VAT) declarations, the Social Security declarations, the annual accounts, and the BACI data on Belgian imports from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII).

2.1 The Belgian PRODCOM survey

The first data set is firm-product level production data (PRODCOM) collected by Statistics Belgium[2]. The survey is designed to cover at least 90% of production value in each NACE 4-digit industry. All Belgium firms with a minimum of 10 employees or total revenue above a certain threshold are covered in the survey. The sampled firms are required to disclose monthly product-specific revenues and quantities 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 aggregate to quarterly revenues and quantities and calculate the associated quarterly unit price. We focus our analysis on the period 1995-2007 because the PRODCOM survey size was significantly reduced in 2008 when they revised the product classification system. 1995-2007 is the main period of trade liberalization.

We start with standard cleaning procedures. First, we keep only firms that have their principal business activities in manufacturing. Second, 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 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 in the firm's portfolio is at least 5%.

Our next source of information, 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.

[2] 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).

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 4-digit PRODCOM). We observe 137,453 firm-product observations between 1995-2007. As has been noted in other multi-product data sets the majority of firms are multi-product firms. At the 8-digit level of disaggregation multi-product firms are responsible for 75% of total value of manufacturing output. Most firms produce between one and five products only and this accounts for 75% of the 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 4-digit level of aggregation the fraction of manufacturing revenue coming from single product firms jumps to 55% and the revenue from firms producing three or more goods falls to 20%, suggesting firms specialize by typically producing goods within the same 4-digit category.

2.2 Firm Input Measurements

Quarterly measurements of firms inputs from 1995 to 2007 are obtained from three different data sets, including the Value Added Tax fiscal declarations of firm revenue, the Social Security database, and the Central Balance Sheet Office database. Belgian firms have to report in their VAT fiscal declarations both their sales revenues and their input purchases for tax liability purposes. Using this information we construct quarterly measures for intermediate input use and investment in capital (purchases of durable goods) from 1995Q1 to 2007Q4. For measures of firm employment we use data from the National Social Security Office to which Belgian firms report on a quarterly basis their level of employment and wages. 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.[3]

[3]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

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

2.3 The Increase in Import Shares: 1995-2007

Over the last 25 years the competitive environment in Europe has changed significantly. The Single Market Program was implemented on January 1, 1993 and this has led to increased competition within the European Union. More recently has been the entry on December 11, 2001 of China into the World Trade Organization.

We construct three separate measures of import shares by combining information from the PRODCOM database with the Belgian customs data that contains detailed information about imports and exports transaction at the firm, product and origin or destination.[4] Our first measures is given as:

$$IS_{1,jt} = \frac{M_{jt}}{Y_{jt} + M_{jt}}$$

where Y_{jt} is the value of production of good j in quarter t in PRODCOM and M_{jt} is the value of imports of good j in quarter t from the customs data. We compute a similar indicator - $IS_{2,jt}$ - using physical quantities instead of values, both of which are recorded in PRODCOM and the customs data.

A significant fraction of the products entering Belgium are subsequently re-shipped to other markets. We use as the measure of net imports $Max\left\{M_{ijt} - X_{ijt}, 0\right\}$ where X_{igt} is the physical quantity of exports of good j from firm i at time t. Our third import share measure is then given as

$$IS_{3gt} = \frac{\sum\limits_{i\,\in\,\text{Importers}} Max\left\{M_{igt} - X_{igt}, 0\right\}}{Y_{gt} + \sum\limits_{i\,\in\,\text{Importers}} Max\left\{M_{igt} - X_{igt}, 0\right\}}.$$

Table 2 shows the changes in import shares at the 8-digit product level between 1997 and 2007 using the "export-corrected" measure of imports. 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 0.044. 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.

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.

[4] Customs data are recorded at the CN8 level while PRODCOM is recorded at the PRODCOM8 level. We follow the procedure by Van Beveren et al. (2012) to establish the concordance between nomenclatures and over time. See data appendix for more details about the construction.

3 Multi-Product Production Functions

Using Diewert (1973) and Lau (1976) we review the theoretical conditions under which a single- or multi-product production function exists and its properties when it does exist. Readers not interested in the details can jump directly to section 4.

3.1 Single Product Firms

In the single-product setting the primitive of production analysis is the firm's production possibilities set T, 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 $x = (x_1, x_2, \ldots, x_N)$. Formally, if $(\tilde{q_1}, \tilde{x}) \in T$ if $\tilde{q_1}$ is producible given $\tilde{x}$, The single-product production function $F(x)$ - the production frontier - is defined as:

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

Testable properties of $F(x)$ like concavity or quasi-concavity in elements of x, or q^* non-decreasing in x have been derived using primitives on T, and there is a very large literature where applied researchers have checked whether their estimated production functions satisfy these conditions.

3.2 Diewert-Lau Multi-Product Production

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 $q = (q_1, q_2, \ldots, q_J)$ that can be produced by using N non-negative inputs $x = (x_1, x_2, \ldots, x_N)$. In this multi-product case if $(\tilde{q}, \tilde{x}) \in T$ then $\tilde{q} = (\tilde{q_1}, \ldots, \tilde{q_J})$ is achievable using $\tilde{x} = (\tilde{x_1}, \ldots, \tilde{x_N})$. For good j produced by the firm let the output production of other goods be denoted by q_{-j}. Diewert (1973) defines the multi-product transformation function as

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

if there exists a q_j such that $(q_j, q_{-j}, x) \in T$. If $(q_j, q_{-j}, x) \notin T \ \forall q_j \geq 0$

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

.

In the single product case if T is convex then inputs are freely variable. Similarly, in the multi-product case if T convex then both inputs and outputs are freely variable. Non-convexities in T can arise in both settings for a variety of economic reasons. One very common posited non-convexity arises because of adjustment costs associated with investment. In order to allow for non-convexities it will be useful to divide inputs and outputs into variable v and fixed K, and we sometimes re-express (q_{-j}, x) as (v, K), and abuse notation by writing both $F(q_{-j}, x)$ and $F(v, K)$.

We assume T satisfies the following five conditions and we refer to these conditions as *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,

(iii) P.3 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.

