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

Emmanuel Dhyne
NBB, UMons

Amil Petrin
U. Minnesota

Valerie Smeets
Aarhus U.

Frederic Warzynski
Aarhus U.†

April 18, 2016

Abstract

We study how increased import competition induced by falling Chinese import tariffs 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 1995Q1-2007Q4, 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. We find import competition is strongly positively related to firm-product level productivity, with a increase of 0.05 in the import penetration rate leading to a 5% gain in technical efficiency. Firms appear to be less technically efficient at producing goods the further they get from their core-revenue product. Import competition is most highly correlated with the core-revenue products' technical efficiency and less so for non core-revenue product efficiencies. 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. Up to the OLS/IV distinction our results are robust to the choice of addressing simultaneity or not (OLS, Wooldridge-OP/W-LP), hold for both single-or multi-product firms, and are not "affected" by the firm's own international trade decision.

*We thank seminar participants at the 2014 NBB Conference, Riksbank, the 11th International Conference, Monash University, Mannheim, EITI2015, IIOC2015, ATW2015, Rice University, Texas A&M, DIEW2015, NOITS2015, Uppsala, the final COMPNET conference, ESWC2015, LSE and Hong Kong University. A. Petrin, V. Smeets and F. Warzynski thank the National Bank of Belgium for its financial support. The authors are also extremely grateful for the support provided by the NBB Statistical department for the construction of the dataset used. The results presented respect the confidentiality restrictions associated with some of the data sources used. The views expressed are those of the authors and do not necessarily reflect the views of the NBB. All errors are ours.

†Corresponding author - email : fwa@asb.dk

1 Introduction

Product market competition is often considered to be an important mechanism to promote efficiency (see e.g. Aghion and Howitt, 1996 for a theoretical motivation; see also Holmes and Schmitz, 2010 for a recent review of the literature). It is supposed to discipline firms and provide them strong incentives to innovate and adopt new practices in order to remain profitable or simply survive. Several important contributions in the productivity literature (e.g. Olley and Pakes, 1996; Pavcnik, 2002; Bloom, Draca and Van Reenen, 2016) have established a clear relationship between productivity growth and increased competition.

We study how increased import competition induced by falling Chinese import tariffs affects the evolution of firm-product technical efficiencies in the small open economy of Belgium. We observe quarterly firm-product observations at the 8-digit level on quantities sold and unit prices (the PRODCOM data) from the period 1995Q1-2007Q4. We also observe quarterly measures of labor, capital, and intermediate inputs at the firm level from the same period. Using Diewert (1973) and Lau (1976) we show how to estimate quarterly firm-product technical efficiency shocks without assuming multi-product production is a collection of single-product production processes and without having to allocate the inputs across the different products produced by the firm.

These technical efficiency shocks 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. We relate these quarterly firm-product technical efficiency shocks to last-period's - last quarter's - technical efficiency shock, 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.

We find that firms' strongly react to competition, with an increase of 0.05 in the import penetration rate associated with a 5% gain in technical efficiency. We find that firms appear to be less technically efficient at producing goods that account for a lower share of their revenue, and that import competition is less strongly connected to technical efficiency gains for non-core products. We also find that instrumenting, 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. Up to the OLS/IV distinction our results are robust to the choice of the econometric technique, to the subset of firms selected (all firms or only multi-product firms), and to the firm's own trade decision.

One clear finding in our multi-product data, a finding which is consistent with other papers that have looked at multi-product data, is that most production is multi-product production.[1] To estimate multi-product production functions 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. Single-product production relationships are defined as the set of single-product output levels that are possible given a particular set of inputs. The single-product production function assigns the maximal output achievable for any given set of inputs.

The multi-product generalization is similar; for any particular set of inputs the relationship gives the sets of output vectors that are producible using that input set. For any given vector of outputs it gives the sets of inputs capable of producing that output vector. The generalized production function is the maximal amount of one output achievable holding all input and other output levels constant. The existence result is critical for motivating estimation of each quantity as a function of total input levels and quantities of all other products produced by the firm. Once we have motivated existence we then show how to address the simultaneity of both inputs and outputs using a slight extension of Olley-Pakes or Levinsohn-Petrin.

The closest paper to us is perhaps De Loecker et. al (2016) who study the effect of trade liberalization in India on prices, marginal costs and markups using similar multi-product data from India. They assume that multi-product production is a collection of single product production functions and suggest a novel algorithm to estimate production function parameters where they endogenously derive the share of inputs allocated to each output. Their method delivers one technical efficiency term for each firm. Our approach has firm-product technical efficiency shocks, it does not require multi-product production to be a collection of single product productions functions, and it does not require us to allocate inputs among the different products produced.[2]

A key empirical challenge for our approach is that the theory applies only to particular production tuples and in a small country like Belgium the number of observations per production tuple can be limited. For example, firms producing five products cannot all be pooled together; only firms producing the exact same five products can be pooled together, and in Belgium for many production tuples the number of observations is small. We show the standard aggregation assumptions under which using a quantity aggregator is valid for the production function. This allows the researcher to "add back" many of the firm-product observations that would otherwise be lost due to a lack of observations

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

[2] The production possibilities set is defined in terms of aggregated inputs and outputs.

on production tuples. Alternatively parts of or all of the approach of De Loecker et. al (2016) could be combined with our moment conditions in a hybrid approach that could address paucity of data. In this sense our work is highly complementary.

Our work is related to theoretical predictions of recent theoretical papers on international trade with multi-product firms (e.g. Eckel and Neary, 2010; Bernard, Redding and Schott, 2010, 2011; Mayer, Melitz and Ottaviano, 2014). These papers consider that firms have a clear ordering of products based on their capability. The most important (core) product corresponds to the core competency of the firm. Because we are able to measure productivity at the firm-product level we can address these papers and indeed our results are consistent with firms behaving as these models predict.

