

Heterogeneous Firms and Import Quality: Evidence From Transaction-Level Prices

Benjamin R. Mandel*

JOB MARKET PAPER: OCTOBER 2008

Abstract

A key emerging insight in international economics is that the scope for quality differentiation can help to explain patterns in export prices. In this paper, I bring a unified theoretical framework of firm heterogeneity in cost and quality to bear on an expansive data set of U.S. import transaction prices collected by the Bureau of Labor Statistics (BLS). In contrast to commonly used unit values, the distribution of these micro-data can be observed at the level of highly disaggregate products. I exploit the higher moments of the price data to document four facts pertaining to U.S. import quality: (i) using a novel methodology to identify the scope for quality differentiation, highly differentiated products account for about half of import value; (ii) quantile regression techniques reveal that productive foreign exporters specialize in high-priced varieties in goods with a large scope for quality differentiation, and conversely for low scope goods; (iii) within a product, the prices of high-quality varieties are increasing over time in a pattern suggesting both process and product innovation; and (iv) changes in the real exchange rate are passed through more to prices in products with a higher scope for quality differentiation. (JEL F12, F41)

*UC Davis, PhD candidate in the Department of Economics. Email: brmandel@ucdavis.edu. I especially thank Robert Feenstra for guidance and constructive suggestions. Thanks to Rozi Ulics, Daryl Slusher and Kristen Locatelli at the BLS for orienting me in the IPP data. I also gratefully acknowledge helpful insights by Mary Amiti, Roc Armenter, Paul Bergin, Donald Davis, James Harrigan, David Hummels, Amit Khandelwal, Robert McClelland, Giovanni Peri, Katheryn Russ and seminar participants at the Federal Reserve Bank of NY, UC Davis, and the 2008 conferences of ITFA and EIIT. Any remaining errors or omissions are mine. The views expressed here do not necessarily reflect those of the BLS.

The price levels of internationally traded goods are largely driven by: (i) marginal costs of production, reflecting the underlying productivity differences across exporting firms, and (ii) product quality, the heterogeneity in desirable characteristics across competing varieties. A key emerging insight in international economics is that the scope for quality differentiation can help to explain observed patterns in average export prices at the level of products or firms.¹ That is, in contrast to standard industry models of firm heterogeneity in which high productivity firms set lower prices,² a theory in which higher productivity firms set higher prices for higher quality goods helps to match broad empirical facts.

In addition to improving our understanding of trade patterns, quality's role in price setting has important implications for how we actually measure prices. Firstly, mismeasured or ignored compositional changes create bias in prices, as discussed at length in the index number literature.³ There is also mounting evidence that the dynamics of quality differentiated goods are different relative to more homogeneous goods.⁴ Therefore, there is strong impetus to be able to measure the scope of quality differentiation across products and exporting countries, and to account for their respective dynamics.

In this paper, I model a straightforward departure from existing 'cost' models⁵ of firm heterogeneity to allow for an endogenous array of quality types, and bring this unified framework to bear on an expansive data set of transaction-level U.S. import prices collected by the International Price Program (IPP) of the Bureau of Labor Statistics (BLS). I focus on the distribution of transactions prices and firm productivity within narrowly defined product groups to make inference as to the scope of unobserved product quality and to explore the

¹Quality differentiation is used by Kugler and Verhoogen (2008) to explain plant-level size-price correlations, by Baldwin and Harrigan (2007) to explain increasing unit value prices in exporter distance, and suggested by Schott (2004) and Hummels and Klenow (2005) to explain increasing unit values in exporter income. The first of these studies uses firm data from Colombia while the latter three studies use product level export data. Of note, all of these studies, even those at the plant-level such as Kugler and Verhoogen, use unit value prices and not individual transaction prices.

²Firms differ across an array of productivity levels and compete in a monopolistically competitive industry. See Melitz (2003).

³For example, a price increase for an upgraded model of automobile may be reflecting its more desirable features relative to its predecessor. Alternatively, a shift in demand into higher priced goods would increase an average (non-quality-adjusted) price even if each underlying price went unchanged. The distinction and large potential differences between constant quality and non-quality-adjusted price indexes is discussed and illustrated in Alterman (1991).

⁴For instance, see Auer and Chaney's (2007) discussion of quality and exchange rate pass-through where varieties of different quality (within an industry) have different price sensitivity to exchange rates.

⁵Herein I refer to the absence of quality differentiation with the descriptor: 'cost.'

higher moments of the price distribution. I then construct indexes of product quality by country and measure the sensitivity of prices and quality to changes in the macroeconomy with an application to exchange rate pass-through. I classify the empirical exercises and results into four groups, outlined in the quadrants of the following table:

	Time-Series	Cross-Section
Cross-Industry	IV. Identify industry differences in exchange rate pass-through (Section 4)	I. Identify 'cost' vs. 'quality' industries (Section 2)
Within-Industry	III. Identify sectors with process or product innovation over time (Section 3.1)	II. Identify countries by export productivity (Section 3)

First, in section 1, I provide a descriptive analysis of the price distribution of U.S. imports *within* harmonized system 10-digit categories. I find significant clustering of prices within products and skewness that is highly industry-specific. I then extend a benchmark model of heterogeneous firms to show that these patterns are consistent with a theoretical framework in which firms endogenously choose their level of quality and sort into export markets accordingly.

Second, in section 2, I use the theoretical setup's sharp predictions about the higher moments of the price level distribution to identify differences in the scope for quality differentiation across sectors. This contrasts with prior studies of product or sectoral quality measurement, such as Hallak and Schott (2008), Johnson (2008), Khandelwal (2007), Harrigan & Barrows (2006), Feenstra (1988) and Aw and Roberts (1986) in that it directly exploits intra-product pricing patterns without relying on inference from aggregate trade data at any level. Employing measured import price skewness, and controlling for other factors affecting the distribution of prices, I distinguish between 'cost' industries, with low scope for quality differentiation, and 'quality' industries, with high scope for quality differentiation. I find that quality industries account for roughly half of U.S. import value.

Third, the theory also suggests that within an industry, each exporting country's productivity level and specialization in quality characteristics can be ascertained by its location

in the U.S. import price distribution. In section 3, I use quantile regression techniques to discern country export productivity across sectors and find that more productive countries tend to sell ‘quality’ products at higher prices and ‘cost’ products at lower prices on world markets. This result refines the income-quality nexus suggested by Schott (2004), Hummels and Klenow (2005) and Choi, Hummels and Xiang (2006), in that country export quality is not a monolith: high unit value prices in wealthier (more productive) countries belie specialization in low priced varieties in less-quality-differentiated sectors. This ‘intra-distribution’ analysis also implies that the prices of export goods with differing quality evolve distinctly over time. Indeed, within products, I find evidence that suggests continuous innovation in both the products and process in foreign exports to the U.S.

Finally, the theoretical framework of cost and quality also has implications for the time-series of average prices in response to *particular* structural changes in the economy (like, for instance, a productivity shock or policy change). In section 4, I describe and measure the implications of quality sorting for real-exchange rate pass-through. Consistent with the predicted ordering of firms in the model, I find that pass-through is systematically higher in unit values (i.e., not controlling for composition) than in constant-quality prices. Across industries, quality industries have systematically higher pass-through, indicating that firms in highly quality differentiated sectors are better able to pass-through changes in their marginal costs to consumers.

The remainder of the paper is organized as follows. The next section describes patterns in the price distribution of U.S. imports, which motivate the model of endogenous firm quality choice presented in Section 2. Then, the four data exercises in the table above, beginning with the top-right quadrant, are addressed in the sections 2-4. Section 5 concludes.

1 The IPP Import Price Data

The IPP data, which consist of approximately 20,000 monthly transaction level ‘at-the-dock’ prices, provides a large breadth of coverage for roughly the entire range of U.S. goods import industries over the period 1994-2004. A panel of this size and diversity makes it an extremely

useful tool in the investigation of international price-setting.⁶

Previously, studies have used *national* micro-data to investigate the quality composition of aggregate price deflators. For example, for the micro-data underlying the CPI, Bils (2004) quantifies the difference between price and quality growth by examining the point at which one product is substituted for another and the explicit quality adjustment made by the BLS. Bils's work is motivated by earlier estimates of quality bias in the CPI by the Boskin Commission (1996) and by Moulton and Moses (1997). Since the IPP constructs a matched model index for imports, which is quality-adjusted by construction,⁷ the empirical methods used by Bils are not applicable and new means of inference must be devised to obtain information about aggregate quality from individual prices. I begin by analyzing the price distribution for very disaggregate product groups, which offers some clues to that end.