(iv) P.4 If $(q, x_k, x_{-k}) \in T$ then $(q, x'_k, x_{-k}) \in T \ \forall x'_k \geq x_k$.

(v) P.5 if $(q_j, q_{-j}, x) \in T$ then $(q'_j, q_{-j}, x) \in T \ \forall q'_j \leq q_j$.

Conditions (i), (ii), (iv), and (v) are from Diewert (1973) and condition (iii) is from Lau (1976). Conditions (i) and (ii) can be viewed as weak regularity conditions. Condition (iv) is a free disposal condition on inputs; if you can produce q_j given (q_{-j}, x) then you can produce q_j with any $x^{'} \geq x$. Condition (v) is a free disposal condition on output; if you can produce q_j given (q_{-j}, x) then you can produce any level of output $q_j^{'}$ such that $0 \leq q_j^{'} \leq q_j$.

Condition (iii) is Disjoint Biconvexity and it allows for fixity in some inputs and outputs. From Lau (1976) pg. 133

> Biconvexity allows the existence of overall increasing returns while preserving the properties of diminishing marginal rates of transformation (substitution) amongst certain subsets of commodities.

For the flexible inputs v convexity in them holding the fixed inputs K constant results in the production function continuing to be concave in these inputs. For the fixed inputs convexity in K given v results in the production function being quasi-concave in K given v.[5]

Theorem 3.1 (The Transformation Function) *Under P.1-P.5 the function $F(q_{-j}, x)$ 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. $F(v, K)$ is concave in v, quasi-concave in K, and $F(q_{-j}, x)$ is non-increasing in q_{-j} and non-decreasing in x.*

[5] Diewert (1973) maintains a stronger condition that convexity holds on the set of all inputs and outputs, which rules out fixity in inputs and results in a function that is concave in all inputs and outputs, and thus rules out increasing returns to scale.

See the Appendix for the proof. The existence result motivates estimation of each quantity as a function of the quantities of all other products produced by the firm and total input levels.

4 Functional Forms for Production

In this section we describe simple Cobb-Douglass approximations for multi-product production. Diewert (1973) argues for a trans-log specification and we add quadratic terns in our robustness section.

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

$$q_{ijt} = \beta_0^j + \beta_l^j l_{it} + \beta_k^j k_{it} + \beta_m^j m_{it} + \gamma_{-j}^j q_{i-jt} + \varepsilon_{ijt} \quad j = 1 \cdots J \tag{1}$$

where l_{it}, k_{it}, and m_{it} denote the three inputs labor, capital and materials and q_{-j} denotes the vector of all other outputs excluding q_j. The input production parameters $\beta^c = (\beta_l^c, \beta_k^c, \beta_m^c)$ denote the percentage change in output of q_j holding other inputs and q_{-j} constant. γ_{-j}^j denotes the parameters that are the elasticities of the output of q_j with respect to any one element of q_{-j} holding inputs and other outputs constant. The function is only well-defined when $\beta^j > 0$ and $\gamma_{-j} < 0$. In addition to needing to instrument the inputs because of the standard input simultaneity problem raised by Marschak and Andrews (1944), this system of simultaneous supply equations leads quantities to also generally be a function of $\varepsilon_{ijt} \quad j = 1 \cdots J$, so they also will have to be instrumented.

We illustrate with the two-good production function used in Dhyne, Petrin and Warzynski (2014). They look at the bread and cakes industry in Belgium, where most firms that produce bread also produce cakes. Let q_{iBt} and q_{iCt} denote the output quantities of bread and cakes respectively. For firms producing both bread and cakes the production function for bread is given as a function of inputs and cake production:

$$q_{iBt} = \beta_0 + \beta_l^b l_{it} + \beta_k^b k_{it} + \beta_m^b m_{it} + \gamma_C q_{iCt} + \varepsilon_{iBt} \tag{2}$$

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. The function is only consistent with a production function if $\beta^b > 0$ and $\gamma_C < 0$. Similarly, the production function for cakes is given as

$$q_{iCt} = \beta_0 + \beta_l^c l_{it} + \beta_k^c k_{it} + \beta_m^c m_{it} + \gamma_B q_{iBt} + \varepsilon_{iCt} \tag{3}$$

with the production parameters $\beta^c = (\beta_l^c, \beta_k^c, \beta_m^c)$, and γ_C. As noted above in this two equation supply system for both equations the simultaneity implies inputs and the quantity of output will generally be correlated with the supply errors.

4.1 Quantity Aggregation

Most firms produce more than two goods. Belgium has a small manufacturing economy (e.g. relative to China) which results in very few observations on multi-product tuples. Similar to the index restrictions used in the construction of capital and materials aggregates (and sometimes the labor aggregate) we use a quantity index, as in Roberts and Supina (2000).[6] We experiment with four different variants of quantity indices, which we generically denote as $r_{i(-j)t}$. Our estimation equation becomes

$$q_{ijt} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \gamma_j r_{i-jt} + \varepsilon_{ijt}. \quad (4)$$

For any particular good j that is produced the first index sums the quantities of all the other goods produced by the firm weighting by price ($\sum_{g \neq j} p_g q_g$). Our second index sums log of quantity of all the other goods weighted by price ($\sum_{g \neq j} p_g ln(q_g)$). The third one aggregates the sum of the log of deflated value of the other goods but j ($\sum_{g \neq j} ln(p_g q_g)$). The last one simply sums the log of physical quantity of all the other goods except j ($\sum_{g \neq j} lnq_g$). Our primary specification uses the first index and we report results in the robustness section to the other three indices.

5 Estimation

We extend the Wooldridge (2009) formulation of the Olley and Pakes (1995) (OP) and Levinsohn and Petrin (2002) (LP) methodologies to the multi-product setting where we must instrument for quantities in addition to inputs. In the multi-product case we have for q_j:

$$q_{jt} = \beta_l l_t + \beta_k k_t + \beta_m m_t + \gamma'_{q-j} q_{-jt} + \omega_{jt} + \epsilon_{jt} \quad (5)$$

where we have replaced the shock with its two components, i.e. $\varepsilon_t = \omega_t + \eta_t$. ω_t is the productivity shock, a state variable observed by the firm but unobserved to the econometrician and assumed to be a first-order Markov. ω_t is the source of the simultaneity problem as freely variable inputs l_t and m_t respond to it. k_t is a state variable and is allowed to be correlated with $E[\omega_t|\omega_{t-1}]$, but it is assumed that $\xi_t = \omega_t - E[\omega_t|\omega_{t-1}]$, the innovation in the productivity shock, is uncorrelated with k_t. ϵ_t denotes an i.i.d. shock that is assumed to be uncorrelated with all of the inputs.