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 Secton 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. Quantities and unit prices are available at the 8-digit PRODCOM level (more below) from the PRODCOM survey. We use quarterly information coming from 3 different sources - the Value Added Tax (VAT) declarations, the Social Security declarations and the annual accounts - in order to construct quarterly estimates of the inputs of labor, capital, and intermediate inputs. We use the international trade data hosted at the National Bank of Belgium (NBB) coupled with the PRODCOM data to construct quarterly 8-digit product-specific import penetration rates. From the World bank we obtain information on the evolution of European tariffs on Chinese imports which we use as instruments. We discuss each data source in turn.

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. 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 Chinese tariffs fell significantly for many products over this period.[4]

We keep only firms that have their principle business activities in manufacturing and we exclude firms that report a total value of production at odds with the value that they report in their annual accounts. 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%. See the data appendix for more details about data cleaning.

The Value Added Tax revenue data provides us with a separate check agains 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.[5]

Table 1 displays the average relative share of products in firms' portfolios when they are producing a different number of products at various levels of aggregation (8-digit and 4-digit PRODCOM). The majority of firms are multi-product firms. They also have a much larger weight in the economy as they contribute for around 75% of total value in our sample. The average firm in our sample produces around 2.5 products and multi-product firms typically have a core product that represents the major part of their sales;(77.5% for firms producing 2 goods and 50% for firms producing more than 5 goods).

One clear implication of Table 1 is the standard approach to estimating production functions - where the dependent variable is total deflated revenue across all of a firm's

[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]Two other reasons for stopping in 2007 specifically are that the product classification system was significantly revised in 2008 and the sample sizes were reduced at that time.

[5]Anecdotally it has been suggested to us that many firms have one piece of software reporting the same number to both agencies.

products - is mixing outputs of potentially different production technologies, one for each product produced. If so then the resulting estimates are a reduced form description of some "hybrid" technology, but have no structural interpretation. We will estimate separate production technologies for each product in our analysis.

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 the 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.[6]

2.3 The Increase in Import Penetration Rates: 1995-2007

We construct three separate measures of import penetration using the international trade database and the PRODCOM database together. The trade database provides firm-level information on international transactions of goods, by product, classified according to the CN 8 digit product classification, and by country of destination for export or country of

[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.

origin for imports. Our first measures is given as

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

where Y_{jt} represents the value of production of good j in quarter t as measured in PROD-COM and M_{jt} represents the value of imports of good j in quarter t as measured in the trade dataset. We compute a similar indicator - $IS_{2,jt}$ - using physical quantities instead of value.

Neither one of these measures accounts for re-exports which play an important role in Belgian trade, as a significant fraction of the product entering in Belgium are re-shipped to other EU markets. When computing the import penetration ratio one might want to correct the numerator and denominator should be corrected for re-export, but this is not reported in the data.In order to proxy for such a measure, we assume that, if a firm imports and exports the same good j, its import of that particular product for the Belgian market is given by $Max\left\{M_{ijt} - X_{ijt}, 0\right\}$, which means that if a firm is producing and importing the same product, it first exports what has been imported and it only exports its domestic production if the amount exported is larger than the amount imported. Net imports should be expressed in physical units:

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

Table 2 shows that import competition at the product level displays significant heterogeneity both within industries and over time.[7] While import competition has increased on average for all industries shown in the table, we also observe that some producers are facing relatively little competition for the goods that they make, while other product markets are completely flooded with imports.

2.4 The Fall in European Import Tariffs: 1995-2007

Over the last 25 years, the competitive environment has changed quite a lot for Belgian firms. The Single Market Program was implemented on January 1, 1993 and this has led to increased competition within the EU. More recently, the most important shock for firms in advanced economies has been the entry of China in the WTO.

[7]This table shows the summary statistics for our third measure of import share that controls for re-export, since this is the main measure we will use in our subsequent analysis. We will also discuss the results with the alternative measures in the subsection on robustness checks. Appendix A1 shows the summary statistics for the other two measures.

In our analysis, we will require instrumental variables for our import competition variable. 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.[8] 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.

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

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.

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

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.

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.

The single-product production function gives the maximal output q that can be produced using N non-negative inputs denoted $x = (x_1, x_2, \ldots, x_N)$. Under assumptions outlined below it exists and one can write $q = F(x)$, motivating estimating a production function by regressing output on inputs. There are several well-known testable implications like $F(x)$ weakly increasing in every element of x, which follows from the free disposal of inputs (Diewert (1973)). Thus if all estimated elasticities of output with respect to inputs are not significantly weakly positive then the function is not a production function.

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

In the multi-output and multi-input setting the firm's production possibilities set T lives on the non-negative orthant of R^{J+N} and contains all of the combinations of J non-negative outputs $q = (q_1, q_2, \ldots, q_J)$ that can be produced by using N non-negative inputs x. The multi-product analog to the single product production function is given as

$$q_j = F_j(q_{-j}, x),$$

where q_{-j} denotes all other products produced by good j. It denotes the maximal output that can be achieved for good j given inputs x and production of other goods fixed at q_{-j}. The assumptions that deliver existence are similar to the single product case.

In order for the estimated function to be consistent with multi-product production function two conditions must hold. The conditional other-output elasticities must be negative; holding inputs constant at x an increase in production of any product in q_{-j} holding the others constant weakly leads to a decrease in the amount of produced output q_j. Second, the conditional input elasticities must be positive; holding other outputs constant at q_{-j} an increase in an input weakly holding other inputs constant leads to more weakly output of q_j. These follow from generalized free disposal assumptions in the multi-input and multi-output setting.

In both the single product case and the multi-product case there is the possibility that inputs or outputs suffer from "fixity" - defined precisely below - which leads to increasing returns to scale. Lau(1976)'s disjoint biconvexity condition extends the convexity assumption on the production possibilities set in Diewert (1973) to allow for fixity in subsets of inputs or outputs.

3.1 Single Product Firms

Single-product production relationships are defined as the set of single-product output levels that are possible given a particular set of inputs. One can also characterize this relationship as - for a given level of output - what sets of inputs can produce that output. The single-product production function assigns the maximal output achievable for any given set of inputs.