In terms of classification, I define a disaggregate product group as a Harmonized System 10-digit (HS10) category. The IPP uses a similar definition called 'classification', which groups together smaller, similar HS10 products;⁸ since in roughly half of cases, classification groups are identical to HS10 groups (with the majority of the remainder containing two HS10 groups), I will refer to them synonymously. Examples of HS10 groups in U.S. imports are:

1. Portable digital automatic data processing machine, not more than 10 kg, w/ CPU, keyboard & display
2. Cucumbers, gherkins; Entry 12/1-end of February; fresh or chilled

The first example is simply the description ascribed to laptop computers, which composes the majority of the more aggregate HS6 category: handheld computers. In the IPP sample, a laptop price observation would be for a particular, precisely defined model and brand

⁶The IPP data has also been used for the measurement of the frequency of price changes as well as exchange rate pass through (Gopinath & Rigobon (forthcoming); Gopinath, Itskhoki & Rigobon (2007)).

⁷The IPP tracks unique varieties of product groups over time and then aggregates the varieties using fixed weights. Therefore, the characteristics and share of the index are held literally constant in each period's price index calculation.

⁸The reason that the BLS uses slightly more aggregate groups is that not every group (particularly smaller ones) are represented in the IPP sample.

imported from a given country in a given month.⁹ For laptops, it is clear that most differentiation across laptops takes place within the HS10 group; that is, differentiation in screen size, memory and processor speed will all be reflected in price differences at the variety level. In contrast, the category of winter cucumbers and gherkins is relatively homogeneous, and there are only six sub-categories defined by the USDA denoting cucumber coloration, formation and size. I will show that the price distribution is indeed quite different between these types of products, which can be used to distinguish their scope of quality differentiation.

The general contours of the sample at the classification level are as follows. The entire 11 year sample contains over 66,000 items (specific varieties) categorized into over 7,000 classification groups.¹⁰ Certain product groups (e.g. HS84 and HS85 which contain the sizable machinery and electric equipment categories) are relatively large, though the number of items per classification group is stable over the sample at approximately 9.

Figure 1 shows an illustrative example of (log) import prices for a classification group over time. Within product groups, there is a clear distinction between the high and low priced goods, typically manifested in a tight group of prices around the median and a few outlying higher or lower priced items.¹¹ The clustering of prices is consistent with what we would expect from a Pareto-type distribution of firm productivity; the large mass of firms with similar (relatively low) productivity sets prices which are similar. The high outliers, however, are not what we would expect from a Pareto distribution of firm productivity since the outliers in the productivity distribution should be setting prices that are *low*. One potential explanation is that more productive firms elect to produce higher quality, more costly goods whose prices are high outliers.

⁹Although the frequency of the sample is monthly, actual price observations are not available each period and are imputed by the BLS; this either means that the item price remains unchanged or are imputed linearly based on group price changes. For a typical item, prices are relatively stable with occasional changes. For a typical classif group, certain items are observed only sporadically while others enter or exit over the course of the data span; this creates several issues for aggregation which will be addressed separately for the uses of the data described below. For our purposes it will often be convenient to leave imputed price values in the sample, as the BLS does when it computes import price deflators. Leaving in imputations contrasts with other uses of the IPP data, such as the examination of the frequency of price changes. Whereas in frequency calculations imputations can cause biased statistics, imputed values actually add needed stability to the sample over time when computing the distribution at low levels of aggregation.

¹⁰Due to changing classification categories over time, the number of groups in any given month is less than 7,000.

¹¹In the analysis of classification group price distribution, the reported units of sale are also controlled for; I distinguish between goods sold by the ton versus those sold by container which would be priced non-comparably. Also removed from the sample are those items not priced in dollars.

Table 1 illustrates some of the sample's price distribution properties, distinguished by 16 sector categories.¹² The statistics are calculated monthly by HS10 group and then averaged over months and HS10 groups within a sector. I confirm the significant clustering of prices, with average kurtosis typically found to be greater than 3 (i.e., leptokurtic, with a more acute peak than a standard normally distributed variable). The skewness statistic, on the other hand, appears to have a large industry-specific component. For industries with a lower degree of product differentiation, such as wood and mineral products, skewness is negative (skewed left with a long left tail). For industries with a higher degree of product differentiation, such as textiles, electric machinery and computers, skewness is positive (skewed right with a long right tail).

	Average # Items/ Classif	Standard Deviation	Skewness	Kurtosis	Freq. of High Outliers	Freq. of Low Outliers
Wood & Wood Products	29	0.32	-0.37	4.57	0.14	0.12
Mineral Products	21	0.25	-0.33	4.98	0.16	0.10
Animal & Animal Products	40	0.43	-0.11	4.48	0.10	0.14
Raw Hides, Skins, Leather	17	1.03	-0.10	3.04	0.18	0.13
Stone / Glass	20	1.01	-0.01	2.79	0.17	0.13
Metals	15	0.83	0.01	3.46	0.16	0.14
Footwear / Headgear	29	0.61	0.03	3.43	0.18	0.14
Miscellaneous	23	1.40	0.03	2.94	0.16	0.15
Vegetable Products	18	0.29	0.05	3.42	0.17	0.13
Transportation	29	1.06	0.13	2.93	0.16	0.16
Foodstuffs	21	0.52	0.16	3.28	0.17	0.15
Electric Machinery	35	1.58	0.28	3.29	0.17	0.12
Mechanical & Computers	35	1.60	0.29	3.71	0.18	0.12
Chemicals & Allied Ind.	14	2.08	0.35	2.79	0.19	0.12
Textiles	20	0.56	0.38	4.15	0.17	0.11
Plastics / Rubber	21	1.35	0.73	3.99	0.18	0.10
	30	1.18	0.15	3.43	0.17	0.13

Table 1: Intra-classification distribution properties of the IPP data, by sector¹³

Based on the observed distribution of price levels in the data, the skewness statistic is indicative of the *type* of differentiation in each industry. In the less quality-differentiated

¹²Sector categorization is defined by HS2: Animal and animal products (1-5); Vegetable products (6-15); Foodstuffs (16-24); Mineral products (25-27); Chemicals & allied industries (28-38); Plastics & rubber (39-40); Raw hides, skins & leather (41-43); Wood & wood products (44-49); Textiles (50-63); Footwear/Headgear (64-67); Stone/glass (68-71); Metals (72-83); Mechanical and computers (84); Electric machinery (85); Transportation (86-89); Miscellaneous (90-96).

¹³Sample includes those classification groups with greater than 10 item price observations in a given monthly period. All statistics are calculated within a classification group and then aggregated over classifications and time, weighted by the dollar sales value of imports.

industries, one might expect a higher degree of cost and price competition, as goods are less defined by their characteristics. With more competition in cost, only the high productivity firm outliers are able to break from the cluster of median prices in each category to offer lower prices, thus skewness is negative. On the other hand, with a higher degree of differentiation in characteristics, it is only those firms that are productive enough to bear the costs of innovation and more intricate processes that are able to produce high quality, high priced goods, causing skewness to be positive.

The overall skewness of the data is positive, which is reflected in the higher incidence of HIGH outliers relative to LOW outliers.¹⁴ This is consistent with empirical work such as Baldwin and Harrigan (2007), which suggests that *on average*, unit value prices are biased upward by quality. What I show here is that underlying the average positive skewness of U.S. import prices is an array of industries whose price distribution (and hence unit values) reflect the cost advantages of high productivity firms in two distinct ways.

Also of interest is the observation that variable skewness across industries is caused not only by an increase in high priced outliers, but a decrease in low priced outliers. Aside from quality, another interpretation of low-price outliers is the new entry onto world markets of low cost producers, sometimes referred to as a ‘Wal-mart effect.’ In the following sections, I attempt to (jointly) quantify these effects for U.S. imports and find that there are very important product- and country-specific components that determine a good’s likelihood of being a high or low outlier in the IPP sample. To guide those empirical exercises, in the next section I specify a model of firm heterogeneity in productivity and quality.

2 A Model of Endogenous Quality Choice

The model uses the probabilistic framework of firm heterogeneity with monopolistically competitive firms distinguished in their productivity, as in Melitz (2003), Ghironi and Melitz (2005), Bergin, Glick and Taylor (2005), and Melitz and Ottaviano (2005), among several others. Firms are differentiated along an array of productivities (indexed by $\varphi(\omega)$) where each firm produces a unique variety ω . Production of each variety in every HS10 product

¹⁴HIGH outliers are defined as prices greater than one standard deviation above the median price. LOW outliers are defined as prices less than one standard deviation below the median price.

group is subject to positive consumer demand which, in turn, is based on a constant elasticity of substitution sub-utility function:

$$X = \left\{ \int_{\omega \in \Omega} [x(\omega)z(\omega)]^{\frac{\sigma-1}{\sigma}} d\omega \right\}^{\frac{\sigma}{\sigma-1}}$$

where $x(\omega)$ is the quantity of variety ω , and $z(\omega)$ is the ‘weight’ attributed to the unique characteristics of that variety. Of course, consumers only care about the composite good $x(\omega)z(\omega)$, which defines the ‘quality-adjusted’ quantity $d(\omega) = x(\omega)z(\omega)$. Consumers compare quality-adjusted varieties and their respective quality-adjusted prices in deciding their purchase allocation, where quality-adjusted price $q(\omega)$ is defined as the sticker price $p(\omega)$ normalized by quality: $q(\omega) = \frac{p(\omega)}{z(\omega)}$. This specification of utility gives rise to the demand and expenditure ($r(\omega)$) functions:

$$d(\omega) = \left(\frac{q(\omega)}{Q} \right)^{-\sigma} D \quad (1)$$

$$r(\omega) = \left(\frac{q(\omega)}{Q} \right)^{1-\sigma} R \quad (2)$$

where D is a composite quantity of the differentiated product and R aggregate expenditure on that product. The aggregate quality-adjusted price index is:

$$Q = \left(\int_{\omega} q(\omega)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \quad (3)$$

