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Are unit export values correct measures of the exports' quality?

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Abstract

It has become common to measure the quality of exports using their unit export value (UEV). Applications of this method include studies of intra-industry trade (IIT) and analyses of industrial 'competitiveness'. This literature seems to assume that export quality and export price (the most natural interpretation of UEV) are not merely correlated but that they follow each other one-for-one. We put this assumption under scrutiny from both a theoretical and empirical point of view. In terms of theory, we formalize this assumption as a hypothesis of the proportionality of equilibrium prices and equilibrium qualities. We discuss several cases for which this hypothesis is theoretically doubtful (non-linear utility- and cost functions; strong and asymmetric horizontal product differentiation). We also suggest two methods of verifying the hypothesis for cases in which it cannot be easily rejected theoretically. These two methods are then applied to German imports in the period of 1994-2006. We find that the implications of the proportionality hypothesis are largely contradicted by the data.

1. Introduction

The goal of this paper is to contribute to the methodology used in empirical analyses of international trade. We attempt to examine one of the principal indicators used in this literature, unit export value (UEV), and in particular its popular use as a measure of the quality of an export product.

UEV is a basic tool that is used in the studies of intra-industry trade (IIT) that seek to divide this kind of trade into vertical and horizontal components (e.g. Greenaway, Hine, Milner 1993, Fontagné, Freudenberg, Gaulier 2002). UEV is also frequently used to measure export quality in empirical research into the "export performance" and international "competitiveness" of industries (see Aiginger 2000, Dullek et al 2005).

It should be stressed that it is not about the mere *correlation* between export price (which is the most natural interpretation of UEV) and export quality: the literature quoted above assumes that export quality can be *measured* by export unit values. As stated by Fontagné, Freudenberg, and Gaulier (2002), 'differences in prices within one product category *mirror* differences in quality' (emphasis added). The implications of such assumptions are numerous. For one it becomes possible to distinguish between goods of similar quality and those of different quality by setting a limit on the permitted difference in their UEVs. This is done in the studies on vertical and horizontal IIT. More generally, this assumption makes it possible to draw conclusions from the observed differences in UEVs between industries, countries and over time (for instance Dulleck et al, 2005, list Central and Eastern European countries that improved quality in the early 1990s and those that failed to do so). Note that these applications would not be possible had UEVs been only a statistical *proxy* for quality.

Given such strong methodological implications, it would seem worthwhile to consider the viability of UEV as a measure of quality. This, however, is hardly ever done, even if authors are usually aware of the problem. As Fontagné, Freudenberg, Gaulier (2002) say (in a footnote): 'There are numerous reasons leading to slight departures from a strict association of prices with quality. Trade economists are accustomed to this simplification'.

Are trade economists right and is the departure really 'slight'? Lüthje and Nielsen (2002) offer an interesting critique of UEV as a tool for breaking down IIT into vertical and horizontal parts. They analyzed the product-level bilateral trade between France and Germany in 1961-1999, and for each year, they attributed each product to either inter-industry trade, vertical intra-industry trade or horizontal intra-industry trade. Then they performed run tests to verify if the attribution of goods into categories is stable. Apparently it is not: the hypothesis that the attribution is random cannot be rejected in a vast majority of cases. This result suggests that the use of UEV, at least the way it is done in IIT studies, is doubtful, since it is unlikely that the quality of exported/imported products is so unstable. It is not clear, however, why the empirical method does not work: is the quality measure fundamentally wrong, is there a problem with the definition of vertical and horizontal IIT (cf. Gullstrand 2002 , Azhar and Elliot 2006), or is there simply a “practical” problem with statistical data (for instance due to aggregation, misallocation of goods into trade categories, and measurement units used to determine quantity)?

This last question cannot be resolved as long as one remains in the realm of trade data, but we would argue that there is a fundamental conceptual problem with UEV as a measure of export product quality. Our critique begins with the observation that prices might not follow quality closely if goods are differentiated not only by quality but also by other factors (e.g. due to horizontal product differentiation). This might benefit some producers allowing for markups higher than those of competitors selling similar quality goods. Even if the demand structure does not give an advantage to any producer, then prices might not follow qualities one-for-one due to consumers’ “love of variety”. Prices might also reflect international trade costs as stressed in the pricing-to-market literature (see Atkeson and Burnstein 2008). Note that these costs will differ among the pairs of trading partners. Our empirical results support these reservations. We performed two kinds of tests. First, we analyzed the CES function with products differentiated by quality (cf. Hallak 2004). We proved that the assumption regarding the strict association between equilibrium price and equilibrium quality implies a rather restrictive condition about import values. We tested this conclusion by analyzing German imports between 1994-2006 and we found that it does not hold true for a vast majority of markets.

Our second test can be potentially applied to a wider class of functions. It is based on a simple demand function estimation according to the following logic. Suppose that quality is the principal differentiation factor and that UEV is the correct way to measure it. Then for a given market, small differences in prices among sellers should not result in substantial changes in quantities sold (because quality is the only non-price decision parameter, and apparently quality has changed only slightly if price has changed only slightly). In other words, we would expect the distribution of E(Q|P) over sellers to be not far from continuous.

Again, we tested this hypothesis for a possible demand function using German imports between 1994-2006 by analyzing the conditional distribution of import quantities on import unit values (over countries of origin). We found that for a majority of goods, this distribution is strongly discontinuous as it has ‘thresholds’: quantity falls abruptly with an incremental increase in export unit value. Since our analysis controlled for exporters’ GDP, population, distance from Germany and participation in a free trade area with the EU, one can argue that such effects as variation in income and international trade costs are already accounted for. Consequently, the most plausible explanation is that the problem is using UEV as a measure of quality.