[6] They use quantity aggregators when estimating cost functions.

LP write intermediate input demand as a function of the state variables $m_t = \mathbf{m}_t(\omega_t, k_t)$ and provide weak conditions under which $\mathbf{m}_t(\cdot,\cdot)$ is strictly monotonic in ω_t holding k_t constant. The intermediate demand function can then be inverted to obtain the control function for ω_t as a function of observed m_t and k_t, written as $\omega_t = h_t(m_t, k_t)$.[7] Wooldridge (2009) uses a single index restriction to approximate unobserved productivity, so in the LP setting one has

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

where $\mathbf{c}(m_t, k_t)$ is a known vector function of (m_t, k_t) chosen by researchers. He also writes the nonparametric conditional mean function $E[\omega_t|\omega_{t-1}]$ as

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

for some unknown function $p(\cdot)$.[8] Rewriting multi-product production we have

$$q_{jt} = \beta_l l_t + \beta_k k_t + \beta_m m_t + \beta'_{q-j} q_{-jt} + E[\omega_{jt}|\omega_{j,t-1}] + \xi_{jt} + \epsilon_{jt} \tag{6}$$

which yields the error

$$[\xi_{jt} + \epsilon_{jt}](\theta) = q_{jt} - \beta_l l_t - \beta_k k_t - \beta_m m_t - \beta'_{q-j} q_{-jt} - p(\mathbf{c}(m_{t-1}, k_{t-1})'\beta_\omega)$$

with the new parameters β_{-j} added to $\beta = (\beta_l, \beta_k, \beta_m, \beta_{-j}, \beta_\omega)$. The 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.) $x_{jt} = (q_{-j,t-1}, k_t, k_{t-1}, m_{t-1}, m_{t-2}, l_{t-1})$. Let θ_0 denote the true parameter value. Wooldridge shows that the conditional moment restriction

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

is sufficient for identification of β in the single product case and the result extends directly to the multi-product case.[9] In equation (6) 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, and $q_{-j,t-1}$ instruments $q_{-j,t}$.

[7] OP write investment as a function of the two state variables $i_t = \mathbf{i}_t(\omega_t, k_t)$ and provide conditions under which investment is strictly monotonic in ω_t holding k_t constant. They then invert this function to get the control function with arguments i_t and k_t.

[8] OP use i_t and i_{t-1} instead of m_t and m_{t-1} respectively for ω_t and $E[\omega_t|\omega_{t-1}]$.

[9] The Wooldridge formulation is robust to the Ackerberg, Caves, and Frazer (2006) criticism of OP/LP.

5.1 The link between productivity and imports

We estimate three different specifications to investigate the relationship between technical efficiency, import competition, and product ranking as determined by its revenue shares. All of our regressions contain 8-digit product indicator variables (ν_j), and year-quarter indicator variables (δ_t). We use the import share net of re-exporting for our preferred results and show robustness of our results to our two other measures of import shares. In our first specification, we regress current firm-product level technical efficiency on last quarter's technical efficiency and the import share:

$$\omega_{ijt} = \alpha_1 \omega_{ij(t-1)} + \alpha_2 IS_{j(t-1)} + \nu_j + \delta_t$$

In our second specification we include rank indicator variables ($Rank_{ijt}$) for the second product, the third product, and products above rank 3 (the omitted category being the core product).

$$\omega_{ijt} = \alpha_1 \omega_{ij(t-1)} + \alpha_2 IS_{j(t-1)} + \alpha_3 Rank_{ijt} + \nu_j + \delta_t$$

In our third specification we interact these rank dummies with the lagged product-level import share in order to measure whether import competition affects technical efficiency differently for products with different ranks in terms of the revenue they generate for the firm.

$$\omega_{ijt} = \alpha_1 \omega_{ij(t-1)} + \alpha_2 IS_{j(t-1)} + \alpha_3 Rank_{ijt} + \alpha_4 IS_{j(t-1)} * Rank_{ijt} + \nu_j + \delta_t$$

We estimate these equations using ordinary least squares and instrumental variables for a total of six primary specifications. We now discuss the instruments that we use.

5.2 Instruments for Import Share

The import shares that enter into the equations above are measures of the quantities of imports at the 8-digit level. One concern is that these shares may be correlated with the innovations in the firm-product technical efficiencies. If imports are able to more easily penetrate 8-digit product categories for those categories where firm-product technical efficiencies are falling then import shares will be negatively correlated with the technical efficiency shocks, biasing the effect of import competition on technical efficiency down. Because of this concern, we also estimate the three equations using instrumental variables.

We build two instruments inspired by the recent trade literature. First, we follow Trefler and Lilleva (2010) and use tariffs at the HS6 level. While their focus is on the unexpected change in tariffs between Canada and the US in 1991, we on the other hand use tariff information from all potential trade partners for the period 1998-2006. The data are obtained from the World Bank WITS website.[10] We use the effectively applied tariffs to the EU from all potential sourcing countries but we pay specific attention to China. Our first instrument is the product-level effective tariff applied to Chinese goods weighted by the share of China in the pre-sample period.

$$IV1_{jt} = \alpha_{j,1995}^{China} * Tariff_{jt}^{China},$$

This measure captures the fact that one of the most significant *change* in the environment faced by firms has been the increase in imports from China as a result of tariff reductions due to trade liberalization and China's entry in WTO.