Production accounts explicitly for the costs of quality, and each firm employs labor inputs $L(\omega)$:

$$L(\omega) = f + x(\omega) \left\{ \kappa z(\omega)^b + \frac{\eta z(\omega)^a}{\varphi(\omega)} \right\} \quad (4)$$

Labor consists of a fixed cost f and two variable costs which are increasing in the level of quality. In order to have an interior solution for quality level, the average cost of quality must have a well-defined minimum. As I will show, a sufficient condition for a non-degenerate distribution of quality is $b < 1 < a$. What these unit cost curvature assumptions imply is that there are increasing returns to quality in $z(\omega)^b$, and decreasing returns to quality in $z(\omega)^a$. For intuition, consider $\eta z(\omega)^a$ to be a ‘process’ component and $\kappa z(\omega)^b$ to be a ‘monitoring’ component. Process costs, in addition to increasing in quality at an increasing

rate, are lower for more productive (higher φ) firms. These can be understood as something analogous to an input material cost: a graphite tennis racquet costs more to produce than a wooden one, and a more productive firm requires fewer people to assemble it. Units of monitoring cost, on the other hand, increase in quality at a decreasing rate and are the same across firms. One might imagine this as quality control infrastructure: adding a supervisor to inspect the tennis racquets for visible flaws decreases the incidence of defects (i.e., increases quality), though his or her cost is no greater for a graphite racquet than a wooden one.¹⁵ This monitoring aspect of production can alternatively be interpreted as a reduced form of the O-ring production function proposed by Kremer (1993).¹⁶ In this case, firms that choose to produce more complex/ higher quality products have an incrementally higher wage bill due to monitoring costs.

Given this technology, the Home firm's profit function is:

$$\begin{aligned}\pi(\omega) &= x(\omega)p(\omega) - wL(\omega) \\ &= x(\omega) \left\{ p(\omega) - w \left[\kappa z(\omega)^b + \frac{\eta z(\omega)^a}{\varphi(\omega)} \right] \right\} - wf\end{aligned}$$

where w is the wage rate, considered exogenous by the firm. The expression for profit can also be written in the quality-adjusted notation described above:

$$\pi(\omega) = d(\omega) \left\{ q(\omega) - w \left[\kappa z(\omega)^{b-1} + \frac{\eta z(\omega)^{a-1}}{\varphi(\omega)} \right] \right\} - wf \quad (5)$$

Quality and quality-adjusted prices are chosen simultaneously by the firm, which allows us to separate the firm problem into two parts. For the quality component, (5) is maximized by the firm with respect to z (z^*); given that the expression for profit is in terms of quality-adjusted quantity and price, it is immediately clear that maximizing profits is equivalent to

¹⁵A more specific interpretation of monitoring costs could be as the costs of quality-differentiated inputs (whose quality level is complementary to that of the output), as in Kugler and Verhoogen (2008). Here, the particular reason for increasing returns to quality is not as relevant, so I will proceed with the more general specification.

¹⁶In Kremer (1993), production is separated into a set of tasks undertaken by workers of varying skill. The equilibrium outcome is that workers of the same skill are matched together in firms, with higher skill firms paying a higher wage bill. Moreover, when technology choice is endogenous (i.e., firms choose the number of tasks, and hence complexity, associated with production), higher skill firms choose more complex production processes. Verhoogen (2007) employs an O-ring production function to explicitly show returns to skilled and unskilled labor.

minimizing the term in square brackets, the average cost of quality:

$$\begin{aligned} & \min_z \left\{ \kappa z(\omega)^{b-1} + \frac{\eta z(\omega)^{a-1}}{\varphi(\omega)} \right\} \\ \implies & z(\varphi) = \theta_z \varphi^{\frac{1}{a-b}} \end{aligned} \quad (6)$$

where $\theta_z = \left(\frac{(1-b)\kappa}{(a-1)\eta} \right)^{\frac{1}{a-b}}$ is a positive constant. The result is an expression for the quality characteristics chosen by each firm as a function of its productivity draw, where the quality of each variety is increasing in the level of firm productivity.

The pricing rule is derived by maximizing profits (5) with respect to the quality-adjusted price, subject to the consumer demand relation (1). This setup leads to the standard constant markup pricing rule for the firm, only now the marginal cost term contains a measure of the good's quality. Quality-adjusted price q is expressed in terms of z , w and the firm-specific productivity parameter:

$$q[z(\varphi), \varphi] = \left(\frac{\sigma}{\sigma-1} \right) w \left[\kappa z(\omega)^{b-1} + \frac{\eta z(\omega)^{a-1}}{\varphi(\omega)} \right] \quad (7)$$

Substituting (6) into (7), the quality-adjusted price can be expressed purely as a function of the wage and productivity parameter:

$$q(\varphi) = \theta_q w \varphi^{\frac{b-1}{a-b}} \quad (8)$$

where $\theta_q = \left\{ \left(\frac{\sigma}{\sigma-1} \right) \left(\kappa \left(\frac{(1-b)\kappa}{(a-1)\eta} \right)^{\frac{b-1}{a-b}} + \eta \left(\frac{(1-b)\kappa}{(a-1)\eta} \right)^{\frac{a-1}{a-b}} \right) \right\}$ is a positive constant. The quality-adjusted price diminishes in productivity, similar to the prices in Melitz (2003), which are a CES markup of w/φ .

Quality-inclusive prices can be reconstituted by multiplying quality-adjusted prices by quality:

$$p(\varphi) = \theta_p w \varphi^{\frac{b}{a-b}} \quad (9)$$

where $\theta_p = \left\{ \left(\frac{\sigma}{\sigma-1} \right) \left(\kappa \left(\frac{(1-b)\kappa}{(a-1)\eta} \right)^{\frac{b}{a-b}} + \eta \left(\frac{(1-b)\kappa}{(a-1)\eta} \right)^{\frac{a}{a-b}} \right) \right\}$ is a positive constant.

Equation (9) is particularly interesting since prices are not constrained to be a negative function of firm productivity. If $\frac{b}{a-b} > 0$, more productive firms choose quality that is sufficiently high so as to increase price relative to low productivity firms: this is what I refer

to as a quality industry. If $\frac{b}{a-b} < 0$, more productive firms choose higher quality, but cost advantages still lead them to set lower prices relative to low productivity firms: this is what I refer to as a cost industry.

2.1 Distinguishing Cost versus Quality Industries

In this section, the observed IPP import price moments are matched with those predicted by the model in order to estimate the parameters underlying the scope of quality differentiation across products. The intuition behind this identification is that the productivity (φ) distribution of firms, usually assumed to be skewed right (i.e., with high outliers), maps very differently into prices depending on the level of sectoral quality differentiation. As in standard models, in more homogeneous sectors high productivity maps directly into low costs and price, so the distribution is skewed left (i.e., with low outliers). In contrast, one might expect high productivity firms to be more adept at producing quality characteristics, as demonstrated by the equilibrium levels of quality in the model, so in quality differentiated sectors high productivity maps into higher quality, cost and prices; thus, the price distribution is also skewed right.

Switching to discrete notation, we have expressions for quality, quality-adjusted price and quality-inclusive price by item i , HS-10/classification product j , country k , and month t :

$$\text{Quality:} \quad z_{ijkt} = \theta_j^z \varphi_{ijkt}^{\frac{1}{a-b}} \quad (10)$$

$$\text{Adjusted Price :} \quad q_{ijkt} = \theta_j^q w_{jkt} \varphi_{ijkt}^{\frac{b-1}{a-b}} \quad (11)$$

$$\text{Inclusive Price :} \quad p_{ijkt} = \theta_j^p w_{jkt} \varphi_{ijkt}^{\frac{b}{a-b}} \quad (12)$$

where θ_j^z , θ_j^q and θ_j^p are positive product-specific constants.