The remainder of this article is structured as follows. Section II discusses the theoretical justification for using UEV as a measure of quality. Section III presents an empirical analysis . Section IV discusses the results and concludes.

2. Quality measurement and trade theory

Although UEV is a popular measure of quality, there has not been much economic modeling in support of it. Take the method of breaking down IIT into vertical and horizontal components proposed by Abd-El-Rahman (1986)[1]. While it has been used by several authors, none of them, to the best of our knowledge, has presented a formal model. The same applies to the ‘competitiveness’ studies mentioned above.

It seems natural to look for appropriate models in the trade theory literature. The approach to modeling quality offered in this literature follows that of Industrial Organization (e.g. Shaked and Sutton 1983 and 1987; Gabszewicz and Thisse 1982, Rosen 1974). In this literature, quality is identified with a parameter that

[1] The method consists in observing the ration of export unit value and the import unit value of goods classified as IIT. Values between 0.85 and 1.15 indicate horizontal IIT while values outside this range are an evidence of vertical IIT (0.75-1.25 according to the other method)

enters the demand function and in most cases (though not all, see below) the costs function. Formally, consider a market in which a product is differentiated. Let varieties (or models) of the product be indexed by $z \in Z$. Usually it is assumed that

$$Q_z = Q_z(\mathbf{P}, \mathbf{A}) \qquad (1)$$

Where $\mathbf{P} = (P_z)$ and $\mathbf{A} = (A_z)$ are vectors of prices and qualities respectively. Typically it is assumed that:

$$\frac{dQ_z}{dP_z} < 0 < \frac{dQ_z}{dA_z} \qquad \text{and} \qquad \frac{dQ_z}{dA_x} < 0 < \frac{dQ_x}{dP_z} \quad \text{if } z \neq x .$$

In some approaches, the quality parameter also enters the cost function of variety z , which is increasing in both arguments:

$$C_z = C_z(Q_z, A_z)$$

We can now attempt to express the problem of quality measurement. If price indeed "mirrors" quality, then we would expect that in equilibrium these variables are proportional:

$$\mathbf{A}^* \approx k\mathbf{P}^* \quad \text{where } k > 0 \qquad (2)$$

We have thus arrived at a formalized hypothesis (henceforth: 'proportionality hypothesis') that can be investigated both theoretically and empirically. Note that this formulation is very broad; in particular we have made no assumptions about the nature of equilibrium.

Since price and quality are co-determined by supply and demand, the proportionality hypothesis would be guaranteed if both supply and demand functions were linear in both these variables. It is less obvious why (2) would hold in other cases. However some models do make it possible, at least theoretically. Flam and Helpman analyze two-way trade in vertically differentiated products between two countries ("North" and "South"). There is a continuum of varieties ($Z = R$), differentiated by quality only. Producers are identified with varieties. Unit costs are constant in quantity but increasing in quality, i.e.

$$C_z^{ctr}(Q_z, A_z) = Q_z \hat{C}^{ctr}(A_z)$$

Where ctr stands for country (North or South). There is also a continuum of consumers, differing in income. In equilibrium, complete specialization takes place: models up to a certain quality are produced only in the South while above that point, quality production takes place only in the North.

The assumption of a continuum of producers, of which each adds little to the market, implies in this kind of model (as shown by Rosen 1974) that products in the long run are priced at the minimum average cost, thus at the marginal cost. Hence:

$$P_z = \min\left(\hat{C}^N(A_z), \hat{C}^S(A_z)\right)$$

The price is determined by the supply side only. Therefore the proportionality hypothesis could theoretically be true if unit costs were linear in quality. However, the authors assume that $\hat{C}^{ctr}$ is a convex function. A similar model which has the same implications about prices is the one by Falvey and Kierzkowski (1987).

By contrast in the discrete-choice model by Gabszewicz, Shaked, Sutton and Thisse (1981), prices are determined solely by the demand side, as costs are assumed to be zero. Contrary to the Flam-Helpman model, there is a finite number of varieties (identified with producers) enjoying a certain monopoly power over a continuum of consumers, indexed by income. The utility of an individual consumer depends on his income but it is linear in quality. Although no general analysis is offered, the authors solve a duopoly model and demonstrate that under the assumption of a uniform distribution of income, the prices of both varieties are nearly proportional to their qualities[2].

On the other hand, it is clear that even in the two models quoted above, equilibrium prices can be proportional to equilibrium qualities only under certain (rather strong) assumptions[3]. Moreover, both models rely on a more general (also strong) assumption: that products are differentiated by quality only.

However including horizontal product differentiation in the analysis can alter the results substantially. We will demonstrate this by referring to an additive discrete choice model (following Anderson, de Palma and Thisse 1990). Consider a population of consumers indexed by $w \in W$, choosing among n varieties of a differentiated good. The choice is made by maximizing the consumer's conditional utility function:

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[2] While this outcome is relevant for our study, the focus of the Gabszewicz et al. paper is different. The authors prove that that under certain assumptions, the number of varieties that can be supported in equilibrium with free trade is smaller than the total number of varieties supported in both countries when they do not engage in trade.