In the single-product setting the primitive of production analysis is the firm's production possibilities set T, which 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 non-negative inputs $x = (x_1, x_2, \ldots, x_N)$; if $(\tilde{q}_1, \tilde{x}) \in T$ if $\tilde{q}_1$ is producible given $\tilde{x}$, Formally the production function (production frontier) $F(x)$ is defined as:

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

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 an enormous literature where applied researchers have checked whether their estimated production functions satisfy these conditions.

3.2 Diewert-Lau Multi-Product Production

The multi-product generalization is similar. For any particular set of inputs the relationship gives the sets of output vectors that are producible using that input set. For any given vector of outputs it gives the sets of inputs capable of producing that output vector. The generalized production function (or transformation function) is the maximal amount of one output achievable holding all input and other output levels constant. In this section we use a combination of results from Diewert (1973) and Lau (1976) to generalize well-known single-product production function results - existence of it and testable restrictions on it - to multi-product settings.

In the multi-output and multi-input setting the firm's production possibilities set T lives on the non-negative orthant of R^{J+N} and 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 $x = (x_1, x_2, \ldots, x_N)$; 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}. The multi-product transformation function is defined 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 $(q_j, q_{-j}, x) \in T$, and

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

if $(q_j, q_{-j}, x) \notin T \; \forall q_j \geq 0$.[9] Before turning to the assumptions on the multi-product production possibilities set we briefly discuss notation.

In the single product case it is possibility loosen the assumption of freely variable inputs - equivalent to convexity over inputs in the production set - to allow for the possibility of input-fixity, that is, the inability to instantaneously change the level of an input. In the multi-product setting, the generalization allows for the possibility of fixity both in inputs and outputs.In the statement of the conditions on the production possibilities set and in the proof of the multi-product extension it will be useful to divide inputs and outputs

[9]Note this qualification on the transformation function only arises once there are two or more outputs. In the single product case if no output can be produced then the function takes on zero value. The multi-product case has to account for the fact that certain couples of inputs and outputs may not be possible.

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.[10]

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.*

[10]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 is critical for motivating estimation of each quantity as a function of the quantities of all other products produced by the firm and total input levels. Our approach does not require multi-product production to be a collection of single product productions functions. It also does it require us to allocate inputs among the the different products produced by the firm because the production possibilities set is defined in terms of aggregated inputs.

4 Functional Forms for Production

In this section we describe simple Cobb-Douglass approximations for both single- and multiple-product production. It is straightforward to move to the trans-log by adding higher-order terms.

4.1 Single- and Two-Product Production

We start with the case where a firm may produce one of two products or both together. A simple example is found in Dhyne, Petrin and Warzynski (2014) who look at the bread and cakes industry in Belgium, where some firms produce only bread, some produce only cake, and some produce both bread and cake. They estimate four separate production processes. Let q_{iBt} and q_{iCt} denote the output quantities of bread and cakes respectively and let (l_{it}, k_{it}, m_{it}) denote labor, capital and intermediate inputs (outputs and inputs are in logs). For firms producing just bread or cakes the production model is the standard single product production model with different parameters for the production function depending upon whether bread or cakes is the dependent variable, e.g.:

$$q_{iBt} = \beta_0 + \beta_l^0 l_{it} + \beta_k^0 k_{it} + \beta_m^0 m_{it} + \varepsilon_{iBt} \tag{1}$$

with the production parameters $\beta^0 = (\beta_l^0, \beta_k^0, \beta_m^0)$ now having the interpretation as the percentage change in bread output due to a percent change in any one input holding the other inputs constant. The function is only a production function if $\beta^0 > 0$. The analogous approach is used to estimate the cake production function.

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 $\beta^b = (\beta_l^b, \beta_k^b, \beta_m^b)$ now having the interpretation as the percentage change in bread output due to a percent change in any one input holding other inputs and cake output constant. γ_C is the 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 $\gamma_C < 0$.

For firms producing both bread and cakes the production function for cakes is given as a function of inputs and bread production:

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

with the production parameters $\beta^c = (\beta_l^c, \beta_k^c, \beta_m^c)$ now having the interpretation as the percentage change in cake output due to a percent change in any one of the inputs holding all other inputs and bread output constant. γ_C is the change in cake output that results from increasing the output of bread by one percent holding overall input use constant. The function is only a production function if $\beta^c > 0$ and $\gamma_B < 0$.

In the single product case there is the well-known simultaneity problem Marschak and Andrews (1944) where input demand is in part determined by the productivity shock. In the two-product case the same simultaneity concern remains, where part of (e.g.) ε_{iBt} - the part of productivity known by the firm when it makes inputs choices - is correlated with the input levels. There is the added challenge in the two-product case in that q_{iCt} and q_{iBT} is a system of equations so by construction they will both be correlated with both ε_{iBt} and ε_{iCt}, so they will have to be instrumented as we discuss further in the estimation section.

4.2 J-Product Production Model

The general J product system of production equations is given as:

$$q_{ijt} = \beta_0^j + \beta_l^j l_{it} + \beta_k^j k_{it} + \beta_m^j m_{it} + \gamma_{-j}^j q_{i-jt} + \varepsilon_{ijt} \quad j = 1 \cdots J \tag{4}$$

where q_{-j} denotes the vector of all other outputs excluding q_j and γ_{-j}^j denote 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 production parameters $\beta^j = (\beta_l^j, \beta_k^j, \beta_m^j)$ now have the interpretation as the percentage change in q_j due to a percent change in any of the inputs holding all other inputs and outputs q_{-j} constant. The function is only well-defined when $\beta^j > 0$ and $\gamma_{-j} < 0$. Just as in the two-product case all quantities will generally be a function of $\varepsilon_{ijt} \quad j = 1 \cdots J$ so they will have to be instrumented in addition to addressing the input simultaneity problem.