For our second instrument, we follow Hummels et al. (2014) and use the log of world export supply (except Belgium) using the BACI database from CEPII.[11]

$$IV2_{jt} = log(WES_{jt})$$

The intuition behind this IV is that other countries exports capabilities affect their ability to penetrate foreign markets and compete with Belgian firms. These might also have evolved over time. This variable is likely to be uncorrelated with the productivity shock affecting Belgian firms.[12]

6 Results

6.1 Estimation at the firm-product level

Our baseline production functions specifications are Cobb-Douglas with parameters assumed constant at the 2-digit level, although our observational unit is the 8-digit firm-product level of output quantity. All of our estimates include both 8-digit firm-product indicator variables and year-quarter product indicator variables. We address simultaneity using the Wooldridge version of the Levinsohn and Petrin (2003) estimator. The quantity aggregate used in our baseline is the log of the revenues of all the other goods deflated by the quarterly producer price index. We include the own-product price control suggested in De Loecker et al (2016) but our results are robust to dropping it and to the exploration

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

[11]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.

[12]One important difference with Hummels et al. (2014) is that their measure of import (offshoring) is at the firm-product level, while our measure is at the firm level. Therefore, we do not need to care about shares.

of a wide variety of estimators and functional forms for production in our robustness analysis.

Table 3 reports the results of our production function estimates for the 12 largest 2-digit product groups, which represent, which represents 1,655 products or 70% of products made in Belgium.[13] 35 of the 36 input coefficients have the correct (positive) sign and in the case where capital is negative it is not significant. 29 out of 36 are statistically significant. The quantity aggregate coefficient is negative and significant for all 12 industries and ranges between -0.083 for paper and -0.148 for apparel.

In the Diewert-Lau hybrid method, input returns to scale have a different interpretation from the standard production function estimation setting where aggregated deflated revenue over all goods a firm produces is regressed directly on the input aggregates. In the latter returns to scale is the percent increase in deflated revenue given a one percent increase in all input aggregates. In our setting returns to scale are defined more generally, where aggregate returns to inputs holding outputs constant appear to be around 0.8. These differences in results suggest differences in the meaning of the coefficients across these two approaches.

6.2 The link between technical efficiency and import competition

Table 4 presents results from the regression of technical efficiency on lagged technical efficiency and import share where all regressions include 8-digit product indicators and quarterly-time indicator variables.

6.2.1 Non-instrumented Results

Columns 1-3 present results when we use OLS and columns 4-6 present the results when we use our two instruments. In column 1 we regress firm-product technical efficiency (in logs) on lagged firm-product technical efficiency (in logs) and lagged product import share. Import competition is positively and significantly associated with technical efficiency. Our coefficient is 0.121 and statistically significant at 1%. This indicates that an increase in 10% in import competition is associated with a 1.2% increase in firm-product technical efficiency. We also find a high persistence in firm-product technical efficiency over time with a coefficient of 0.915 for lagged productivity, statistically significant at 1%.

[13] 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. The 2-digit PRODCOM product categories at the 2-digit are a 1 to 1 match to European industry codes (NACE).

In column 2, we test whether various products exhibit different levels of technical efficiency by including a rank indicator based on the share of the firm's revenue the product generates. The omitted category is the core product. Products further away from the firm's core competence exhibit a decrease in their technical efficiency of 9.5% for the second product, 21.1% for the third product and 32.2% for products ranked 4 or above. All rank indicator variables are statistically significant at 1%.

Column 3 adds interactions between import share and the rank of the product to test whether the firm's various products react differently depending on their firm-product revenue shares. The coefficient of import share now measures the relationship between technical efficiency and imports for the core product. This coefficient is 0.139, significant at 1% and 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 -0.018 for the second product (but not statistically significant), -0.040 for the third product (significant at 1%) and -0.148 for products ranked more than 3 (significant at 1%). The positive effect of competition decreases with rank and becomes negative for peripheral products (i.e. products above rank 3). The coefficients of the product rank dummies are not strongly affected by adding those interactions. Import competition affects the technical efficiency of core products more than non-core products.

6.2.2 Instrumented Results

Columns 4 to 6 report the IV results for our three main specifications. Our first stage F-statistics are above the critical values in all specifications.[14] The qualitative effect of our variables of interest is similar and all coefficients exhibit the same sign, however the magnitude of those effects is much larger. For example, if we look at the most complete specification (column 6), the coefficient is 1.067 (statistically significant at 5%) for the IV estimation with respect to 0.139 for the OLS estimation. The effect of import share is seven time larger with IV than OLS, supporting the hypothesis that a negative correlation between the innovation shock and the import shares may exist. In column 5 the product rank dummies coefficients are virtually unchanged, they become smaller in column 6. Products ranked second or third are no longer different from each other. The interactions between import share and product rank are -0.093 for the second product (but not significant), -0.469 for the third product (significant at 1%) and -0.471 for products ranked more than 3 (significant at 1%). Under our OLS estimations, products beyond rank 3 do not enjoy any positive effect of increase import competition on their technical efficiency. However, when we rely on IV estimations, all products positively benefit from

[14]Results are available from the authors.

an increase in competition. The effect is however still non homogeneous: the magnitude of the effect for the firm's top two products is more than twice as large as the effect on peripheral products.

6.3 Robustness checks

We perform several robustness checks on the type of estimation method used, the sample definition, the number of controls added, various choices of quantity aggregate measures and the way we compute import shares. All our robustness checks rely on our most complete specification, using instrumental variables for import competition (see column 6 of Table 4).

6.3.1 The estimation method of productivity

We experiment alternative estimation methods to compute firm-product technical efficiency to assess whether it impacts our results from Table 4. Our first alternative specification uses the productivity measure obtained from the estimation of our Diewert-Lau hybrid production function using OLS (Table A2, column 1). Our number of observations slightly increases. The coefficient of import share is lower and only significant at the 10% level. The coefficients of the interactions are marginally lower, while the coefficients of the rank dummies are larger. The difference between each product's reaction to import competition is smaller than before, however the main results that core products are more affected than marginal products and that core products are more efficiently produced than marginal products still remain.

We also use the firm-product productivity estimates obtained from our Diewert-Lau hybrid production function using the Wooldridge modified version of the Olley and Pakes estimator (Table A2, column 2). In this case, our number of observations diminishes as investment is often missing. The import share for the core and second product are no longer statistically significant from 0, and products ranked three or above experience now a negative effect of an increase in product competition. The rank dummies have larger coefficients than in our baseline specification. The main message that import competition heterogeneously affect products' technical efficiency still remains.