[3] And in fact we would expect that utility is concave in quality. As for unit costs, both convex and concave functions are discussed in the literature (Sutton 1981, Berry and Waldfogel 2003).

$$V_i(w) = -P_i + A_i + F_i(w) \qquad (3)$$

where $F_i(w)$ is the utility drawn by the consumer w from the consumption of one unit of variety i (where $i = 1 \ldots n$), A_i is the quality of model i, while $F_i(w)$ is the individual valuation of variety i by consumer w and it represents horizontal differentiation of the good. It is worth stressing that $\mathbf{A} = (A_1, \ldots, A_n)$ is indeed the same parameter that we introduced in formula (1). To arrive at (1) requires aggregating the individual decisions of consumers (cf. Anderson, de Palma and Thisse 1990, pp. 66-70). In addition we assume that each consumer buys only one unit of the preferred variety.

Note that (3) accounts for *both*, the vertical and the horizontal aspect of product differentiation. It seems realistic to assume that goods are differentiated in both dimensions, a fact that is somehow overlooked in the empirical literature on international trade, which seems to ignore the fact that some goods, by their very nature, might be difficult to ascribe to either horizontal or vertical IIT, even in theory.

For simplicity's sake we will assume that there are only two sellers and that consumers cannot refrain from buying (there is no outside option). In that case the demand for variety 1 equals the mass of consumers for whom $V_1 > V_2$ or

$$-(P_1 - P_2) + (A_1 - A_2) + (F_1(w) - F_2(w)) > 0$$

Now suppose that firms compete in prices with the qualities given and that $A_1 > A_2$. Even though seller 1 offers a higher quality product, she might not be the one that charges a higher price in the Nash equilibrium if most consumers have a subjective predilection for variety 2, i.e. $F_2(w) > F_1(w)$ [4]. While this particular example might seem artificial, it is intuitive that prices will not follow qualities one-for-one if consumers subjectively prefer certain products over others (even if that does not lead to "reversals" of the kind characterized above).

However the problem with horizontal product differentiation is a more serious one. In fact, even when no variety enjoys the preferential interest of consumers, hypothesis (2) might not hold. Consider the well-known CES demand function:

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[4] For instance, suppose that $A_1 - A_2 = \alpha > 0$. It can be verified that $P_2{*} > P_1{*}$ if $F_2(w) - F_1(w) > 2\alpha$ for a sufficient number of consumers, while $F_1(w) - F_2(w) < 1/2\,\alpha$ for the remaining ones.

$$Q_i(\mathbf{P},\mathbf{A}) = \frac{\left(P_i / A_i^{\gamma}\right)^{-1/(1-\gamma)}}{\sum_j \left(P_j / A_j^{\gamma}\right)^{-\gamma/(1-\gamma)}} \cdot E \qquad (4)$$

where E is the total amount spent on the good and $0 < \gamma < 1$. This is a "love of variety" kind of demand function and this property turns out to be particularly relevant in the context of quality measurement. It implies that even if the seller of the worst quality variety chooses to charge the highest price in the market, the product will still remain on the market. This suggests that measuring quality using prices might be difficult. Indeed, it is easily verified that:

$$\ln A_l - \ln A_m = \tfrac{1}{\gamma}\left(\ln P_l - \ln P_m\right) + \tfrac{1-\gamma}{\gamma}\left(\ln Q_l - \ln Q_m\right) \qquad (5)$$

implying that (2) holds if and only if :

$$P_l^* \big/ P_m^* = Q_m \big/ Q_l \quad \Leftrightarrow \quad P_l^* \, Q_l = P_m^* \, Q_m \qquad (6)$$

In other words, in the CES model, prices and qualities are proportional if and only if all varieties generate exactly the same revenue!

This observation gives us an idea of how can the proportionality hypothesis can be tested empirically. Let (4) represent a given country's demand for a differentiated good. Each variety r is either imported or domestically produced. We will assume that in the equilibrium full specialization takes place. Thus each variety is produced by only one country. Following Hallak (2004) and Feenstra (2004) we assume that all models (varieties) produced by one country have the same (or similar) quality and the same (or similar) price. Thus if M_i denotes the total value of imports from country i, then:

$$M_i = N_i \, Q_{r_i} \, P_{r_i}$$

where N_i is the number of varieties imported from country i and r_i is any of the varieties imported from that country. Note (6) implies:

$$\frac{M_i}{N_i} = \frac{M_j}{N_j} \qquad (7)$$

for any two countries i and j exporting to the country under consideration (or for one exporting country and the importing country itself).

Consequently assuming the CES demand function, the hypothesis about proportionality of price and quality can be tested using (7). This is done in the next section (for German imports).

The second test we are going to perform can be applied to a wider class of demand functions. Again, consider a differentiated good market in an importing country. Suppose the demand (1) for variety r has the following “symmetry” property[5]:

$$Q_r(\mathbf{P},\mathbf{A}) = \hat{Q}(P_r, A_r)\ \tilde{Q}(\mathbf{P},\mathbf{A})\ E^{\lambda} \qquad (8)$$

In words, demand for variety r can be expressed as a product of two functions, one of the price and quality of variety r and one of the entire vector $(\mathbf{P},\mathbf{A})$, and of E, which is the country’s total expenditure on the differentiated good (to the power of $\lambda > 0$). About both functions, $\hat{Q}$ and $\tilde{Q}$ we will assume that they are continuous. The CES function and the multinomial logit model are among the demand functions that have property (7).

Again, under perfect specialization and assuming equal prices and qualities within countries:

$$Q_i = N_i\ Q_{r_i}(\mathbf{P},\mathbf{A}) = N_i\ \hat{Q}(P_{r_i}, A_{r_i})\ \tilde{Q}(\mathbf{P},\mathbf{A})\ E^{\lambda}$$

where Q_i is the *quantity* imported from country i. Again, suppose that (2) holds. Then:

$$Q_i \approx N_i\ \hat{Q}(P_{r_i}, kP_{r_i})\ \tilde{Q}(\mathbf{P}, k\mathbf{P})\ E^{\lambda} \qquad (9)$$

An implication of (9) is that that small differences in prices among countries should not result in substantial changes in quantities sold. In other words, we would expect the distribution of E(Q|P) over exporting countries to be *not far from continuous*. This is the hypothesis we will take to data for test.