4.3 Quantity Aggregation

In reality, many firms produce more than 2 goods and industries are composed of firms with different product portfolios. We generalize the theory by simplifying the problem and assuming we can aggregate all the other products produced by the firm (except good g).[11] We are therefore suggesting an hybrid method, and we estimate instead:

$$q_{ijt} = \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \gamma_j r_{i-jt} + \varepsilon_{ijt} \tag{5}$$

where q_{igt} denotes the log of physical quantity of a good g produced by firm i and $r_{i(-g)t}$ denote the log of deflated revenue. We also experiment with alternative quantity indices. Our second index sums log of quantity of all the other goods weighted by price ($\sum_{j \neq g} p_j lnq_j$) and then substracts from this sum the log of the quantity of good g multiplied by the price of good g. The third one aggregates the sum of the log of deflated value ($\sum_{j \neq g} ln(p_j q_j)$) minus the deflated value of good g. The last one simply sums the log of physical quantity of all the other goods except g ($\sum_{j \neq g} lnq_j$) and we then substract lnq_g. Depending on the economic environment that the firm is facing, these various aggregation methods will be more or less realistic. Our main purpose however is to use these alternative indices as robustness checks so as to verify if our results are affected by the choice of the aggregation method chosen.

5 Estimation

We review the Olley-Pakes and Levinsohn-Petrin methodologies within the Wooldridge (2009) framework, which allows us to address the simultaneity issue that induces a correlation between the productivity residual and inputs. In the multi-product setting we must also instrument for any quantities that are explanatory variables because they are simultaneously determined with all other outputs in the system of output equations. We first review the methodology for the single-product case and then show how it extends directly to the multi-product case.

5.1 Wooldridge OP/LP Methodology: Single Product

From before we have the production function written with the log of output as a function of the log of inputs and shocks

$$q_t = \beta_l l_t + \beta_k k_t + \beta_m m_t + \omega_t + \epsilon_t$$

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

[11]Roberts and Supina (2000) follow a similar procedure when estimating cost functions.

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.

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.[12] Wooldridge (2009) uses a single index restriction to approximate unobserved productivity, so in the OP setting one has

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

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

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

for some unknown function $p(\cdot)$.[13]

Rewriting the production function as

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

yields

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

with $\beta = (\beta_l, \beta_k, \beta_m, \beta_\omega)$, $\theta = (\beta, q)$. Let the set of conditioning variables be $x_t = (k_t, k_{t-1}, m_{t-1}, l_{t-1})$ and let θ_0 denote the true parameter value. Wooldridge shows that the conditional moment restriction

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

is sufficient for identification of $(\beta_l, \beta_k, \beta_m)$ and $E[\omega_t|\omega_{t-1}]$. It is also robust to the Ackerberg, Caves, and Frazer (2006) criticism of OP/LP. In equation (7) a function of i_{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 lagged materials m_{t-1} serve as instruments for l_t and m_t.

[12] 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 $\omega_t = h_t(m_t, k_t)$.

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

5.2 Multi-Product Production

In the multi-product case we have for q_j:

$$q_{jt} = \beta_l l_t + \beta_k k_t + \beta_m m_t + \beta'_{q-j} q_{-jt} + E[\omega_{jt}|\omega_{j,t-1}] + \xi_{jt} + \epsilon_{jt} \tag{7}$$

yields

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

with the new parameters β_{-j} added to $\beta = (\beta_l, \beta_k, \beta_m, \beta_{-j}, \beta_\omega)$. Add to the set of conditioning variables either further lags in inputs or the lagged output levels so (e.g.) $x_{jt} = (q_{-j,t-1}, k_t, k_{t-1}, m_{t-1}, l_{t-1})$. 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 and $E[\omega_t|\omega_{t-1}]$. 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.

5.3 The link between productivity and imports

We now discuss how our productivity measures are related to import share.[14] In our first specification, we regress firm-product level technical efficiency on last quarter's lagged technical efficiency and lagged product import share. We also include product dummies (ν_j) and year-quarter dummies (δ_t).

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

In our second specification we control for the rank of the product by including a vector of rank dummies ($Rank_{ijt}$) 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 has a different relationship with productivity depending on the rank of the product.

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

[14] We use the import share net of re-exporting in most of our analysis, but we show that the results are robust when we consider our two other measures.

Since input shares are dependent on all demand and supply factors and shocks in a market, the shock to the productivity equation could very well be correlated with the import share. As discussed in Section 2.3 we use as instruments Chinese tariffs over the period 1995-2007 to instrument these changes in import share.

6 Results

In this section, we first present the results from the estimation of our MPPF. We start with the estimation with physical quantities on both sides of the regression and restricting our attention to those firms producing goods in two 4-digit product categories (what we refer to as the "pure" Diewert-Lau approach). We then switch to the hybrid approach where we use an aggregate variable for all the other goods produced by the firm on the right hand side, while keeping the physical quantity of the good considered on the left hand side. Last, we relate our TFP estimates with product specific measures of competition and product rank.

6.1 The pure Diewert-Lau approach

For this analysis, we first looked at the most common pairs of goods that firms were producing at the 8-digit PRODCOM level. We realized that there were not many examples of economic environments where a sufficiently high number of firms produce exactly the same two products (with the exception of bread and cake, or doors and windows). Therefore, we tried to aggregate the analysis at the 4-digit PRODCOM level (equivalent to NACE). By doing so, we were able to identify a larger subset of economic environments where firms produce the same "combinations" of goods. In many cases, firms produce goods within the same 2-digit or even 3-digit product category, so it justifies the fact that we use a common production function for both types of products.

Table 4 shows the estimates for the 12 "combos" where we observe the largest number of observations (after applying our Wooldridge algorithm that requires the use of lagged instruments and lagged variables in the control function). We follow the suggestion in De Loecker et al. (2016) and adjust for the quality differences within product code (possibly due to input price heterogeneity bias) by adding output price in the control function.[15] We observe that the coefficients behave as expected. The coefficient of $logQ_2$ is always negative and significant, although the size varies a lot between combos. This possibly reflects differences in substitution patterns and economics of scope.

[15] De Loecker et al. (2016) also add market share in their algorithm, but it did not make a big difference in our case. We thank Jan De Loecker and Penni Goldberg for suggesting this approach in our research framework.