Our baseline specification for productivity estimation relies on a linear function of the quantity aggregate. An alternative hypothesis is to allow for nonlinear effects and therefore provide more flexibility to our procedure (Table A2, column 3). Most effects are unchanged except the magnitude of some of the coefficients. The coefficient of the import share for the core product is now 20 percent larger and the coefficients of the interactions for the products of rank three and above are smaller. While the differences between products' response to import competition are smaller than before, our main result of a heterogeneous product response is still present.

Our next robustness check tests whether controlling for prices in our control function impacts the results of Table 4. When we do not control for input prices, our production function estimates misbehave in some cases, as some of the coefficients end up being negative and significant, a problem emphasized in De Loecker et al. (2016).[15] Turning to the link between import competition and firm-product productivity (Table A2, column 4), it is interesting to note that while this affects the value and sometimes the sign of our production function estimates, it does not affect the link between import competition and productivity. The magnitude of the coefficient of import share for the core product slightly decreases and the magnitude of the coefficients of the rank dummies somehow increases. Results are however unchanged.

6.3.2 Sample used

So far, we have pooled observations from single-product and multi-product firms, and we have used $log(1+R_{i(-g)t})$ to proxy for the quantity aggregate for single-product firms. We relax this assumption here by rerunning our favorite specification on products belonging only to multi-product firms (Table A3, columns 1 and 2 with and without price control). Our number of observations drops to 81,940. The coefficient of import share for core product is 1.347. The coefficient is 50 percent larger than in our baseline, indicating that core products of multi-product firms are more affected by international competition than products of single-product firms. The magnitude and the significance of the rank dummies are somehow affected (the coefficients are lower, the dummy for the third product is statistically significant only at 10%). The interactions are nearly unchanged. The main result of the paper is unaffected by the type of sample used for our estimation.

6.3.3 Adding more controls

We also test the robustness of our results by adding other control variables to our estimation. Products made by firms that are active in international markets may behave differently than products of purely domestic firms. International firms may be more efficient and therefore exhibit a different level of firm-product productivity than domestic firms. We add two dummy variables reflecting the international status of the firm: a dummy variable for importing and a dummy variable for exporting. Both variables are lagged by one quarter (Table A3, column 3). The coefficient of the import share of the core product increases to 1.034 or by a magnitude of 20 percent. The magnitude, signs

[15]The coefficients of our hybrid Diewert-Lau method without price control are reported in Table A1.

and statistical significance of the other coefficients are in line with the results of our baseline specification. The coefficient of the importer dummy is 0.016 and statistically significant at 5%. Firms that import appear to have products with a higher level of technical efficiency of 1.6% with respect to non importers. The coefficient of the exporter dummy is however not statistically significant. The exporting status does not seem to affect firm-product technical efficiencies.

We also consider whether the international status of a product as opposed to the international status of the firm. Some products may be traded while others are only produced for the domestic market. This may again affect our results. We add two dummies for the international status of products: a dummy variable for the firm-product import status and a dummy variable for the firm-product export status (Table A3, column 4). The coefficients and the significance of our baseline variables are unaffected. Using the international status of the firm-product as opposed to the firm's status reveals a different pattern. Products that are both produced and imported by the firm do not exhibit a different level of productivity than products that are produced only. The coefficient of the firm-product exporter dummy is 0.026 and is statistically significant at 1%. Products that are both produced and exported enjoy technical efficiency premium of 2.6% as opposed to goods produced only for the domestic market.

6.3.4 The aggregation of $r_{i(-j)t}$

Our hybrid method allows us to estimate firm-product technical efficiencies in a wide array of environments. The applicability of our method to many environments is only made possible by assuming a given aggregation for the various goods a firm produces ($r_{i(-j)t}$, our quantity aggregate). We have to assume some kind of aggregation as we do not have enough firms producing exactly the same portfolio of goods. We try different quantity aggregate indexes based on different assumptions, as discussed in section 4.

Our first quantity index sums the log of physical quantity of all the other goods weighted by price or ($\sum_{g \neq j} p_g ln(q_g)$) (Table A4, column 1). The coefficient of the import share for the core product as well as the coefficient of the interactions for the other products are unaffected. However, the coefficient of import share for the core product is less precisely estimated and is not statically significant anymore. The coefficients of the rank dummies increase by at least a magnitude 2. Products ranked third or lower experience a negative effect of import competition while the core and second product appear to be statistically unaffected. Products are impacted differently depending where they stand in the product portfolio.

The second quantity index sums the log of the deflated revenues of all the other goods (instead of the log of the sum) or $\sum_{g \neq j} p_g ln(q_g)$ (Table A4, column 2). The coefficient of the import share for the core product is lower by a magnitude of 25 percent and only statistically significant at the 10% level. The coefficient of the rank dummies and the interactions are slightly affected, although their sign and their statistical significance remain unchanged. The main results found in our baseline specification are still present, although the magnitude of the different responses between the various products is lower.

The third quantity index simply weight the log of the physical quantity of all other goods or ($\sum_{g \neq j} lnq_g$) (Table A4, column 3). With respect to our baseline, the coefficient of import share drops by a large 40 percent and is no longer statistically significant. The coefficients of the interactions are larger and the coefficients of the rank dummies are also somehow affected. While rank products do not enjoy any positive effect of import competition anymore, products of rank 3 or below experience negative effects of an increase in import competition. Core products are more productive per se, while products away from the core competence of the firm are negatively hit by a shock in product competition.

6.3.5 The import share measure

The import share measure we use for the baseline is computed in quantity controlling for re-exporting. We experiment with two alternative measures. We first use import shares computed in value and do not control for re-export (IS1). If prices of imported goods differ from prices of domestically produced goods, computing import shares in quantity may not reflect those pricing differences, suggesting a measure computed in value may be a better alternative. Results are presented in Table A5 (Column 1). The magnitude of the coefficients is affected. The coefficient of import share drops to 0.514 or nearly 50 percent from the baseline value. The coefficients of the interactions are also smaller, the statistical significance of the interaction of import share and product of rank 3 moves from 5% to 10%. The magnitude of the coefficients of rank dummies is larger than before. However, our main message still persists in this table. Core products are more affected by import competition, products further away from the core are less efficiently produced.