[5] It implies, in particular, that the demand function has the property of independence of irrelevant alternatives: the ration of demands for two varieties depends solely on the prices and qualities of these two models. Competition between varieties in this model is “symmetric”: an increase in price (or quality) of a given model increases (reduces) demand for all remaining varieties by the same proportion. No variety is privileged due to horizontal product differentiation.

3. Empirical verification of the proportionality hypothesis

A. Dataset and Sources

Trade data are taken from the Comext statistics of the Eurostat. All our estimates are done on the most disaggregated level available in Comext, i.e. the 8th digit level of the Combined Nomenclature. Comext includes approximately 13900 8th digit-goods that were exported to Germany in at least one year between 1994-2006 but we will limit our analysis to those exported by a sufficient number of countries (at least 20). This decision will facilitate econometric analyses while the number of remaining goods (3911) is high enough to claim the generality of our conclusions.

Our dataset consists of two parts. First, for those goods for which there were data for more than one year a balanced panel was set up. This was the case for about 60% (2374) of goods. For the remaining goods our analysis is based on cross-country data for the year for which the data was available.

For each of 183 countries and territories exporting to Germany in 1994-2006, we needed data on GDP in current prices and population. These were drawn from the International Monetary Fund's World Economic Outlook Database. In the World Economic Outlook GDP is expressed in US dollars. We convert dollars to euro using the InfoEuro tables of the European Commission[6].

Finally, we needed data on distances between Germany and countries exporting to Germany. We used theglobetrotter.de website to determine distances (in km) between Berlin and the capital of the country in question. In case of some particularly small and remote countries and entities, some simplifying assumptions about GDP, population and distance were made.

B. Test for the CES demand function

We started by testing the (7) property of the CES function (assuming the proportionality hypothesis). It can be alternatively written:

[6] While this dataset was created for administrative purposes, it is convenient inasmuch as it contains a consistent database of ECU/USD exchange rates from the period before fixing of the Euro-zone exchange rates on 31.12.1998. Since InfoEuro rates are calculated on a monthly basis, we take the average over 12 months to obtain the exchange rate in a given year.

$$m_i - n_i = m_j - n_j \qquad (10)$$

(from now on small letters will denote logarithms of variables). In order to check whether $\forall_{i,j}\, m_i - n_i = m_j - n_j$, no statistical procedure is required. It would be enough to calculate the values of $m_i - n_i$ for each country and check whether this value is the same for all countries. But we shall not apply this procedure: the hypothesis that equality $m_i - n_i = m_j - n_j$ is satisfied for each pair i, j is in a sense too strong, as errors in measuremen*t* (e.g. of export) and possible errors in specification have to be taken into consideration. Consequently we are going to check if (10) holds *approximately*.

Let $d_{ij} = (m_i - n_i) - (m_j - n_j)$. Since we take into consideration the possibility of a measurement or specification error, we will interpret d_{ij} as random variables. Assuming that (10) holds, subject to an error in measurement or specification, random variables $\{ d_{ij} : i < j \}$ all have mean zero and equal variances[7]. Thus for the cross-country part of our dataset the following hypothesis:

$$H_0 : \mu_d = 0,$$
$$H_1 : \mu_d \neq 0.$$

can be tested using the standard t-statistics. In the case of panel data, this hypothesis is verified for each year separately: if for at least one year it is rejected, then we assume that approximated equality (10) does not hold.

Testing (10) empirically involves making an assumption about N_i. We would expect that bigger economies export more varieties (cf. Feenstra 2004 ch. 5). Therefore we will use GDP as proxy for N_i (in the next section we will apply a more sophisticated procedure to determine N_i).

The results of the test (at the 0.05 significance level) are reported in Table 1. Hypothesis H_0 can be rejected for a vast majority of goods (80%), implying that *if the demand function is of the CES type, then the proportionality hypothesis does not hold*. Additionally, we present results broken down by Combined Nomenclature sections.

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[7] If J is the number of countries, then we are comparing $\binom{J-1}{2}$ numbers

Table 1. Percentages of goods for which the proportionality hypothesis in the CES model is rejected

Section	Percentage of rejections
I. Live animals; Animal products	81 %
II. Vegetable products	73 %
III. Animal or vegetable fats and oils and their cleavage products; Prepared edible fats; Animal or vegetable waxes	82 %
IV. Prepared foodstuffs; Beverages, spirits and vinegar; Tobacco and manufactured tobacco substitutes	82%
V. Mineral products	74%
VI. Products of the chemical or allied industries	86%
VII. Plastics and articles thereof; Rubber and articles thereof	81%
VIII. Raw hides and skins, leather, furskins and articles thereof; Saddlery and harness; Travel goods, handbags and similar containers; Articles of animal gut (other than silkworm gut)	76%
IX. Wood and articles of wood; Wood charcoal; Cork and articles of cork; Manufactures of straw, of esparto or of other plaiting materials; Basketware and wickerwork	79%
X. Pulp of wood or of other fibrous cellulosic material; Recovered (waste and scrap) paper or paperboard; Paper and paperboard and articles thereof	83%
XI. Textiles and textile articles	77%
XII. Footwear, Headgear, umbrellas, sun umbrellas, walking-sticks, seat-sticks, whips, riding-crops and parts thereof; Prepared feathers and articles made therewith; Artificial flowers; Articles of human hair	84%
XIII. Articles of stone, plaster, cement, asbestos, mica or similar materials; Ceramic products; Glass and glassware	62%
XIV. Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metal, and articles thereof; Imitation jewelry; Coin	69%
XV. Base metals and articles of base metal	78%
XVI. Machinery and mechanical appliances; Electrical equipment; Parts thereof; Sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	80%
XVII. Vehicles, aircraft, vessels and associated transport equipment	78%
XVIII. Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical instruments and apparatus; Clocks and watches; Musical instruments; Parts and accessories thereof	78%
XIX. Arms and ammunition.; parts and ammunition, parts and accessories thereof	83%
XX. Miscellaneous manufactured articles	74%
All goods	80%