One important problem however is that we can only apply this methodology to a limited subsets of firms and products, in those environments where firms' product mix is not too complex and relatively homogeneous between firms probably facing similar competitive environment and technology. Therefore, we next turn to our hybrid approach.

6.2 The hybrid approach

We next use our extended Diewert approach to estimate MPPF. Our left hand side variable is now the physical quantity of a given good produced by the firm, and we pooled within a 2-digit PRODCOM category using all observations of multi-product firms, as long as these products contributed at least to 5% of the turnover of a firm (the analysis was also conducted at the 4-digit and even 8-digit, although for a limited set of products for which we had enough observations). Table 4 shows the estimates using the Wooldridge approach and controlling for price for the 9 most important industries in Belgian manufacturing.[16]

We get reasonable estimates as coefficients are more or less in the range than we would expect. The coefficient of $r_{i(-g)t}$ is always negative and ranges around -0.10 across industries. Differences across 2-digit product categories were expected, as firms differ in their technologies and product scope. In particular, the negative coefficient of $r_{i(-g)t}$ captures how the constraint of producing more other goods limits the physical production of good g, controlling for the use of inputs. In any case, it is important to note that we have to consider the four coefficients together to interpret them. Indeed, the input coefficients are all conditional on the production of other goods.

6.3 The link between productivity and imports

Table 5 displays the results of the link between firm-product level productivity and product-level import share. All specifications include quarter-year and product dummies. In column 1, we find that the import competition is positively related to firm-product level productivity, in line with our theoretical prior that competition provides incentives to innovate and remain competitive. In column 2, we control for the rank of the product and find that firms appear to be less productive the further away from their core product. This is consistent with recent theories of multi-product firms in the trade literature, as previously discussed. The coefficient of import share and productivity remain relatively unchanged when adding these variables. Finally, in column 3, we add an interaction between a dummy for the rank of the product and the import share for the product. The

[16] Appendix A2 shows the coefficients when we do not control for price. As in De Loecker et al. (2016), some coefficients were out of the usual range. Note that controlling for price does not affect our results in the next subsection.

coefficient of import share (related to the core product) increases, while the coefficients of import share interacted with the rank dummies become more negative the higher the rank, suggesting that import competition is less strongly connected to productivity the further is the product from the core competence of the firm.

As discussed previously, we suspect our measure of import competition might be endogenous and we therefore instrument import competition with tariffs and world export supply. The last three columns of table 5 show the IV results for our three main specifications.We observe that the coefficient of import share increases almost by a magnitude of ten from 0.1 to 0.9. Moving to column 5 where we control for product rank, the result remains robust, and we find again evidence regarding the productivity ranking by product order. Finally, our third specification is also similar to the OLS, although the magnitude of the coefficients is much larger.

These results suggest that import competition affects the various products that firms produce very differently. Firms tend to be more efficient in the production of their core product (relative to non-core products), as suggested by recent theoretical contributions (see e.g. Bernard, Redding and Schott, 2011; Mayer, Melitz, Ottaviano, 2014) but they are also increasing their core-product efficiency in response to increase in foreign competition.

6.4 Robustness checks

We perform several additional robustness checks to see if our results depend on the econometric method chosen, on the aggregation method chosen or on firms' international trade decisions.

The first column of table 6 shows the results from our main specification when we add a price control in the control function. In the second column, we also add a quadratic term for $logR$. None of our results appear to be affected. The next two columns show that our results are also relatively similar if we use our TFP measures obtained using OLS or WOP (results are a bit less strong in the latter case, as two coefficients are not significant).

In table 7, we use the productivity measures obtained from the pure Diewert-Lau approach in table 4. Even if we have a smaller sample size and if the coefficients were sometimes a bit "out of range", we still find a similar result that firm-product level productivity is positively associated with the import share; that the second product is around 20% less productive than the core product; and that the interaction between import share and second product has a negative coefficient, although not significant in this case. It might be because of the limited variation in this limited sample with only a few product combinations being considered.

In the first two columns of table A3, we consider only multi product firms (without and with price control). In the next two columns, we control for the firm's decisions to import and/or export at the firm-product or firm level. Our coefficients of interest are unchanged. In table A4, we use alternative measures of TFP obtained with the different aggregate measures discussed in section 4. It does not appear to affect our results. Last, in table A5, we show the results when we use our alternative measures of import shares (IS1 and IS2). Results are a little bit less convincing when not correcting for re-export, but most of the results hold through.

7 Conclusion

In this paper, we develop several tools to estimate TFP with multi-product firms using detailed quarterly data on physical quantities produced by firms. We use our estimates to study the link between productivity and import competition. We show a generally positive relationship between firm level productivity and import competition, pointing towards the disciplinary effect of competition on efficiency. In addition, based on our firm-product analysis, it seems that the disciplinary effect of import competition on firm efficiency is not uniformly distributed across the various manufactured goods of the firm's products portfolio. Our results indicate that this disciplinary effect is at play only for the core products. When non core activities are considered, increased foreign competition does not seem to generate efficiency gains. On the contrary, it may be associated with lower efficiency, what might lead to a relative withdrawal in the production of those goods. Our analysis also confirms recent predictions of theoretical models of multi-product firms in trade (e.g. Bernard, Redding and Schott, 2011; Mayer, Melitz and Ottaviano, 2014) as firms are shown to be more productive for their core products.

References

[1] Aghion, P. and Howitt, P., 1996. *Endogenous Growth Theory.* MIT Press.

[2] Bernard, A., E. Blanchard, I. Van Beveren and H. Vandenbussche, 2012. Multi-Product Exporters, Carry-Along Trade and the Margins of Trade. NBER Working Paper #18246.

[3] Bernard, A. B., Redding, S. J. and Schott, P. K., 2010. Multiple-Product Firms and Product Switching. American Economic Review 100, 70-97.

[4] Bernard, A. B., Redding, S. J. and Schott, P. K., 2011. Multi-product Firms and Trade Liberalization. Quarterly Journal of Economics 126, 1271–1318.