Taking logs of the quality-inclusive price (12) yields:

$$\ln p_{ijkt} = \ln \theta_j^p + \ln w_{jkt} + \left(\frac{b_j}{a_j - b_j} \right) \ln \varphi_{ijkt} \quad (13)$$

As noted above, $\frac{b}{a-b}$ is the slope of the productivity-price schedule, which I assume is

HS10-specific: for positive values, the costs of producing (a higher number of) quality characteristics outweigh the cost savings of being farther right along the productivity distribution. Since firm-level productivity data are not available across a broad array of products and countries to estimate (13) directly, I proceed by using approximations of the *distribution* of firm productivity and wage to try to identify the sign and magnitude of $\frac{b}{a-b}$. From (13), the second and third moments of the price distribution can also be expressed as:¹⁷

$$Var_{jt}(\ln p_{ijkt}) = Var_{jt}(\ln w_{jkt}) + \left(\frac{b_j}{a_j - b_j}\right)^2 Var_{jt}(\ln \varphi_{ijkt}) \quad (14)$$

$$\frac{Skew_{jt}(\ln p_{ijkt})}{[Var_{jt}(\ln p_{ijkt})]^{-\frac{3}{2}}} = \frac{Skew_{jt}(\ln w_{jkt})}{[Var_{jt}(\ln w_{jkt})]^{-\frac{3}{2}}} + \left(\frac{b_j}{a_j - b_j}\right)^3 \frac{Skew_{jt}(\ln \varphi_{ijkt})}{[Var_{jt}(\ln \varphi_{ijkt})]^{-\frac{3}{2}}} \quad (15)$$

The left-hand side variables of (15) can be measured at the HS10 level using the IPP data, and the distribution of industry-level wage across countries is calculated using annual industry data from the ILO Yearbook of Labor Statistics.¹⁸ For the firm productivity distribution, I exploit another statistic used by the BLS in the construction of its aggregate international prices. Specifically, the BLS uses firm-level export sales weights to aggregate within HS10 groups for its U.S. export price indexes. To the extent that the size distribution of product sales corresponds to firm productivity, these weights provide a handy approximation of the U.S. export productivity for thousands of disaggregate products, and I apply these weights uniformly to foreign exporters.

Figure 2 portrays summary statistics for the skewness of transaction prices, cross-country wages and firm export size across products. Consistent with Table 1, the price distribution is divided with a substantial number of both positive and negative skewness products. Wages, on the other hand, are almost all left skewed, likely reflecting the high incidence of trade among high income countries, with low-wage exceptions. Finally, consistent with firm-level studies, US export sales are primarily positively skewed.¹⁹

¹⁷See Appendix for derivation.

¹⁸ILO Yearbook wage data are available at the SIC 4-digit industry level.

¹⁹The high number of products with close to symmetric distributions may reflect the small number of firms that the BLS samples within certain HS10 product groups. In Figure 2 and the analysis below, included products contain a minimum of 5 observations. In the regression below, the estimates are not substantially different if the minimum number of firms per product is increased to 10, although over a smaller number of HS6 groups.

Denoting the dollar export weights y_{ijkt} , the estimating equation for (15) is:

$$Skew_{jt}(\ln p_{ijkt}) = \alpha_0 + \alpha_1 * Skew_{jt}(\ln w_{jkt}) + \sum_{hs6} \alpha_{2,hs6} * Skew_{jt}(\ln y_{ijkt}) + \varepsilon_{jt} \quad (16)$$

where $\alpha_{2,hs6}$ is the point estimate for $\left\{ \left(\frac{Var_{jt}(\ln y_{ijkt})}{Var_{jt}(\ln p_{jkt})} \right)^{\frac{3}{2}} \left(\frac{b_j}{a_j - b_j} \right)^3 \right\}$ within a given HS6 category.²⁰ The OLS regression is pooled across all product categories for which price, wage and size data are available: 41,633 product-time pair observations. Also included are year dummy variables, to control for secular trends in the respective distributions. This specification yields estimates for approximately 1,100 HS6 categories, approximately 450 of which are statistically distinguishable from zero.

The resulting estimates for the largest 20 products in cost industries ($\frac{b}{a-b} < 0$) and quality industries ($\frac{b}{a-b} > 0$) are shown in Table 2. At first glance, the quality industries in the top panel seem to conform to our prior notions of products with a high degree of quality differentiation (e.g., passengers cars, clothing and wine). Likewise, the bottom panel includes goods with a ‘cost story’ such as machine parts and accessories, and metal furniture. On the other hand, both panels contain products that are not so intuitively categorized, such as transport motor vehicles and parlour games in the cost panel, and liquefied butane in the quality panel. There are several reasons not to get bogged down in constructing stories to explain the level of quality differentiation across product groups. Firstly, categories at the HS6 or HS10 level are somewhat arbitrary. Hypothetically, if a new categorization scheme emerges including a separate group for the Dell Inspiron 710m laptop, 2GB SD RAM, 80GB hard disk drive, we would not observe much quality differentiation within that product despite the fact that the broader product class has a lot of quality heterogeneity. What is important is that there is a consistent way to characterize what is going on *within* each product group, however defined, which is the key feature of this estimation strategy.

Secondly, we must be careful in discerning between horizontal and vertical (quality) differentiation, where the former is differentiation that occurs across product features that cannot be ordered. For example it would be difficult to place ice cream as either a cost or a quality industry; while there is a lot of horizontal differentiation in flavors, it is not clear

²⁰Technically it is possible to estimate the quality cost parameters at the classification/HS10 level (as opposed to HS6). However, since the BLS classification and HS10 codes are identical at the HS6 level, for ease of interpretation I use the slightly more aggregate codes.

whether there is a broad array of quality differences among Ben & Jerry's, Haagen Dazs, and other varieties.

Top 20 Largest Quality Products by Value

	<u>2005</u>				
	<u>Import</u>				
<u>HS6</u>	<u>(\$bn)</u>	<u>b/(a-b)</u>	<u>sigma</u>	<u>Description</u>	
870323	46.50	2.02	27.08	PASSENGER VEHICLES, SPARK-IGNITION, ENGINE >1500 CC	
852520	24.90	2.30	3.08	TRANSMISSION APPARATUS INCORPORATING RECEPTION APPARATUS	
300490	24.00	0.44	11.03	MEDICAMENTS NESOI, MEASURED DOSES, RETAIL, NESOI	
852990	5.14	0.36	2.97	PARTS FOR TRANSMISSION, RADAR, RADIO, TV, NESOI	
620342	5.11	1.65	4.57	MEN'S OR BOYS' TROUSERS, NOT KNIT, COTTON	
901890	4.86	0.29	2.07	INSTRUMENTS & APPLIANCES FOR MEDICAL SURGICAL DENTAL VET., NESOI	
850440	4.81	0.29	8.91	STATIC CONVERTERS; AUTOMATED DATA PROCESSOR POWER SUPPLIES	
848180	4.39	1.03	2.38	OTHER VALVES AND OTHER APPLIANCES FOR PIPES, TANKS, VATS OR THE LIKE	
271112	4.24	1.11	6.25	PROPANE, LIQUEFIED	
852190	3.97	1.73	2.20	VIDEO RECORDING/REPRODUCTION APPLIANCES	
853710	3.81	0.82	3.82	BASES FOR ELECTRIC CONTROL OR DISTRIBUTION, NOT EXCEEDING 1,000V	
401110	3.74	2.44	4.88	NEW PNEUMATIC TIRES OF RUBBER, FOR MOTOR CARS	
760110	3.73	1.20	27.85	UNWROUGHT ALUMINUM, NOT ALLOYED	
760120	3.47	4.34	9.16	UNWROUGHT ALUMINUM ALLOYS	
740311	3.24	8.28	33.70	REFINED COPPER CATHODES AND SECTIONS OF CATHODES	
220421	3.05	1.35	4.07	WINE, FROM GRAPES, NESOI, <2 LITERS	
271114	2.87	2.28	29.76	ETHYLENE, PROPYLENE, BUTYLENE	
842952	2.51	1.58	18.00	MECHANICAL SHOVELS & EXCAVATORS	
271113	2.34	2.74	9.55	BUTANES, LIQUEFIED	
853400	2.12	0.29	9.71	PRINTED CIRCUITS	