The second import share measure we use for our robustness checks is import share computed in quantity, without controlling for re-export (IS2). Results are only marginally affected (Table A5, column 2). The coefficient on import share for the core product and some of the rank dummies are slightly smaller than in our baseline. The economic magnitude of the effects is however unchanged.

7 Aggregate Effects of Increased Import Competition

Results from the previous section supports the neo-Schumpeterian theories that suggest a positive relationship between competition and productivity. As discussed in section 2, the weighted average of import shares increased by 4.3% over our period of analysis. However, some products experienced large increases in import share, while import competition decreased for others. Due to this heterogeneous response across products, we compute in table 5 the estimated monetary gains and losses from variation in import shares for the manufacturing industry as a whole and at the 2-digit PRODOM2 level. We observe tremendous dispersion within each industry. The median and mean effects are usually positive, as expected.

In table 6, we aggregate these estimated effects at the yearly level and we separate between gains and losses, we can deduct that gains outweigh the losses for almost each calendar year. The aggregate net gains over our period of analysis amount to roughly 1.14 billion euros. Given that value added in the manufacturing industry in our sample was around 18.3 billion euros on average, this is quite a sizable contribution.

8 Conclusion

We develop a new approach to estimate TFP with multi-product firms using detailed quarterly data on physical quantities produced by firms. We use our estimates of 8-digit firm-product technical efficiencies to study the link between productivity and import competition. Our instrumental variable results address the endogeneity of import shares and lead to a tenfold increase in the effect of competition relative to OLS. Our results show a strong positive relationship between firm-product technical efficiency and import competition, pointing towards the disciplinary effect of competition on efficiency. In addition, it seems that import competition does not have the same effect on the various manufactured goods in the firm's product portfolio. Our results indicate that this disciplinary effect is at play mostly for the core products. Our analysis is consistent with recent predictions of theoretical models of multi-product firms in trade (e.g. Bernard, Redding and Schott, 2010, 2011; Mayer, Melitz and Ottaviano, 2014) where one outcome of these models is firms are more productive for their core products.

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Table 1: Product portfolio of firms

# Products	1	2	3	4	5	6+	N
PRODCOM 8							
share of product 1	1.000	0.775	0.695	0.642	0.578	0.494	
share of product 2		0.225	0.230	0.235	0.236	0.224	
share of product 3			0.075	0.092	0.111	0.118	
share of product 4				0.031	0.053	0.067	
share of product 5					0.022	0.039	
share of product 6 and +						0.058	
Share in total value	0.263	0.190	0.129	0.117	0.041	0.260	1.000
# firms-quarter	60,638	34,552	15,379	9,460	5,024	12,400	137,453
PRODCOM 4							
share of product 1	1.000	0.825	0.721	0.698	0.631	0.594	
share of product 2		0.175	0.216	0.207	0.218	0.217	
share of product 3			0.063	0.073	0.099	0.097	
share of product 4				0.022	0.040	0.047	
share of product 5					0.012	0.024	
share of product 6 and +						0.021	
Share in total value	0.556	0.233	0.072	0.044	0.023	0.072	1.000
# firm-date obs.	96,644	26,872	7,705	3,002	1,518	1,712	137,453

Note: the shares are computed as the fraction of each product in the total value of the firm's products. Products with zero or missing value were discarded when computing the shares. Products are defined as 8-digit (upper panel) and 4-digit (lower panel) PRODCOM codes.

Table 2: Change in import shares at the 8-digit product level between 1997 and 2007

Code	Industry	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	1,075

Note: The table reports the distribution of changes in import shares at the 8-digit product level between 1997 and 2007 using the export-corrected measure of imports for all 8-digit categories together and separately by 2-digit product category.

Table 3: Production function estimation - by prodcom2 - WLP - controlling for quality differences

	(1) Food & beverages 15	(2) Fab. metal 28	(3) Other 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
$r_{(-j)}$	-0.108***	-0.096***	-0.108***	-0.099***	-0.087***	-0.098***	-0.103***	-0.096***	-0.148***	-0.083***	-0.113***	-0.084***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.004)	(0.001)	(0.002)	(0.002)
l	0.155***	0.393***	0.356***	0.044**	0.316***	0.055**	0.359***	0.183***	0.241***	0.319***	0.165***	0.483***
	(0.009)	(0.014)	(0.020)	(0.020)	(0.014)	(0.023)	(0.029)	(0.019)	(0.019)	(0.028)	(0.025)	(0.041)
m	0.446***	0.346***	0.636***	0.667***	0.456***	0.794***	0.216**	0.684***	0.427***	0.539***	0.693***	0.495***
	(0.044)	(0.056)	(0.068)	(0.064)	(0.069)	(0.090)	(0.096)	(0.085)	(0.045)	(0.093)	(0.100)	(0.124)
k	0.133***	0.148***	0.022	0.085	0.159**	0.234***	0.057	0.308***	0.0413	0.133	0.158	-0.169
	(0.037)	(0.056)	(0.078)	(0.086)	(0.069)	(0.073)	(0.097)	(0.088)	(0.112)	(0.086)	(0.115)	(0.115)
# obs.	52,573	20,100	15,031	14,760	12,653	12,272	12,106	11,369	8,545	6,291	6,017	4,437

Note: Each column reports the firm-product TFP estimation coefficients computed using our Diewert-Lau hybrid method. The left hand side variable is the physical quantity of a given good produced by the firm q_{ijt}. The right hand side variables are firm-level inputs (labor, materials and capital) and an index of quantity aggregation $r_{i(-j)t}$, defined here as the revenues of the other goods produced by the firm deflated by PPI. For the estimation, we only kept the products of multi-product firms which accounts for at least 5 percent of the firm's turnover. The unit of analysis is at the 8-digit product level (PRODCOM8) and every column bundles 8-digit products belonging to the same two-digit product category (PRODCOM2). For the estimation, we only kept products accounting for at least 5 percent of the firm's turnover. Estimations are adjusted for potential input price bias following a similar approach to De Loecker et al. (2016). Results are reported for the largest 12 PRODCOM2 categories. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Import competition and firm-product productivity