[5] Bloom, N., Draca, M. and Van Reenen, J., 2016. Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity. Review of Economic Studies 83, 87-117.

[6] De Loecker, J., 2011. Product Differentiation, Multi-Product Firms and Estimating the Impact of Trade Liberalization on Productivity. Econometrica 79, 1407-1451.

[7] De Loecker, J., Goldberg, P., Khandelwal, A. and Pavcnik, N., 2016. Prices, markups and Trade Reform. Econometrica 84, 445-510.

[8] Dhyne, E., Petrin, A. and Warzynski, F., 2014. Deregulation and Spillovers in Multi-Product Production Settings. Work in progress.

[9] Diewert, 1973. Functional Forms for Profit and Transformation Functions. Journal of Economic Theory 6, pp. 284-316.

[10] Foster, L., Haltiwanger, J. and Syverson, C., 2008. Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability? American Economic Review 98, 394-425.

[11] Goldberg, P., Khandelwal, A., Pavcnik, N. and Topalova, P., 2010a. Imported Intermediate Input and Domestic Product Growth: Evidence from India. Quarterly Journal of Economics 126, 1727-1767.

[12] Goldberg, P., Khandelwal, A., Pavcnik, N. and Topalova, P., 2010b. Multiproduct Firms and Product Turnover in the Developing World: Evidence from India. Review of Economics and Statistics 92, 1042-1049.

[13] Holmes, T. and Schmitz, T., 2010. Competition and Productivity: A Review of Evidence. Annual Review of Economics 2, 619–42.

[14] Hummels, D., Jørgensen, R., Munch, J. and Xiang, C., 2014. The Wage Effects of Offshoring: Evidence from Danish Matched Worker-firm Data. American Economic Review 104, 1597–1629.

[15] Klette, T. J. and Griliches, Z., 1996. The Inconsistency of Common Scale Estimators When Output Prices Are Unobserved and Endogenous. Journal of Applied Econometrics 11, 343-361.

[16] Lau, L., 1976. A Characterization of the Normalized Restricted Profit Function. Journal of Economic Theory 12, 131-163.

[17] Levinsohn, J. and Melitz, M., 2001. Productivity in a Differentiated Products Market Equilibrium. Mimeo.

[18] Levinsohn, J., and A. Petrin, 2003. Estimating Production Functions Using Inputs to Control for Unobservables. Review of Economic Studies 70, 317-341.

[19] Lileeva, A. and Trefler, D., 2010. Improved Access to Foreign Markets Raises Plant-Level Productivity... for Some Plants. Quarterly Journal of Economics 125, 1051-1099.

[20] Mairesse, J. and Jaumandreu, J., 2005. Panel-data Estimates of the Production Function and the Revenue Function: What Difference Does It Make? Scandinavian Journal of Economics 107, 651–672.

[21] Mayer, T., Melitz, M. and Ottaviano, G., 2014. Market Size, Competition, and the Product Mix of Exporters. American Economic Review 104, 495-536.

[22] Mundlak, Y., and A. Razin, 1971. On Multistage Multiproduct Production Functions. American Journal of Agricultural Economics, 53, 491-499.

[23] Olley, S., and A. Pakes, 1996. The Dynamics of Productivity in the Telecommunications Industry. Econometrica 64, 1263-1297.

[24] Pavcnik, N., 2002. Estimating Production Functions Using Inputs to Control for Unobservables. Review of Economic Studies 70, 317-341.

[25] Roberts, M. and Supina, D., 2000. Output price and markup dispersion in micro data: the roles of producer heterogeneity and noise. Industrial Organization 9, 1-36.

[26] Wooldridge, J. M., 2009. On estimating firm-level production functions using proxy variables to control for unobservables. Economics Letters 104, 112-114.

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 number of products is computed after removing the products with 0 or missing value. Products are defined as 8-digit and 4-digit PRODCOM codes.

Table 2: Summary statistics on import share at the product level

	import shares computed in quantity controlling for re-exports				
	Mean	25th	Median	75th	N
All products					
1997	0.482	0.159	0.431	0.841	1,518
2007	0.546	0.204	0.541	0.924	1,611
Chemicals					
1997	0.477	0.174	0.403	0.859	350
2007	0.507	0.170	0.437	0.906	395
Food and beverages					
1997	0.425	0.136	0.327	0.718	258
2007	0.478	0.163	0.387	0.838	281
Machinery and equipment					
1997	0.954	0.385	0.830	0.954	184
2007	0.979	0.405	0.807	0.979	140
Fabricated metal products					
1997	0.549	0.248	0.553	0.913	107
2007	0.631	0.330	0.725	0.921	115
Rubber and plastic products					
1997	0.508	0.250	0.452	0.774	100
2007	0.533	0.274	0.453	0.850	104

Note: import shares are computed at the 8-digit prodcom level. To classify the product groups, we use the following definition: chemicals (prodcom2=24), food and beverages (prodcom2=15), machinery and equipment (prodcom2=29), fabricated metal products (prodcom2=28), rubber and plastic products (prodcom2=25).

Table 3
Multi-Product Production Functions
Pure Diewert-Lau Approach: lnQ_1 on lnQ_2
Wooldridge-Levinsohn-Petrin Estimator with Quarterly Data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	3613_3614	3614_3613	2811_2812	2812_2811	1512_1513	1513_1512	2522_2521	1571_1561	2213_2211	2875_2811	2212_2213	1513_1520
$logQ_2$	-0.057**	-0.177**	-0.242***	-0.382***	-0.318***	-0.754***	-0.497***	-0.327***	-0.216***	-0.303***	-0.241***	-0.295***
	(0.025)	(0.071)	(0.043)	(0.054)	(0.040)	(0.067)	(0.075)	(0.037)	(0.044)	(0.090)	(0.060)	(0.061)
$logL$	-0.022	0.467**	0.423***	0.477***	-0.094	1.305***	-0.153	0.677***	0.366**	0.248	0.888***	0.072
	(0.117)	(0.234)	(0.120)	(0.116)	(0.126)	(0.274)	(0.253)	(0.216)	(0.169)	(0.159)	(0.161)	(0.088)
$logM$	0.940***	0.485	0.672	0.949	1.198**	-0.227	1.848***	0.022	0.346	0.806	0.362	1.549***
	(0.353)	(0.905)	(0.825)	(0.822)	(0.568)	(0.925)	(0.647)	(0.384)	(0.861)	(0.508)	(0.310)	(0.315)
$logK$	0.0975	0.058	0.540	-0.545	0.522	0.421	-0.129	0.530**	-0.008	0.964	0.041	0.996
	(0.389)	(0.638)	(0.470)	(0.339)	(0.549)	(0.806)	(0.663)	(0.208)	(0.929)	(0.617)	(0.357)	(0.857)
# obs.	855	855	604	604	452	452	442	437	417	291	264	210