Top 20 Largest Cost Products by Value

	<u>2005</u>				
	<u>Import</u>				
<u>HS6</u>	<u>(\$bn)</u>	<u>b/(a-b)</u>	<u>sigma</u>	<u>Description</u>	
847330	27.60	-0.19		PARTS & ACCESSORIES FOR AUTOMATED DATA PROCESSOR MACHINES & UNITS	
870431	10.80	-3.06	42.90	MOTOR VEHICLES FOR THE TRANSPORT OF GOODS, NOT OVER 5 METRIC TONS	
851790	8.59	-0.28		PARTS OF ELECTRICAL APPARATUS FOR LINE TELEPHONY OR LINE TELEGRAPHY	
840734	6.66	-2.77	26.62	RECIPROCATING PISTON ENGINES FOR VEHICLES, EXCEEDING 1, 000CC	
854430	5.78	-0.23		INSULATED WIRING SETS FOR VEHICLES, SHIPS, AIRCRAFT	
940190	5.74	-0.32		PARTS OF SEATS (EX MEDICAL, BARBER, DENTAL ETC)	
950490	3.58	-0.90	1.20	OTHER ARTICLES FOR FUNFAIR, TABLE OR PARLOUR GAMES	
610910	3.42	-2.44	5.61	T-SHIRTS, SINGLETs, OTHER VESTS, KNITTED OR CROCHETED, OF COTTON	
30613	2.80	-3.36	5.25	SHRIMPS AND PRAWNS, INCLUDING IN SHELL, FROZEN	
940320	2.72	-1.75		METAL FURNITURE, NESOI	
620520	2.66	-1.04	5.24	MEN'S OR BOYS' SHIRTS, OF COTTON	
843149	2.63	-0.33	2.57	PARTS OF DERRICKS, CRANES, GRADERS, LEVELLERS, SCRAPERS OR PILE-DRIVERS	
903289	2.61	-0.79	1.72	AUTOMATIC REGULATING OR CONTROLLING INSTRUMENTS & APPARATUS	
950410	2.52	-1.67		VIDEO GAMES OF A KIND USED WITH A TELEVISION RECEIVER	
940161	2.48	-1.06	2.17	SEATS WITH WOODEN FRAMES, UPHOLSTERED, NESOI	
847989	2.46	-0.29	21.75	AIR-COOLERS, AIR PURIFIERS OF OTHER MACHINES AND MECHANICAL APPLIANCES	
300439	2.31	-0.56	4.10	MEDICAMENTS CONTAINING OTHER HORMONES	
847340	2.07	-0.43		PARTS AND ACCESSORIES OF OFFICE MACHINES, NESOI	
901819	1.92	-0.39	28.58	ELECTRO-DIAGNOSTIC APPARATUS NESOI, AND PARTS	
853669	1.75	-0.56	1.99	PLUGS AND SOCKETS, FOR A VOLTAGE NOT EXCEEDING 1,000V	

Table 2: Quality scope estimates, $\left(\frac{b}{a-b}\right)$, and a measure of horizontal differentiation, σ .

To check the extent that the measured quality scope corresponds to product-level horizontal differentiation, I compare $\frac{b}{a-b}$ with previous estimates by Broda and Weinstein of intra-product elasticity of substitution (σ). In the CES framework above, σ indexes consumers' willingness to substitute among quality-adjusted varieties, so in this context it can be strictly interpreted as an index of horizontal differentiation. In Table 2, there is no clear pattern between $\frac{b}{a-b}$ and σ , and on average a slight negative relationship (i.e., cost industries have a low σ while quality industries have a high σ). Taking the model of vertical differentiation very seriously, one might expect producers in a horizontally homogeneous sector (high σ) to want to distinguish themselves vertically, however I find that over all estimates the correlation between $\frac{b}{a-b}$ and σ is only 0.01.

A more subtle point is that the sign of $\alpha_{2,hs6}$ in (16) could reflect the magnitude of the skewness of productivity rather than its sign. That is, considering a product where both prices and firm export size are positively skewed, a negative sign could still arise for $\alpha_{2,hs6}$ if the prices are simply less positively skewed relative to other product groups of equal productivity skewness. Thus positive skew prices can still be cost industries, which is less intuitive. As an indirect way of decomposing how much of the scope estimates are due to sign versus magnitude, I run (16) for only the set of products with both positive skew prices and productivity.²¹ I find that even though there are still quite a number of significant negative estimates for $\alpha_{2,hs6}$, the average magnitude of the estimates changes substantially. For products with a significant negative estimate (indicating that they are a cost industry) in the unrestricted sample, the average size of $\alpha_{2,hs6}$ is -1.70, compared to 22.30 for the identical set of products in the restricted sample. The estimates for quality industries remain roughly unchanged at 4.82 in the unrestricted sample versus 3.42 in the restricted sample. This suggests that the sign of price skewness plays an important role in determining cost versus quality industries.

Finally, using the estimates of $\frac{b}{a-b}$ I construct the shares of U.S. import trade accounted for by cost and quality industries, illustrated in Figure 3. In panel (a), approximately 50-60 percent of total import value is categorized as either cost or quality, with the asterisk superscript denoting estimates of $\frac{b}{a-b}$ that are significantly different from zero. Between 1993 and 2005, the share of cost industries declined from 40 percent to about 25 percent

²¹For a fair comparison, I redo the estimates for the whole sample with wage skewness on the left-hand side (i.e., $Skew_{jt}(\ln p_{ijkt}) - Skew_{jt}(\ln w_{jkt})$) and then compare the results to the restricted sample.

with quality industries growing from 20 percent to about 25 percent. Thus, the current proportion of imports with a large scope for quality differentiation is roughly 50 percent. Within a balanced panel of products in panel (b), the shares of cost and quality imports are more stable at 50 percent. In the sections that follow, I will maintain the distinction between cost and quality products in order to further explore the cross-section and dynamic features of the import price distribution.

3 Quality Specialization by Country & Over Time

After discerning the scope for quality differentiation across products, we can take a different view of the data by picking a product and observing which countries inhabit the tails of its price distribution. Countries consistently selling in a quality industry's right tail are considered to be specialized in quality, with the converse holding for cost industries. In this section, I use quantile regression techniques to discern countries' propensity to sell in the tails of the price distribution and find that, indeed, similar sets of countries populate the tails; a country exporting at a high price in a quality industry tends to export at a low price in a more homogeneous cost industry. In other words, the price distribution and the underlying productivity-price mapping reveals the productivity of exporting countries. Previous studies find that average prices vary systematically with country characteristics (e.g., wealth and distance), and so this exercise can be interpreted as additionally documenting the intra-product heterogeneity in country pricing patterns.

Once again the first order conditions of the firm problem offer a convenient starting point. The item pricing equation (13) is a simple relationship between quality-inclusive price, wage and firm productivity. Controlling for wage, the residual of item price contains information about the exporting firm's location along the productivity distribution as well as any other country- or firm-specific factor. Conditioning by country (as opposed to firm productivity in the previous section) allows for analysis in levels:

$$\ln p_{ijkt} = \alpha_0 + \alpha_1 \ln w_{jkt} + \sum_k \alpha_{2k} d_k + \sum_j \alpha_{3j} d_j + \sum_t \alpha_{4t} d_t + \varepsilon_{ijkt} \quad (17)$$

where α_{2k} estimates the average country-specific component of item price, controlling for product composition with HS10 dummy variables d_j and for time variation with year dummy

variables d_t . Given the observation above of asymmetric price distributions, and the implication that quality levels differ substantially across the spectrum of observations within a product, least squares estimates of the conditional mean country elasticities confound effects in the tightly clustered body of the price distribution with those in the more disperse tail. To additionally condition on location within the distribution, I separate positive and negatively skewed classification groups, then estimate quantile regressions at the 15th and 85th quantiles of each set.²² Each regression pools across products within a sector, so each sector has four estimates for each active country: the 15th quantile of the positive skew products (i.e. the ‘body’ of the distribution), the 85th quantile of the positive skew products (i.e. the ‘tail’ of the distribution), the 15th quantile (tail) of the negative skew products and the 85th quantile (body) of the negative skew products. Herein I will refer to the positive skew as quality, and the negative skew as cost, products. Again, using ILO Yearbook data to construct country-product-year wage measures, I regress monthly transaction prices on wage and fixed effects within each of seven sectors. The country coefficients can be interpreted as relative to Canada, the omitted country dummy.

Table 3 displays the wage coefficients of (17) by sector. Recall from (13) that the simple model predicts a wage elasticity of one. While not always precisely estimated, all but one of the significant coefficients (denoted by an asterisk) are positive, some with coefficients quite close to one.

	Skewness>0 Products			Skewness<0 Products		
	15th	85th	N	15th	85th	N
Animal & Animal Products	-0.06	-0.09	3,404	0.03	0.05	5,174
Vegetable Products	0.34 *	0.64 *	2,747	0.33 *	0.62 *	1,801
Plastics / Rubber	-0.04	2.63 *	5,176	-0.39	0.65	703
Textiles	0.06	0.48 *	2,633	-0.59 *	-0.02	3,132
Metals	0.22 *	0.36 *	2,816	1.91 *	0.05	2,200
Mechanical & Computers	0.40 *	0.58 *	7,992	0.16	1.06 *	8,550
Transportation	0.70 *	0.09	22,531	2.47 *	2.30 *	6,504

Table 3: Wage coefficients for quantile regressions

Each sectoral regression also produces four lists of country coefficients that can be in-

²²The quantile regression does not function well for large numbers of righthand side variables nor for sparsely populated cells. To cope with this limitation, I divide the sample into the 16 sectors listed in Table 1 (for notational convenience, I suppress sector subscript in (17)). Then, each regression uses only the 5 largest classification groups (by observations) by sector-skewness and only includes countries with at least 75 observations over the course of the sample. Running the quantile regression command in Stata on the resulting restricted samples, convergence of the algorithm is achieved in 7 sectors (listed below).

terpreted as an index of country-sector productivity. Comparing these prices for the same country across products of different skewness reveals an interesting pattern. As an illustration, Table 4 presents the results for the textiles sector.²³ To begin, consider the tails of the price distribution: the 85th quantile of the quality products and the 15th quantile of the cost products. What we observe is that the relatively high prices in the quality sectors correspond with relatively lower prices in the cost sectors; Pakistan and Bangladesh are farther out in the tails while Korea, Macao and Hong Kong reside closer to the dense cluster of prices in the body. This suggests that firms in Pakistan and Bangladesh are more productive in textiles exports, while those in East Asian countries are less so. In contrast, there is not a clearly discernible pattern, or perhaps even the opposite pattern, in the body of the distribution (i.e., 15th quantile of quality and 85th quantile of cost) where a producer like Korea tends to have relatively low prices and a producer like Turkey tends to have relatively high prices in both types of product.