Source: Own calculations

A closer look at Table 1 might be puzzling. Why is the rejection rate relatively the lowest for a category consisting of rather homogenous goods (Section XIII)? But in fact this is something one could have expected in a homogenous category. By definition, in such a market, qualities of all the varieties are similar. If technology is similar around the world, then this further implies that prices of all the varieties are similar. This however brings us to (6) and (7). We should not have expected hypothesis H_0 to be massively rejected in homogenous industries, because it is likely to be true.

On the other hand we can see that for categories grouping differentiated goods (such as XVI, XVII, XVIII), hypothesis H_0 can be firmly rejected: it cannot be supported for about 80% of goods.

C. Analysis of the continuity of the demand function

Our second test of the proportionality hypothesis (2) is based on the more general equation (9), which, assuming the hypothesis is true, can be written for convenience in terms of functions of prices only:

$$Q_i \approx N_i \, \hat{Q}(P_{r_i}) \, \tilde{Q}(\mathbf{P}) \, E^{\lambda} \qquad (11)$$

Q_i is the amount of imports from country i and P_{r_i} is the price of any of the models imported from that country.

It will be important to distinguish carefully between the number of countries and number of varieties. Let L be the number of varieties and J the number of countries exporting to the country under consideration. Thus

$$N_1 + \mathrm{K} + N_J = L$$

Taking logs of equation (11) we obtain:

$$q_i = n_i + \hat{q}(P_{r_i}) + \tilde{q}(\mathbf{P}) + \lambda e \qquad (12)$$

We are going to estimate (12) using German import data[8]. To this end we need to make assumptions about functions $\hat{Q}$ and $\tilde{Q}$. We assume that:

$$\hat{Q}\left(P_{r_i}\right) = \alpha \, P_{r_i}^{\ \beta}$$

$$\tilde{Q}(\mathbf{P}) = \omega \left(\prod_{z=1}^{L} P_z \right)^{\psi}$$

Bearing in mind the distinction between number of varieties and number of countries we can transform (12.5)b:

$$\tilde{Q}(\mathbf{P}) = \omega \left(\prod_{z=1}^{L} P_z \right)^{\psi} = \omega \left(\prod_{j=1}^{J} P_{r_j}^{\ N_j} \right)^{\psi}$$

Taking logs and substituting into (12) we arrive at:

$$q_i = \kappa + n_i + \beta\, p_i + \psi \sum_{j=1}^{J} N_j p_j + \lambda e \quad (13)$$

where: $\kappa = \ln \omega + \ln \alpha$; for simplicity we use the symbol p_i instead of p_{r_i} .

We will proxy E by total value of German imports of a given good:

$$E = \sum_{j=1}^{J} Q_j P_j$$

Note that in a cross-country model, variables λe and $\psi \sum_{j=1}^{J} N_j p_j$ are constant and can be ignored. This will be different in the panel-data model (see below).

Just as it was the case with the CES function, we need to make an assumption about N_i . This time we do not have to make as restrictive assumptions as in the previous section and we can actually estimate the impact of different variables. Consequently we assume that:

$$N_i = GDP_i^{\rho_1} POP_i^{\rho_2} DIST_i^{\rho_3} \exp(\rho_4 eu_i) \exp(\xi_i) \qquad (14)$$

Where POP stands for population, $DIST$ for distance between Germany and the exporting country, eu is a dummy that takes a value of one for the countries of the European Economic Area (as of 2009) as well as Switzerland and Turkey[9] and zero otherwise, while $\xi_1, \ldots, \xi_J$ are i.i.d. error terms with zero mean.

Strictly speaking, formula (14) combines two different effects. One is the effect of the size of the country (measured by its GDP and population). The other is the "border effect" of distance and other factors that might influence trade between, in our case, Germany and country i . The "border effect" is usually assumed to influence demand through prices (cf. Feenstra 2004, Ch.5) because it is associated, for instance, with higher shipment costs. However both approaches lead to the same estimation strategy (at least in our context) so we will stick to our formalization, because it enables us to consider different effects in a concise form.

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[8] Note that while estimating Germany's demand we have to do without one key producer – Germany itself. This is a shortcoming of our study.

[9] This group can be largely considered to have been a free trade area in 1994-2006: since 1.05.2004 the 27 EU member states and Turkey form a customs union while the remaining EEA countries join them in a free trade area (excludig agricultural and fishery products; this applies also the customs union with Turkey). Before 2004, 12 of the current EU member states were only candidates for accession, but they were in a free trade area with the EU based on the Europe Agreements. Turkey signed an Association Agreement with the EEC in 1963. Switzerland is not an EEA country but it has numerous trade agreements and strong historical links with the EU.