Note: Each column reports the results of regressions lnQ_1 on lnQ_2, inputs, and the (log) price of Q_1. The first (second) 4-digit number denotes $lnQ_1(lnQ_2)$. 36 is the two-digit NACE code for furniture, 3613 is other kitchen furniture, 3614 is other furniture, 28 is fabricated metal products except machinery and equipment, 2811 is metal structures and parts of structures, 2812 is builders' carpentry and joinery of metal, 2875 is other fabricated metal products, 15 is food products and beverages, 1513 is production and preserving of poultry meat, 1514 is production of meat and poultry meat products, 1571 is prepared feeds for farm animal, 1561 is grain mill products, 1520 is processing and preserving of fish and fish products, 252 is plastic products, 2522 is plastic packing goods, 2521 is plastic plates, sheets, tubes and profiles, 221 is publishing, 2213 is journals and periodicals, 2211 is books, and 2212 is newspapers. Robust standard errors with *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Production function estimation - by prodcom2 - WLP - controlling for quality differences

	(1) 15	(2) 28	(3) 36	(4) 24	(5) 26	(6) 25	(7) 29	(8) 17	(9) 18	(10) 21	(11) 27	(12) 31
$logR_{(-g)}$	-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)
$logL$	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)
$logM$	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)
$logK$	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

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Columns labeled by two-digit product ISIC

Table 5: Import competition and firm-product productivity

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.: TFP						
Lagged TFP	0.903***	0.872***	0.872***	0.907***	0.878***	0.877***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)
Lagged import share	0.109***	0.098***	0.123***	0.937*	0.975**	0.859**
	(0.013)	(0.013)	(0.014)	(0.482)	(0.474)	(0.437)
Second product		-0.106***	-0.101***		-0.106***	-0.083***
		(0.003)	(0.004)		(0.004)	(0.022)
Third product		-0.234***	-0.225***		-0.236***	-0.093***
		(0.004)	(0.006)		(0.006)	(0.030)
Product above rank 3		-0.352***	-0.307***		-0.352***	-0.185***
		(0.005)	(0.008)		(0.007)	(0.030)
Lagged import share x 2nd prod.			-0.019*			-0.095
			(0.011)			(0.073)
Lagged import share x 3rd prod.			-0.038***			-0.437***
			(0.014)			(0.088)
Lagged import share x higher rank prod.			-0.138***			-0.489***
			(0.016)			(0.084)
Constant	-0.180***	-0.143***	-0.148***	-0.533***	-0.526***	-0.483***
	(0.009)	(0.009)	(0.009)	(0.147)	(0.144)	(0.133)
Observations	154,307	154,307	154,307	101,003	101,003	101,003

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Import competition and firm-product productivity (robustness check #1 - different estimation methods)

Dep. var.: TFP	(1) with price control	(2) with quadratic term for $logR_{(-g)}$	(3) OLS	(4) WOP
	(1)	(2)	(3)	(4)
Lagged TFP	0.894***	0.853***	0.869***	0.878***
	(0.003)	(0.003)	(0.003)	(0.003)
Lagged import share	0.959**	1.122**	0.766*	0.363
	(0.423)	(0.521)	(0.430)	(0.384)
Second product	-0.078***	-0.078***	-0.097***	-0.135***
	(0.021)	(0.026)	(0.021)	(0.031)
Third product	-0.063**	-0.093***	-0.115***	-0.136***
	(0.029)	(0.036)	(0.029)	(0.038)
Product above rank 3	-0.163***	-0.203***	-0.215***	-0.190***
	(0.029)	(0.035)	(0.029)	(0.042)
Lagged import share x 2nd prod.	-0.078	0.033	-0.058	0.085
	(0.071)	(0.087)	(0.071)	(0.107)
Lagged import share x 3rd prod.	-0.454***	-0.301***	-0.393***	-0.282**
	(0.086)	(0.106)	(0.087)	(0.123)
Lagged import share x higher rank prod.	-0.469***	-0.295***	-0.454***	-0.457***
	(0.082)	(0.100)	(0.081)	(0.129)
Constant	0.001	-0.977***	-0.510***	-0.497***
	(0.139)	(0.152)	(0.129)	(0.110)
Observations	101,003	101,003	106,273	80,641

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7
Diewert-Lau Firm-Product-Quarter Productivity (TFP) Residuals
on Import Shares and Product Rank **(OLS only)**

	(1)	(2)	(3)	(4)
Dep. var.: TFP	All Combos	All Combos	Well Behaved Combos	Poorly Behaved Combos
Lagged TFP	0.995***	0.995***	0.936***	0.995***
	(0.001)	(0.001)	(0.003)	(0.001)
Lagged import share	0.366***	0.271	0.561*	0.404*
	(0.133)	(0.168)	(0.300)	(0.209)
Second product	-0.289***	-0.314***	-0.213***	-0.301***
	(0.039)	(0.047)	(0.082)	(0.058)
Lagged import share		0.143	-0.391	0.0574
*second product		(0.155)	(0.334)	(0.175)
Constant	0.041	0.054	-0.120	0.079
	(0.145)	(0.145)	(0.255)	(0.174)
# obs	23,032	23,032	7,752	15,280

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Products aggregated at 4-digit level