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.: TFP						
Lagged import share	0.121***	0.113***	0.139***	1.035**	1.144**	1.067**
	(0.013)	(0.0131)	(0.014)	(0.503)	(0.496)	(0.458)
Second product		-0.095***	-0.092***		-0.097***	-0.077***
		(0.003)	(0.004)		(0.004)	(0.020)
Third product		-0.211***	-0.202***		-0.213***	-0.077***
		(0.004)	(0.005)		(0.005)	(0.026)
Product above rank 3		-0.322***	-0.279***		-0.323***	-0.182***
		(0.005)	(0.007)		(0.007)	(0.026)
Lagged import share x 2nd prod.			-0.018			-0.093
			(0.011)			(0.076)
Lagged import share x 3rd prod.			-0.040***			-0.469***
			(0.014)			(0.087)
Lagged import share x higher rank prod.			-0.148***			-0.471***
			(0.016)			(0.082)
Lagged TFP	0.915***	0.889***	0.889***	0.918***	0.895***	0.895***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)
# obs.	154,307	154,307	154,307	100,967	100,967	100,967

Note: The left-hand side variable is firm-product TFP computed using our Diewert-Lau method. Import shares are computed in quantity controlling for re-export. Product's rank is computed according to the product's share in the firm's total turnover. Only products accounting for at least 5 percent of the firm's turnover are kept for the analysis. The first three columns report a simple OLS estimation, while the last three columns account for endogeneity by using an IV approach. 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: Estimated annual productivity gains in monetary terms at the firm-product level between 1997 and 2007

Code	Industry	10th	25th	Median	75th	90th	# obs.	Mean
24	Chemicals	-319,321	-43,646	3,005.71	78,297.11	439,618	3,923	63,588.37
15	Food and beverages	-76,980.25	-10,504.49	2,492.17	32,291	155,643	14,014	26,525.48
28	Fabricated metal products	-95,253	-21,058.55	1,221.94	32,647.85	118,496.50	5,558	10,953.14
29	Machinery and equipment	-300,226	-41,943.57	2,470.67	73,624.38	411,899.90	1,595	29,858.71
25	Rubber and plastic products	-120,209.80	-27,433.02	2,487.96	43,658.18	169,088.20	3,292	13,056.19
18	Apparel	-57,259.25	-14,382.02	-625.93	9,416.85	43,423.50	2,152	-5,539.38
27	Basic metals	-414,205.30	-57,403.88	2,739.25	91,683	588,871.10	1,591	38,483.37
26	Non metallic mineral	-113,336.90	-18,393.79	2,518.50	36,898.94	144,274	3,193	15,357.44
21	Paper	-158,107.80	-22,680	3,401.25	50,329.75	259,185.10	1,697	34,169.97
17	Textile	-127,128.90	-33,773.50	-1,464.16	35,797	136,887.70	2,990	724.88
31	Electrical machinery	-307,492	-46,025.75	5,663.50	96,678.47	421,188.30	471	24,274.60
	All products	-121,490	-20,339.67	1,830.50	38,011	175,846	40,569	20,858.39

Note: The table reports the distribution of estimated productivity gains and losses in monetary terms at the 8-digit firm-product level between 1997 and 2007. Figures are in euros.

Table 6: Aggregate estimated annual gains and losses in monetary terms

	firm-product with negative change in value	firm-product with positive change in value	all
1997	-228.00	398.00	170.00
1998	-363.00	219.00	-144.00
1999	-246.00	438.00	192.00
2000	-252.00	453.00	201.00
2001	-484.00	287.00	-197.00
2002	-233.00	280.00	47.00
2003	-295.00	273.00	-22.00
2004	-230.00	436.00	206.00
2005	-284.00	307.00	23.00
2006	-233.00	825.00	592.00
2007	-362.00	430.00	68.00

Note: The table reports the sum of all estimated gains and losses at the firm-product level. The last column shows the net aggregate gains.

Table A1: Production function estimation - by prodcom2 - WLP (no control for quality)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	15	28	36	24	26	25	29	17	18	21	27	31
$logR_{(-g)}$	-0.108***	-0.104***	-0.094***	-0.089***	-0.084***	-0.084***	-0.103***	-0.098***	-0.102***	-0.079***	-0.128***	-0.045***
	(0.001)	(0.001)	(0.003)	(0.002)	(0.001)	(0.002)	(0.004)	(0.002)	(0.005)	(0.002)	(0.003)	(0.005)
$logL$	-0.004	0.106***	0.346***	-0.487***	0.129***	-0.283***	0.303***	-0.065***	-0.010	-0.088**	-0.027	0.072
	(0.011)	(0.024)	(0.037)	(0.027)	(0.022)	(0.033)	(0.055)	(0.023)	(0.023)	(0.038)	(0.036)	(0.086)
$logM$	0.668***	0.782***	0.947***	1.280***	0.593***	1.233***	0.346**	1.003***	0.449***	0.839***	1.248***	0.695***
	(0.054)	(0.097)	(0.135)	(0.097)	(0.109)	(0.131)	(0.173)	(0.116)	(0.054)	(0.135)	(0.153)	(0.239)
$logK$	0.205***	0.265***	0.251*	-0.128	0.432***	0.081	-0.077	0.207*	0.257**	0.075	-0.010	0.733***
	(0.044)	(0.095)	(0.130)	(0.122)	(0.100)	(0.112)	(0.179)	(0.113)	(0.124)	(0.129)	(0.163)	(0.200)
# obs.	52,573	20,100	15,031	14,760	12,653	12,272	12,106	11,369	8,545	6,291	6,017	4,437

Note: This table replicates the results presented in Table 3 (see note of Table 3) without correcting for the input price bias in the TFP estimation. All specifications include quarter-year and product dummies. Results are reported for the 12 largest PRODCOM2 categories. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A2: Import competition and firm-product productivity (robustness check #1 - different estimation methods)