Taking the logs of (14) and plugging it into (13) we arrive at the model:

$$q_i = \kappa + \rho_1 gdp_{it} + \rho_2 pop_{it} + \rho_3 dis_i + \rho_4 eu_i + \beta p_i + \xi_i \tag{15}$$

(constant variables are ignored)

To debunk the proportionality hypothesis we will show that, contrary to what the theoretical model suggests, q_i is discontinuous in prices. To demonstrate this we will consider the following model with dummy variables:

$$q_i = \kappa + \rho_1 gdp_{it} + \rho_2 pop_{it} + \rho_3 dis_i + \rho_4 eu_i + \beta p_i + \delta_1 D1_i + \delta_2 D2_i + \xi_i \tag{16}$$

where:

$D1_i = 1\{p_i < \underline{p}\}$ and $D2_i = 1\{p_i > \overline{p}\}$

Where thresholds $\underline{p}$ and $\overline{p}$ are chosen so as to minimize the sum of the squared errors. If parameters δ_1 and δ_2 are significantly different from zero, then the imported quantity is best approximated by a function that is discontinuous in price (Figure 1).

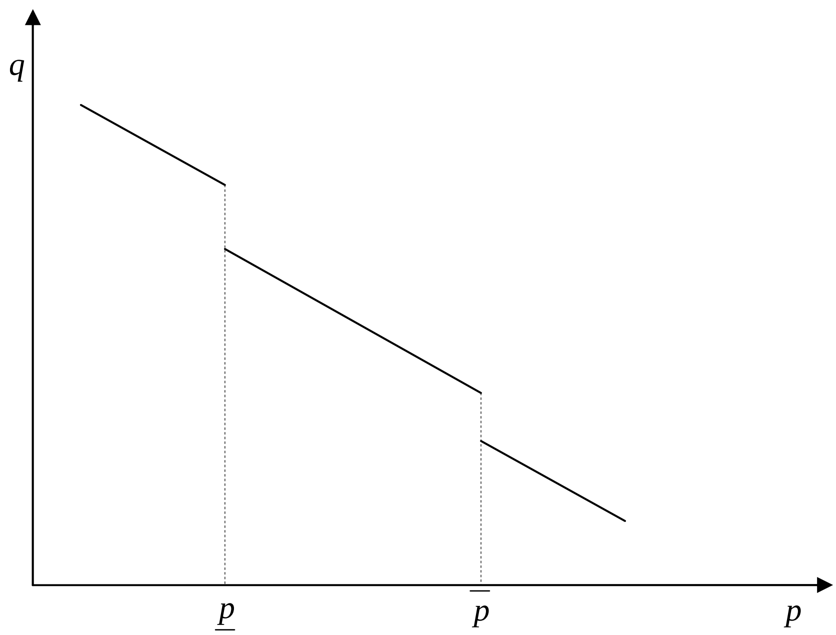

Figure 1. Discontinuity of the regression function (16)

The procedure for panel data models is more complicated. In this case variables e and $\sum_{j=1}^{J} N_j p_j$ are included in the regression. We consider the following panel data regressions:

$$q_{it} = \kappa + \rho_1 gdp_{it} + \rho_2 pop_{it} + \rho_3 dis_i + \rho_4 eu_i + \psi \sum_{j=1}^{J} N_j p_{jt} + \lambda e_t + \beta p_{it} + $$
$$+ \sum_{t=1}^{T} \delta_{1t} D1_{it} + \sum_{t=1}^{T} \delta_{2t} D2_{it} + \xi_{it}$$

(17)

$$q_{it} = \kappa + \rho_1 gdp_{it} + \rho_2 pop_{it} + \sum_{t=1}^{T} \lambda_t U_t + \psi \sum_{j=1}^{J} N_j p_{jt} + \lambda e_t + \beta p_{it} + \sum_{t=1}^{T} \delta_{1t} D1_{it} + \sum_{t=1}^{T} \delta_{2t} D2_{it} + \xi_{it}$$

(18)

$$q_{it} = \kappa + \rho_1 gdp_{it} + \rho_2 pop_{it} + \rho_3 dis_i + \rho_4 eu_i + \psi \sum_{j=1}^{J} N_j p_{jt} + \lambda e_t + \beta p_{it} + \sum_{t=1}^{T} \delta_{1t} D1_{it} + \sum_{t=1}^{T} \delta_{2t} D2_{it} + \nu_{it}$$

(19)

where: $v_{it} = \xi_{it} + \lambda_t, \quad i = 1,\ldots,J, \quad t = 1,\ldots,T,$

U_t takes on value 1 in year t and 0 in the rest of periods. About error terms we assume that $\underset{i}{\forall} E(\boldsymbol{\varepsilon}_i) = \mathbf{0}, \quad E\left(\boldsymbol{\varepsilon}_i \boldsymbol{\varepsilon}_j^T\right) = \sigma^2 \mathbf{I}$ for $i = 1,\ldots,J$, $j = 1,\ldots,J$ and $\underset{i}{\forall} E(x_{it} \varepsilon_{is}) = 0, \quad t = 1,\ldots,T, \quad s = 1,\ldots,T.$

Model (17) is a so called pooled regression, model (18) is a fixed effects panel data model, model (19) is a random effects panel data model.

Note that the latent variable N_j is a power function of parameters $\rho_1, \rho_2, \rho_3, \rho_4$ (cf. equation 14). Consequently all the models listed are nonlinear in these parameters. To circumvent this problem, we estimate them recursively using the expectation-maximization (EM) algorithm by Dempster, Laird and Rubin (1977), which Amemiya (1984) proved to be convergent.

Next, for each good we choose the appropriate model among models (17)-(19) depending on the statistical inference for panel data analysis (the significance of fixed effects and the Hausman test).