Table A-1: Summary statistics on import share at the product level for the other import share measures

	Import shares computed in values					Import shares computed in quantity				
	Mean	25th	Median	75th	N	Mean	25th	Median	75th	N
All products										
1997	0.512	0.230	0.490	0.817	1,784	0.523	0.212	0.510	0.875	1,519
2007	0.580	0.303	0.590	0.896	1,880	0.595	0.286	0.624	0.941	1,613
Chemicals										
1997	0.535	0.246	0.501	0.839	355	0.534	0.253	0.503	0.883	350
2007	0.587	0.293	0.589	0.925	407	0.574	0.274	0.574	0.937	396
Food and beverages										
1997	0.473	0.189	0.428	0.753	270	0.467	0.174	0.400	0.770	259
2007	0.527	0.247	0.503	0.853	293	0.520	0.221	0.479	0.873	281
Machinery and equipment										
1997	0.598	0.331	0.647	0.881	276	0.711	0.479	0.858	0.963	185
2007	0.602	0.352	0.642	0.857	242	0.723	0.498	0.850	0.984	140
Fabricated metal products										
1997	0.568	0.257	0.590	0.888	128	0.583	0.291	0.625	0.924	107
2007	0.610	0.323	0.649	0.906	132	0.662	0.383	0.762	0.939	115
Rubber and plastic products										
1997	0.547	0.346	0.481	0.767	107	0.552	0.297	0.537	0.804	100
2007	0.576	0.342	0.552	0.867	107	0.586	0.347	0.545	0.876	104

Note: import shares are computed at the 8-digit prodcom level. To classify the product groups, we use the following definition: chemicals (prodcom2=24), food and beverages (prodcom2=15), machinery and equipment (prodcom2=29), fabricated metal products (prodcom2=28), rubber and plastic products (prodcom2=25).

Table A2: Production function estimation - by prodcom2 - WLP (no control for quality)

	(1) 15	(2) 28	(3) 36	(4) 24	(5) 26	(6) 25	(7) 29	(8) 17	(9) 18	(10) 21	(11) 27	(12) 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

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Columns labeled by two-digit product ISIC

Table A3: Import competition and firm-product productivity (robustness check #3)

Dep. var.: TFP	(1) Only MP firms	(2) Only MP firms with price control	(3) All firms - with firm-product level import & export dummies	(4) All firms - with firm-level import & export dummies
Lagged TFP	0.838***	0.856***	0.877***	0.877***
	(0.003)	(0.003)	(0.003)	(0.003)
Lagged import share	1.078**	1.234**	0.842*	0.852*
	(0.509)	(0.509)	(0.444)	(0.445)
Second product	-0.073***	-0.069***	-0.084***	-0.083***
	(0.026)	(0.027)	(0.022)	(0.022)
Third product	-0.088**	-0.050	-0.093***	-0.093***
	(0.038)	(0.038)	(0.030)	(0.030)
Product above rank 3	-0.195***	-0.165***	-0.185***	-0.185***
	(0.0380)	(0.038)	(0.030)	(0.030)
Lagged import share x 2nd prod.	-0.060	-0.033	-0.092	-0.095
	(0.089)	(0.089)	(0.073)	(0.073)
Lagged import share x 3rd prod.	-0.425***	-0.450***	-0.438***	-0.438***
	(0.112)	(0.114)	(0.088)	(0.088)
Lagged import share x higher rank prod.	-0.459***	-0.445***	-0.488***	-0.489***
	(0.108)	(0.109)	(0.083)	(0.084)
Lagged Importer dummy			-0.018***	-0.003
			(0.006)	(0.007)
Lagged exporter dummy			0.010*	0.002
			(0.005)	(0.007)
Constant	-0.305*	0.342*	-0.477***	-0.480***
	(0.167)	(0.179)	(0.131)	(0.131)
Observations	81,974	81,974	101,003	101,003

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4: Import competition and firm-product productivity (robustness check #4)

	(1)	(2)	(3)
Dep. var.: TFP	All Firms - spec. 2	All Firms - spec. 3	All Firms - spec. 4
Lagged TFP	0.845***	0.875***	0.874***
	(0.00312)	(0.00281)	(0.00278)
Lagged import share	-0.202	0.770*	0.455
	(0.471)	(0.441)	(0.444)
Second product	-0.183***	-0.140***	-0.128***
	(0.023)	(0.022)	(0.022)
Third product	-0.147***	-0.127***	-0.0940***
	(0.031)	(0.030)	(0.030)
Product above rank 3	-0.273***	-0.180***	-0.145***
	(0.032)	(0.030)	(0.030)
Lagged import share x 2nd prod.	-0.030	-0.059	-0.072
	(0.078)	(0.074)	(0.073)
Lagged import share x 3rd prod.	-0.494***	-0.416***	-0.463***
	(0.094)	(0.089)	(0.089)
Lagged import share x higher rank prod.	-0.410***	-0.493***	-0.511***
	(0.089)	(0.084)	(0.084)
Constant	-0.230	-0.558***	-0.416***
	(0.143)	(0.132)	(0.134)
Observations	101,003	101,003	101,003

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A5: Import competition and firm-product productivity (robustness check #5)

	(1)	(2)
Dep. var.: TFP	All Firms - IS1	All Firms - IS2
Lagged TFP	0.874***	0.877***
	(0.002)	(0.003)
Lagged import share	0.412	0.859**
	(0.265)	(0.437)
Second product	-0.112***	-0.083***
	(0.024)	(0.022)
Third product	-0.166***	-0.093***
	(0.037)	(0.030)
Product above rank 3	-0.225***	-0.185***
	(0.032)	(0.030)
Lagged import share x 2nd prod.	0.009	-0.095
	(0.063)	(0.073)
Lagged import share x 3rd prod.	-0.182**	-0.437***
	(0.088)	(0.088)
Lagged import share x higher rank prod.	-0.316***	-0.489***
	(0.075)	(0.084)
Constant	-0.382***	-0.483***
	(0.100)	(0.133)
Observations	101,003	101,003

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1