	Skewness>0 Products		Skewness<0 Products	
	15th	85th	15th	85th
Pakistan	-1.68	1.15	-0.82	1.39
Bangladesh	-1.53	1.11	-0.32	1.39
Egypt	-1.13	0.47	1.13	1.33
Costa Rica	-1.56	0.34	0.57	0.08
China	-1.12	0.26	-0.20	1.43
India	-1.18	-0.22	-1.52	-0.47
Malaysia	-1.27	-0.77	0.84	0.05
Turkey	-0.91	-0.78	1.96	1.62
Thailand	-1.56	-0.79	0.33	1.47
Philippines	-1.27	-0.88	0.17	0.04
Colombia	-1.37	-0.90	0.35	0.20
Italy	-0.48	-1.15	1.28	0.38
Korea	-1.76	-1.68	0.98	-0.06
Macao	-1.38	-1.76	1.33	-0.06
Hong Kong	-1.44	-1.83	1.40	0.04

Table 4: Country coefficients for the textiles sector

Figure 4 illustrates the ‘tail’ prices across all sectors where each point is a pair of estimates for a particular country-sector combination (i.e., like corresponding estimates in columns 2 and 3 of Table 4, for instance). The pattern in textiles is preserved more generally, with the

²³Note that since the products of different skewness are served by a different mix of countries, the coefficients shown are those for which a country produces both positive and negative skew products. Not shown are those countries in positive skew industries only or negative skew industries only.

majority of estimates falling in the top-left or bottom-right quadrants of the grid, tracing out a downward linear trend. As in textiles, we can pick out some examples: on one end of the spectrum, UK plastics exports have relatively high prices in quality products and relatively low prices in cost products. The quality choice theory would suggest that this reflects UK firms' position on the tail of the productivity distribution. On the other end of the spectrum, Mexican metals exports are low-priced in quality products and high-priced in cost products, denoting lower average firm productivity. The high incidence of estimates in the top-left and bottom-right quadrants indicates that such sign-switching in relative prices occurs frequently, and the general pattern across countries and sectors is a negative relationship, with a one percent higher relative price in quality industries corresponding to a 0.28 percent lower relative price in cost industries. Figure 5 shows the analogous illustration for the body of the price distribution. In contrast to the tail estimates, the resulting price mapping across cost and quality industries actually has a positive upward trend, with a one percent higher relative price in quality industries corresponding to a 0.45 percent higher relative price in cost industries. The incidence of relative prices of like sign is much higher than in the tail of the distribution, as illustrated by the greater number of estimates in the top-right and bottom-left quadrants.

Assuming firms in a country-sector have similar productivity, the pattern in Figure 4 is consistent with the price-setting behavior outlined in the model of quality choice; productivity maps into price inversely for quality and cost industries. How can we then explain the pattern in Figure 5? One possibility is that it is simply harder to discern (or precisely measure) a negative relationship between relative prices across products with different skewness in the body of the price distribution (versus the tail). Alternatively, firm sorting in prices might not be as strong for firms that are not productivity outliers. We also cannot neglect the possibility that firms in a country-sector do not have similar productivity. For example, if Japan has high productivity in the production of automotive engines (positive skewness) and low productivity in the production of office machine parts (negative skewness), then we would observe a positive relationship among Japanese export prices in the machinery sector. However, if that were the case, we would also expect that pattern to be generated by the same sector-countries in the tail of the price distribution, which we do not observe.

In any event, what these relative price patterns suggest is that the nature of firm specialization is particular to where a firm resides in the exporter productivity distribution. The

firms in the tail of the distribution specialize in high quality products in quality industries and low price products in cost industries. There may be additional impetus for firms in the body of the distribution to specialize in *either* high quality or low quality products in *both* quality and cost industries.

We can check the robustness of this result by conditioning on additional features of the price observations. The IPP collects an array of characteristics for each price in its sample, including whether it is a market or transfer price, what its unit of measure is and when it was discontinued.²⁴ I add additional dummy variables to (17) for market-based transfer price, cost-based transfer price, the various units of measure and irregular discontinuation. The last variable denotes an item that was discontinued due to reasons other than regular sample rotation, the price of which may reflect the strong idiosyncrasies of an item at the end of its life cycle.

	Skewness>0 Products			Skewness<0 Products		
	15th	85th	N	15th	85th	N
<u>Wage</u>						
Animal & Animal Products	-0.70 *	-0.66	3,154	0.11	0.09 *	5,591
Vegetable Products	0.56 *	0.31 *	2,384	0.29 *	0.25 *	1,529
Mechanical & Computers	-0.51	-0.93	7,427	1.45 *	1.84 *	8,221
Transportation	0.01	0.07	22,483	1.41 *	0.93 *	5,997
<u>Market Transfer</u>						
Animal & Animal Products				0.21 *	0.11	
Vegetable Products	0.07	0.05		0.73 *	1.04 *	
Mechanical & Computers	0.16	-1.43 *		-1.42 *	0.12	
Transportation	-0.13	-0.17 *		-2.61 *	-1.94 *	
<u>Cost Transfer</u>						
Animal & Animal Products						
Vegetable Products	0.12	-0.11		1.32 *	0.72 *	
Mechanical & Computers	1.30	-1.35 *		-0.18	1.30 *	
Transportation	0.54 *	-0.01		1.04 *	1.73 *	
<u>Irregular Discontinuation</u>						
Animal & Animal Products	-0.09 *	-0.04 *		0.08 *	0.03 *	
Vegetable Products	-0.35 *	-0.16 *		-0.07 *	-0.02	
Mechanical & Computers	-0.39 *	0.02		-0.26 *	0.28 *	
Transportation	0.05	0.01		0.01	-0.36 *	

Table 5: Estimates of additional controls in the quantile regression

The control estimates are shown in Table 5 for sectors with enough observations. As above, the coefficient on wage is generally positive. The estimates for transfer prices do not

²⁴There is also an identifier for whether the item price was imputed for the purpose of index construction. Omitting the imputations does not affect the price distribution statistics very much.

show a clear pattern, though it is interesting to note that ‘market-based’ transfer prices are often significantly different from prices at arms-length. For the most part, and particularly for quality industries, items discontinued irregularly had lower prices than those which were not discontinued over the course of the sample. Based on the ordering of firms by quality level, this implies that it is the low quality varieties that tend to exit the export market. For cost industries, the relationship is somewhat ambiguous with the exiting varieties having either lower or higher prices.

The resulting country estimates for the distribution tail and body are shown in Figure 6 and Figure 7, respectively. Similar to Figure 4, Figure 6 illustrates a negative relationship between the tail relative prices in cost and quality industries, with a one percent higher price in quality industries corresponding to a 0.47 percent lower price in cost industries. In Figure 7, on the other hand, the positive relationship between the body relative prices in Figure 5 disappears.

In this section, I have documented that exporters in the high tail of the price distribution in quality industries also tend to inhabit the low tail of the price distribution in cost industries. This observation is broadly consistent with sectoral comparative advantage translating into price distinctly, depending on the scope for quality differentiation of the export. As such, it is not only supportive of the theory of quality sorting, but reveals the heterogeneous pattern of specialization in quality and cost industries.

3.1 Price Dynamics and the Price Distribution

Time is another dimension in which quality choice and firm sorting affect prices, and the quantile regressions provide suggestive insights into that relationship as well. The time fixed effects in (17), in addition to acting as controls for the country coefficient estimation, are themselves a time-series index of average sectoral prices at both the 15th and 85th quantiles. In other words, after controlling for level differences in industry wage and country-sector productivity, the time dummies trace out annual intra-product price changes. What is interesting about this index is that it allows for a direct comparison, within an identical group of products, of price dynamics in the body and tail of the price distribution.

Panel (a) of Figure 8 plots the two indexes for the 15th and 85th quantile of the negative

skew products (with 95 percent confidence bands) in one of the larger sectors: HS84, primarily mechanical devices and computers. In the figure, there is clearly a significant, sustained decrease in both the body and tail prices. What is surprising is the extent to which the tail prices decreased by a larger amount: the low outliers fell farther relative to the body of the distribution. Panel (b) is the same graph illustrating the positive skew products of HS84. For products with high outliers, it is now the high (tail) prices that exhibit upward, though less pronounced, movements versus average price declines in the body of the distribution: the high price outliers moved higher. The same pattern can be observed for transportation goods in panels (c) and (d), as well as textiles in panels (g) and (h) of Figure 9, with the high outliers increasing and the low outliers decreasing in relative terms. For vegetables in (e) and (f), the tail prices move in the opposite directions. The striking feature of these graphs is the inverse relationship between the tail price changes in every case.