Dep. var.: TFP	(1) OLS	(2) WOP	(3) with quadratic term for $logR_{(-g)}$	(4) without price control
	(1)	(2)	(3)	(4)
Lagged import share	0.849*	0.378	1.292**	0.934**
	(0.472)	(0.390)	(0.558)	(0.474)
Second product	-0.096***	-0.132***	-0.070***	-0.083***
	(0.020)	(0.029)	(0.024)	(0.020)
Third product	-0.127***	-0.147***	-0.066**	-0.106***
	(0.026)	(0.034)	(0.032)	(0.026)
Product above rank 3	-0.235***	-0.212***	-0.193***	-0.205***
	(0.026)	(0.037)	(0.031)	(0.026)
Lagged import share x 2nd prod.	-0.069	0.089	0.043	-0.110
	(0.075)	(0.117)	(0.093)	(0.078)
Lagged import share x 3rd prod.	-0.405***	-0.284**	-0.341***	-0.453***
	(0.087)	(0.127)	(0.107)	(0.089)
Lagged import share x higher rank prod.	-0.452***	-0.450***	-0.269***	-0.491***
	(0.081)	(0.131)	(0.100)	(0.084)
Lagged TFP	0.870***	0.878***	0.871***	0.878***
	(0.003)	(0.003)	(0.003)	(0.003)
# obs.	106,243	80,592	100,967	100,967

This table reports four robustness checks of our results of the last column of Table 4 (see Note of Table 4). Column (1) does not correct for the input price bias in the TFP estimation; column (2) uses a quadratic term for the revenues of the other goods produced by the firm in the TFP estimation; column (3) uses a simple OLS estimation to retrieve TFP and column (4) uses the Wooldridge modification of the Olley and Pakes approach to estimate TFP. 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 A3: Import competition and firm-product productivity (robustness check #2)

Dep. var.: TFP	(1) Only MP firms	(2) Only MP firms with price control	(3) All firms - with firm level import & export dummies	(4) All firms - with firm-product import & export dummies
Lagged import share	1.142**	1.347**	1.034**	1.025**
	(0.547)	(0.547)	(0.465)	(0.465)
Second product	-0.072***	-0.067***	-0.078***	-0.078***
	(0.025)	(0.025)	(0.020)	(0.020)
Third product	-0.098***	-0.062*	-0.077***	-0.077***
	(0.034)	(0.034)	(0.026)	(0.026)
Product above rank 3	-0.214***	-0.183***	-0.183***	-0.183***
	(0.033)	(0.034)	(0.026)	(0.026)
Lagged import share x 2nd prod.	-0.075	-0.050	-0.090	-0.088
	(0.095)	(0.096)	(0.076)	(0.076)
Lagged import share x 3rd prod.	-0.445***	-0.471***	-0.469***	-0.470***
	(0.114)	(0.115)	(0.087)	(0.087)
Lagged import share x higher rank prod.	-0.463***	-0.450***	-0.468***	-0.468***
	(0.109)	(0.110)	(0.082)	(0.082)
Lagged Importer dummy			0.016**	-0.007
			(0.007)	(0.005)
Lagged exporter dummy			0.007	0.026***
			(0.007)	(0.006)
Lagged TFP	0.839***	0.857***	0.893***	0.893***
	(0.003)	(0.003)	(0.003)	(0.003)
# obs.	81,940	81,940	100,967	100,967

Note: This table reports four robustness checks of our results of the last column Table 4 (see Note of Table 4). Column (1) considers only multi-product firms; column (2) considers only multi-product firms and does not correct for the input price bias in our TFP estimation. Columns (3) and (4) control for the firm's decision to import and export by adding firm level import and export dummies in column (3) and firm-product level import and export dummies in column (4). 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 A4: Import competition and firm-product productivity (robustness check #3)

	(1)	(2)	(3)
Dep. var.: TFP	All Firms - spec. 2	All Firms - spec. 3	All Firms - spec. 4
Lagged import share	1.102	0.797*	0.634
	(0.695)	(0.457)	(0.458)
Second product	-0.268***	-0.116***	-0.115***
	(0.0303)	(0.020)	(0.020)
Third product	-0.287***	-0.088***	-0.079***
	(0.039)	(0.025)	(0.025)
Product above rank 3	-0.398***	-0.155***	-0.144***
	(0.039)	(0.025)	(0.025)
Lagged import share x 2nd prod.	-0.002	-0.088	-0.094
	(0.115)	(0.076)	(0.075)
Lagged import share x 3rd prod.	-0.468***	-0.484***	-0.510***
	(0.131)	(0.087)	(0.086)
Lagged import share x higher rank prod.	-0.474***	-0.513***	-0.530***
	(0.123)	(0.081)	(0.081)
Lagged TFP	0.782***	0.896***	0.891***
	(0.004)	(0.003)	(0.003)
# obs.	100,967	100,967	100,967

Note: This table reports three robustness checks of our results of the last column of Table 4 (see Note of Table 4) by using alternative indices of quantity aggregation for $q_{i(-j)t}$ in our TFP estimation. In column (1), the index sums log of quantity of all the other goods weighted by price; in column (2) the index aggregates the sum of the log of deflated value minus the log of deflated value of good; in column (3) the index sums the log of physical quantity of all the other goods. 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 A5: Import competition and firm-product productivity (robustness check #4)

Dep. var.: TFP	(1) All Firms - IS1	(2) All Firms - IS2
Lagged import share	0.514**	0.959**
	(0.258)	(0.423)
Second product	-0.110***	-0.078***
	(0.0230)	(0.021)
Third product	-0.158***	-0.063**
	(0.036)	(0.029)
Product above rank 3	-0.208***	-0.163***
	(0.031)	(0.029)
Lagged import share x 2nd prod.	0.030	-0.078
	(0.061)	(0.071)
Lagged import share x 3rd prod.	-0.143*	-0.454***
	(0.086)	(0.086)
Lagged import share x higher rank prod.	-0.284***	-0.469***
	(0.0731)	(0.0816)
Lagged TFP	0.890***	0.894***
	(0.002)	(0.003)
# obs.	100,967	100,967

Note: This table reports two robustness checks of our results of the last column of of Table 4 (see Note of Table 4) by using import shares computed in value in column (1) and in quantity in column (2). 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.