Analogous to the cross-country model, proving the discontinuity of E(Q|P) in the panel model requires rejecting the hypothesis that all deltas equal zero, i.e.:

$$H_0 : \delta_{11} = \ldots = \delta_{1T} = \delta_{21} = \ldots = \delta_{2T} = 0,$$

However we will be able to say more about the relation between import price and quantity. By testing if parameter β is statistically significant, we can ascribe each good in the database to one of four categories (Table 2).

Table 2. Classification of goods based on the relation between import price and import quantity.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">$H_0 : \delta_{11} = \ldots = \delta_{1T} = \delta_{21} = \ldots = \delta_{2T} = 0,$</td></tr>
<tr><td>rejected</td><td>not rejected</td></tr>
<tr><td rowspan="2">$H_0 : \beta = 0$</td><td>rejected</td><td>No relation between price and quantity
(D)</td><td>Discontinuity,
Linearity in intervals
(B)</td></tr>
<tr><td>not rejected</td><td>Linearity (hence: continuity)
(C)</td><td>Strong discontinuity
(A)</td></tr>
</table>

For goods falling into categories A and B, hypothesis H_0 can be rejected, thus quantity is discontinuous in price. Group B is actually illustrated by Figure 1 above. The difference between B and A is that in the latter, a log-linear relationship between price and quantity demanded cannot be established, even within the price "segments". Therefore we labeled it "strong discontinuity". Category A can be further divided into two subgroups:

A1: The segments are "monotonic", i.e. the mean quantity in the price intervals $[0, \underline{p}]$, $[\underline{p}, \overline{p}]$, $[\overline{p}, \infty]$ is falling.

A2: The segments are nonmonotonic, i.e. the mean quantity is falling at first and then increasing or vice versa

Both A1 and B can be regarded as evidence of the nonlinearity of utility and/or unit costs in quality. On the other hand, A2 would indicate a strong and asymmetric horizontal differentiation in the market. Finally, category C includes goods for which the relationship is log-linear throughout the price spectrum, matching our theoretical model (11), contrary to group D, for which all variables are insignificant.

Table 3 presents cross-country- and panel regression results separately. This distinction is motivated by the theory. While panel data analysis requires making assumptions about both functions, $\hat{Q}$ and $\tilde{Q}$, cross country analysis needs only the former function. As a result, it reflects a wider range of demand functions. This might be a reason why option D, indicating possible misspecification of the model, is less frequent for a cross-country model.

Table 3. Percentages of goods belonging to groups defined in Table 2.

Group / **Estimation method**	**A1**	**A2**	**B**	**C**	**D**
Cross country regression	30,8%	21,3%	23,2%	6,4%	18,3%

Panel regression	24,4%	19,2%	29,8%	3,5%	23,1%

Source: Own calculations

Generally speaking, for more than 70% of goods analyzed, quantity demanded was discontinuous in price. The proportion of those for which continuity can be sustained (group C) is very small. Tables 4 and 5 in the Appendix present the results broken down by Combined Nomenclature sections. This time we would expect homogenous goods to fit well into group D, because of little variation in prices and quantities. This is clearly the case for Section XIII. Less evident values for other homogenous categories are partly a result of aggregation: further disaggregation into 98 *chapters* of Combined Nomenclature (not reported in a table) reveals that such categories as wood (chapter 44, Section IX) and mineral oils and fuels (chapter 27, Section V) have a particularly high proportion of goods in group D.

It is also worth stressing that in all 98 CN chapters hypothesis H_0 can be rejected for at least 50% of goods and in more than a half of chapters it can be rejected for more than 70% of goods. By implication, *for a large majority of goods, quantity demanded turns out to be discontinuous in prices, contradicting the proportionality hypothesis*.

4. Conclusions

In this article, we put measuring export quality by unit export value under scrutiny both from a theoretical and empirical point of view. We formalized the (usually tacit) assumptions that back this method of measuring quality by establishing the ‘proportionality hypothesis’. Then we investigated the validity of this hypothesis. We discussed several cases for which the assumption of proportionality between equilibrium prices and equilibrium quality is theoretically doubtful (non-linear utility- and cost functions; strong and asymmetric horizontal product differentiation). We also suggested two methods of verifying the proportionality hypothesis for cases when it cannot be easily rejected theoretically and we applied them to the analysis of German imports between 1994-2006.

The first method is applicable exclusively to the CES demand function and it yielded strong negative results in the case of German imports (i.e. either the demand function was not CES or price and quality were not proportional).

The second method is based on estimating the demand function. It can potentially be applied to a wider range of models in which the competition between varieties of the differentiated good is symmetric. The key idea is to analyze the continuity of the conditional distribution E(Q|P), because if qualities followed prices closely it should be continuous. Again, the test on German data indicated that the distribution is discontinuous for a large majority of goods in all trade sections. Note that we controlled for such factors as exporters' GDP, population and border effects (distance from Germany and EU membership or participation in a free trade area with the EU).

One could question the way we formalized the problem of quality measurement and argue that the proportionality hypothesis is too strong, and that we are "shooting at fish in a barrel". We would insist, however, that this hypothesis best reflects the logic of empirical literature using UEV as a quality measure. Moreover, only the first of our test ("the CES-test") relied strictly on proportionality of equilibrium prices and equilibrium quantities, while the second one ("the continuity test") would remain viable if symbol k in (2) stood not for a constant but for a function of prices, as long as this function was continuous in prices.