What type of adjustment could conceivably generate inverse relative price changes in the tails of the price distribution? The sustained trend over the 10 year sample make the cause unlikely to be related to the business cycle or other high frequency, cyclical vacillations. Broad programs of trade liberalization would seem only to explain unidirectional movements in prices, though large policy changes may be generating some of the heterogeneous price responses observed in Figures 8 and 9. For instance, the trade liberalization of certain technologies under the U.S. Information Technology Act (adopted in the late 1990s) may have affected body and tail prices unevenly and offers some clues as to why certain protected ‘cost’ industries saw large relative price falls as they opened up. Or, perhaps anticipation of the Multifibre Arrangement’s expiry at the end of 2004 caused the prices of the cheapest textiles products to fall disproportionately toward the end of the sample. Large changes in exchange rate valuations might be able to generate shifts in import prices that affect the body and tail prices distinctly. For example, the devaluation of the Mexican peso in December 1994 may have contributed to the precipitous, disproportionate fall in the dollar export prices of ‘cost’ industries in machinery and computers. The following section will look more carefully at how the exchange rate affects the composition of goods.

A possibility that is consistent with the model of endogenous quality choice is that of continuous technological improvement and process innovation. In the model, the tail prices correspond to the highest productivity firms. If the frontier level of productivity is expanding, then the prices of quality products in the tail of the distribution will rise and those

for cost products will fall. Indeed, that is what is observed for mechanical and computers, transportation and textiles in Figures 8 and 9. While it is a less intuitive a story for vegetables, for which the implication is that productive capabilities shrank, that is also the sector for which the distinction between tail and body is most slight.

Regardless of their underlying cause, we can interpret the relative intra-product movement of outlier prices as systematic differences across varieties of heterogeneous quality. This poses significant challenges to the proper measurement of import prices. First, since statistical agencies choose and weight their sample based on sales shares alone, they neglect the distinction between high revenue exporters in cost and quality industries, whose prices tend to move inversely. Second, *within* cost or quality industries, resampling a higher proportion of outlier varieties will introduce a systematic bias in the aggregate index level.

These arguments underscore the need to better understand the differences in price dynamics due to quality. In the following section I examine a particular change in the macroeconomy and evaluate the comparative statics of the quality choice model using the IPP data.

4 Real Exchange Rate Pass-Through

A well-documented empirical phenomenon for which there is a natural impetus for the study of product composition is the imperfect pass-through of exchange rate changes to traded goods prices. Estimated average pass-through of nominal exchange rates to U.S. import prices was approximately 0.5 in the 1980's, declining to approximately 0.2 in the 1990's (see Goldberg and Knetter (1997), Olivei (2002), Marazzi et al. (2005), Gust et al. (2006), and Bergin and Feenstra (2007)). One explanation for the measured decline in average pass-through, posited by Campa and Goldberg (2005), attributes much of the decline to the changing composition of import bundles, from sectors with relatively high pass-through such as energy to sectors with relatively low pass-through such as manufactures. Following this line of reasoning a step further, sectoral pass-through itself is just the average elasticity across products with disparate scope for differentiation, reflecting the underlying microfoundations of the firms choice of product characteristics.

The model of quality choice has two sets of predictions for systematic differences in import

price changes arising from quality differentiation. The first set is within products, providing evidence that firms sort into export markets according to their quality level. The second set compares pass-through across products. The within-product analysis is indirectly related to the predictions in Auer and Chaney (2007), where firms more likely to export have higher pass-through than firms serving primarily the domestic market, and long-run firm entry and exit can augment or mitigate changes in prices. However, whereas Auer and Chaney (2007) have a particular industry in mind (autos) where they know a priori that low quality products are more likely to be exported, I consider a wide array of cost and quality industries where low and high quality products are more likely to be exports, respectively.

In the model, firms endogenously sort into foreign export markets if they are above some threshold productivity (and hence profit) level.²⁵ It is the firms on the extensive margin of firm entry, at the low end of the productivity distribution of active firms, whose survival in the market is predicated upon any change that affects the location of the threshold firm. For the measurement of average prices in the wake of such a change, key considerations are: who are the marginal firms, and do they have relatively high or low prices? In a cost industry, the marginal, least productive, firms have the highest price and so firm entry will put upward pressure on the average price of remaining firms. In a quality industry, the marginal, least productive, firms have the lowest price, and so entry will put downward pressure on the average price. I test these predictions across a wide array of disaggregate products. I do so by comparing two types of import price index: one that controls completely for import composition, a ‘constant-quality’ index, and a second that allows for changes in the extensive margin, a ‘quality-inclusive’ index.

Exchange rate pass-through is incomplete in this simple framework due to firm entry and exit. With CES preferences, changes in costs pass through on a 1-for-1 basis into prices at the firm level; thus pass-through is complete for each individual variety. To be concrete, an adverse, exogenous change in firm marginal cost is reflected fully as an increase in price. Accounting for the changing mass of firms, however, average prices reflect the changing composition of the import bundle. For example, a real appreciation in the foreign country causes the least productive firms in each industry to drop out of the market, such that in

²⁵In the description above, the model is not closed to solve for the endogenously determined productivity cut-off, though the exact location of the marginal firm will not matter for the results obtained in this section. It is only important to know that there is some well-defined, unique equilibrium in which the firm on the margin of entry into the international market earns zero profits.

a quality industry the lowest price firms exit and the average price of the remaining firms increases. These extensive margin effects are above and beyond any other price change the firm will undertake in response to the shock. In a cost industry, the least productive, highest price firms exit the market and the average price of the remaining firms decreases. These compositional effects will be manifested in a quality-inclusive price index, which I construct from unit values.

In contrast, aggregating transaction-level IPP prices for exactly the same items from period to period allows for the construction of an index that is bereft of quality changes by definition, a constant-quality index. Since the extensive margin is shut down and aggregation weights are fixed in each period in the constant-quality index, the changes in average prices due to composition, as are observed in unit values, are absent. Thus, the sharpest predictions of the model due to quality sorting are that: (i) in quality industries, firms will pass through exchange rate shocks to quality-inclusive prices by more than to constant-quality prices, and (ii) in cost industries, firms will pass through exchange rate shocks to quality-inclusive prices by less than to constant-quality prices.

To explore these predictions for the U.S., I run pass-through regressions for both constant-quality prices and quality-inclusive prices of the form:

$$\ln P_{jt} = \alpha_0 + \sum_{t=0}^{-2} \alpha_1 \ln RER_{jt} + \alpha_3 X_{jt} + \varepsilon_{jt} \quad (18)$$

where $\ln P_{jt}$ is the annual import price index level for each classification group, j , in year t . For the measure of quality-inclusive price, I construct Tornqvist indices of annual unit value price changes using HS10-country export quantity ($x_{jkt} = \sum_i x_{ijkt}$), sales ($r_{jkt} = \sum_i p_{ijkt} x_{ijkt}$) and trade weights ($w_{jkt} = r_{jkt}$) data provided by Feenstra et al. (2002):²⁶

$$\ln P_{j,t-1,t}^{UV} = \sum_k w_{jkt} \ln \left(\frac{\frac{r_{jkt}}{x_{jkt}}}{\frac{r_{jk,t-1}}{x_{jk,t-1}}} \right) \quad (19)$$

For the measure of constant-quality price, I aggregate the Tornqvist indices directly from the individual variety prices (p_{ijkt}) in the IPP sample, using annual country weights to

²⁶In cases where the classification group is more aggregate than HS10, country-HS10 unit value changes are calculated and then aggregated to the classification level (i.e., as opposed to first summing across values and potentially non-comparable quantities in order to calculate classification level unit values).

approximate item sales weights ($w_{jkt} \approx w_{ijkt}$):

$$\ln P_{j,t-1,t}^{IPP} = \sum_k \sum_i w_{jkt} \ln \left(\frac{p_{ijkt}}{p_{ijk,t-1}} \right) \quad (20)$$

Cumulating (19) and (20) yields the cumulative import index levels for quality-inclusive ($\ln P_{jt}^{UV}$) and constant-quality ($\ln P_{jt}^{IPP}$) import prices, respectively, by classification group.²⁷ Additionally, I compute an annual index of the real exchange rate by classification group using IFS country data for real exchange rates, and aggregate using the Tornqvist formula and import sales weights, as above. Included in (18) are current and two lags of the exchange rate index. Finally, I include a vector of controls (X_{jkt}) containing an annual index of competing export prices (published by the BLS at the HS4 level), an index of tariffs, a measure of the Chinese import share in each classification group and a full set of classification group fixed effects. Since the import price indexes are both ‘at-the-dock’ (i.e., net of tariff), we expect either a zero or negative coefficient on the tariff control.²⁸ Bergin and Feenstra (2007) demonstrate that increasing export competition by countries with fixed exchange rates may be lessening exchange rate pass-through in flexible exchange rate exporter prices, so I include the share of Chinese and Hong Kong exports in each classification group as a proxy for fixed exchange rate export competition.