Which empirical studies are affected by our critique and which are not? First of all, let us reiterate that the problem we raised applies only to the attempts to *measure* quality (deterministically) and not to *proxy* it. On the other hand, our reservations directly address the 'competitiveness' studies, which, just as our tests, are based on the analyses of one-way trade. They also apply indirectly to the IIT studies of two-way trade: if one demand function creates problems with measuring quality by UEV, then two demand functions are likely to be even worse (or just as bad – consider the case of trade between countries with similar endowments).

One implication of our study is that a 1% change in price might indicate a change in quality that is different in market A than in market B. This yields support for the suggestion by Lüthje and Nielsen (2002) to use good-specific dispersion factors when breaking down IIT. On the other hand, our results also indicate that within the same market, a similar change in price might reflect different changes in quality, depending on the exporter.

Having said this, our critique is a methodological one. It does not belittle the importance of competitiveness of industries nor that of inter-industry trade or its decomposition into vertical and horizontal parts (which is relevant, as evidenced by Gullstrand 2002).

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Appendix

Table 4. Percentages of goods belonging to groups defined in Table 2 broken down by CN sections – results of the cross-country regression

	A1	A2	B	C	D
I. Live animals; Animal products	34%	23%	30%	5%	8%
II. Vegetable products	36%	19%	34%	4%	7%
III. Animal or vegetable fats and oils and their cleavage products; Prepared edible fats; Animal or vegetable waxes	35%	15%	20%	10%	20%
IV. Prepared foodstuffs; Beverages, spirits and vinegar; Tobacco and manufactured tobacco substitutes	38%	19%	23%	5%	15%
V. Mineral products	28%	25%	11%	16%	19%
VI. Products of the chemical or allied industries	37%	25%	17%	6%	15%
VII. Plastics and articles thereof; Rubber and articles thereof	48%	25%	11%	3%	13%
VIII. Raw hides and skins, leather, furskins and articles thereof; Saddlery and harness; Travel goods, handbags and similar containers; Articles of animal gut (other than silkworm gut)	35%	17%	26%	7%	15%
IX. Wood and articles of wood; Wood charcoal; Cork and articles of cork; Manufactures of straw, of esparto or of other plaiting materials; Basketware and wickerwork	33%	22%	20%	7%	18%
X. Pulp of wood or of other fibrous cellulosic material; Recovered (waste and scrap) paper or paperboard; Paper and paperboard and articles thereof	38%	25%	20%	3%	14%
XI. Textiles and textile articles	24%	17%	29%	8%	22%
XII. Footwear, Headgear, umbrellas, sun umbrellas, walking-sticks, seat-sticks, whips, riding-crops and parts thereof; Prepared feathers and articles made therewith; Artificial flowers; Articles of human hair	28%	21%	22%	4%	25%
XIII. Articles of stone, plaster, cement, asbestos, mica or similar materials; Ceramic products; Glass and glassware	25%	16%	23%	6%	30%
XIV. Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metal, and articles thereof; Imitation jewelry; Coin	28%	22%	23%	5%	22%
XV. Base metals and articles of base metal	28%	20%	32%	2%	18%
XVI. Machinery and mechanical appliances; Electrical equipment; Parts thereof; Sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	19%	20%	25%	11%	25%
XVII. Vehicles, aircraft, vessels and associated transport equipment	24%	21%	25%	7%	23%

Table 5. Percentages of goods belonging to groups defined in Table 2 broken down by CN sections – results of the panel regression

	A1	A2	B	C	D
I. Live animals; Animal products	26%	24%	22%	8%	20%
II. Vegetable products	27%	16%	28%	5%	24%
III. Animal or vegetable fats and oils and their cleavage products; Prepared edible fats; Animal or vegetable waxes	38%	19%	23%	0%	20%
IV. Prepared foodstuffs; Beverages, spirits and vinegar; Tobacco and manufactured tobacco substitutes	29%	20%	27%	3%	21%
V. Mineral products	27%	19%	26%	2%	26%
VI. Products of the chemical or allied industries	30%	18%	27%	4%	21%
VII. Plastics and articles thereof; Rubber and articles thereof	35%	21%	15%	4%	25%
VIII. Raw hides and skins, leather, furskins and articles thereof; Saddlery and harness; Travel goods, handbags and similar containers; Articles of animal gut (other than silkworm gut)	27%	14%	32%	7%	20%
IX. Wood and articles of wood; Wood charcoal; Cork and articles of cork; Manufactures of straw, of esparto or of other plaiting materials; Basketware and wickerwork	22%	20%	33%	3%	22%
X. Pulp of wood or of other fibrous cellulosic material; Recovered (waste and scrap) paper or paperboard; Paper and paperboard and articles thereof	25%	19%	29%	6%	21%
XI. Textiles and textile articles	22%	17%	31%	3%	27%
XII. Footwear, Headgear, umbrellas, sun umbrellas, walking-sticks, seat-sticks, whips, riding-crops and parts thereof; Prepared feathers and articles made therewith; Artificial flowers; Articles of human hair	25%	20%	28%	4%	23%
XIII. Articles of stone, plaster, cement, asbestos, mica or similar materials; Ceramic products; Glass and glassware	23%	16%	24%	6%	31%
XIV. Natural or cultured pearls, precious or semi-precious stones, precious metals, metals clad with precious metal, and articles thereof; Imitation jewelry; Coin	26%	20%	29%	5%	20%
XV. Base metals and articles of base metal	23%	21%	32%	2%	22%
XVI. Machinery and mechanical appliances; Electrical equipment; Parts thereof; Sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles	18%	18%	35%	4%	25%
XVII. Vehicles, aircraft, vessels and associated transport equipment	23%	16%	32%	4%	25%

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