Table 6 shows the results for the fixed effects OLS regression of (18), run annually (1994–2004) over all classification groups for which data are available.²⁹ Additionally, I split the data by cost and quality groups based on the estimates in the method of moments exercise above.³⁰ The results are supportive of: (i) the existence of quality sorting in the data, and (ii) the notion that quality differentiated products have higher pass-through. For sorting,

²⁷Since the IPP data frequency is monthly, once the monthly cumulative index is constructed at the classification level, annual averages are taken to make this series comparable to the lower frequency unit value index.

²⁸Theoretically the coefficient should be zero for small importers and negative for large importers, so it will depend on the size of the US in each particular product market.

²⁹Since the IPP data is a sample and the data does not span the entire set of HS10 product-country groups, unit values were only computed for the sampled product-country groups in the constant-quality price indexes. This ensures that the comparison of HS10 indexes is not itself contaminated by different underlying HS10-country product composition.

³⁰This distinction is based solely on the sign of the estimated scope for quality differentiation. Cost industries are those with $\frac{b}{a-b} < 0$ while quality industries are those with $\frac{b}{a-b} > 0$. Using only the subset of scope estimates that are significantly different than zero does not affect the results.

the theory suggests that in cost industries quality-inclusive prices pass through currency appreciation by less than constant-quality prices. The results are consistent with this prediction, as pass-through of the real exchange rate is positive and significant at approximately 7 percent³¹ in columns (I) and (II), and indistinguishable from zero in quality-inclusive prices in columns (III) and (IV). Though suggestive, large standard errors make it impossible to distinguish between the two coefficients.

Dep. Variable: Import Price Index	Cost Industries				All Industries				Quality Industries			
	Constant-Quality (Transaction-Level)		Quality-Inclusive (Unit Value)		Constant-Quality (Transaction-Level)		Quality-Inclusive (Unit Value)		Constant-Quality (Transaction-Level)		Quality-Inclusive (Unit Value)	
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)	(XI)	(XII)
Real Exch. Rate (w/ 2 lags)	0.071 ** (0.01)	0.065 ** (0.01)	0.091 (0.06)	0.109 (0.06)	0.084 ** (0.01)	0.082 ** (0.01)	0.211 ** (0.04)	0.209 ** (0.05)	0.099 ** (0.01)	0.103 ** (0.01)	0.270 ** (0.08)	0.266 ** (0.08)
Export Price	0.167 ** (0.02)	0.147 ** (0.02)	0.208 * (0.10)	0.201 (0.11)	0.168 ** (0.01)	0.163 ** (0.01)	0.275 ** (0.08)	0.269 ** (0.08)	0.157 ** (0.02)	0.165 ** (0.02)	0.302 * (0.12)	0.295 * (0.12)
Tariff		0.044 ** (0.01)		-0.102 (0.07)		-0.005 (0.01)		0.034 (0.06)		-0.054 ** (0.01)		0.063 (0.10)
China Share		-0.002 ** (0.00)		0.011 * (0.01)		-0.001 (0.01)		0.002 (0.00)		0.000 (0.00)		-0.003 (0.01)
Observations	4,530	4,500	4,530	4,500	13,012	12,892	13,012	12,892	7,035	6,989	7,035	6,989
R-squared	0.76	0.76	0.82	0.82	0.75	0.75	0.75	0.75	0.75	0.75	0.72	0.72

Notes: Shown are estimates for (18) using ordinary least squares and classification group fixed effects. Standard errors are reported in parentheses, and stars denote the 5 and 1 percent significance levels.

Table 6: Exchange rate pass-through by classification group and product type (annual; 1994-2004)

The theory also suggests that in quality industries quality-inclusive prices pass through currency appreciation by more than constant-quality prices, reflecting the exit of the low-priced marginal firms. The results in columns (IX)-(XII) strongly support this hypothesis with estimates of pass through more than doubling in quality-inclusive prices relative to constant-quality prices, with estimates statistically distinguishable from one another at the 5 percent level. Finally, analyzing both cost and quality products jointly in columns (V)-(VIII), we see that overall quality-inclusive prices have higher pass-through than the corresponding constant-quality indexes (also significantly different from one another). This suggests that U.S. import prices behave, on average, like a quality industry.

The second interesting pattern in Table 6 is that, within import price measures, quality industries have higher pass-through coefficients than cost industries. This is suggested by

³¹The seemingly low pass-through estimates likely reflect the low annual frequency of the data relative to other studies. However, the results are not vastly different from pass-through estimates in the 1990's of 20 percent, as reported above.

the monotone increase in estimates from left to right in the sets of columns: {(I),(V),(IX)}, {(II),(VI),(X)}, etc. In quality-inclusive prices, the degree of pass-through in quality industries is significantly greater than that in cost industries.

One might expect a more pronounced impact of quality differentiation on price dynamics in sectors with longer quality ladders and a great diversity of products, such as mechanical devices and machinery: HS84 and HS85. These sectors compose approximately one third of the classification groups for which quality scope estimates exist and (due to their sheer size of import value) tend to have more products sampled by the IPP per classification group than others, augmenting confidence in the measures of sample skewness and quality scope. Indeed, the left panel in Table 7 presents stronger support of quality sorting than Table 6: in cost industries, constant-quality prices are 11 percent while quality inclusive prices are approximately zero and in quality industries constant quality prices are 6 percent compared to 43 percent in quality-inclusive industries.

Dep. Variable:	HS 84 & 85 only						First Differences					
	Cost Industries		All Industries		Quality Industries		Cost Industries		All Industries		Quality Industries	
	Constant-Quality	Quality-Inclusive	Constant-Quality	Quality-Inclusive	Constant-Quality	Quality-Inclusive	Constant-Quality	Quality-Inclusive	Constant-Quality	Quality-Inclusive	Constant-Quality	Quality-Inclusive
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)	(XI)	(XII)
Real Exch. Rate (w/ 2 lags)	0.112 ** 0.02	-0.026 0.22	0.078 ** 0.01	0.299 ** 0.15	0.064 ** 0.01	0.426 ** 0.19	0.022 0.02	0.070 0.12	0.070 ** 0.01	0.158 0.09	0.109 ** 0.02	0.206 0.16
Export Price	0.209 ** 0.03	0.716 * 0.32	0.198 ** 0.02	0.130 0.24	0.191 ** 0.02	-0.129 0.31	0.124 ** 0.03	0.096 0.19	0.172 ** 0.02	0.292 * 0.15	0.193 ** 0.03	0.410 0.23
Tariff	0.304 ** 0.06	-2.063 ** 0.71	0.198 ** 0.02	0.788 ** 0.50	0.112 ** 0.04	1.841 ** 0.63	-0.013 0.02	0.085 0.13	-0.054 ** 0.02	0.048 0.12	-0.117 ** 0.03	-0.023 0.21
China Share	-0.003 * 0.00	-0.020 0.02	-0.002 ** 0.00	-0.007 0.01	-0.002 * 0.00	0.000 0.02	0.000 0.00	0.007 0.00	0.000 0.00	0.005 0.00	0.001 0.00	0.006 0.01
Observations	902	902	3,515	3,515	2,613	2,613	3,104	3,104	8,843	8,843	4,774	4,769
R-squared	0.88	0.87	0.86	0.72	0.85	0.66	0.26	0.26	0.24	0.26	0.22	0.26

Notes: Shown are estimates for (18) using ordinary least squares and classification group fixed effects. Standard errors are reported in parentheses, and stars denote the 5 and 1 percent significance levels.

Table 7: Exchange rate pass-through by classification group, HS84/85 and first differences

Finally, to control for possible non-stationarity in the levels of the exchange rate, the pass-through regressions in Table 6 are run in first differences, with the results shown in the right panel of Table 7. Unfortunately, due to the (already) short panel, taking differences comes at the expense of the number of observations and some precision in the estimates. The possibility of calculating unit value indexes at higher frequencies is also troublesome due to the extreme noisiness of monthly, and even quarterly, unit value price measures. While

less convincing than the regression in levels, the results hold directionally for both quality sorting and higher pass-through to quality differentiated products.

Comparing pass-through in ‘matched model’ prices (in which the composition of varieties is held constant) to unit values is not in itself novel. Alterman (1991) argues that compositional effects have a large effect on pass-through estimation due to the unit value’s imperfect measurement of price. Here, these large difference are shown to be systematic in the way that firms sort into export markets.

Does the model predict higher pass-through in quality differentiated products? For constant-quality prices, the simple framework is silent; since pass-through is complete in varieties and constant-quality prices shut down the extensive margin by construction, there is no prediction on the relative pass-through across products. For quality-inclusive prices, the model does in fact make that prediction. Recall that $\frac{b}{a-b}$ is the slope of the productivity-price schedule. The model suggests that higher scope for quality (a steeper positive slope) increases the response of price to changes in the position of the threshold productivity firm.

It is intriguing to find that firms in quality industries are able to pass on adverse marginal cost shocks to their consumers with greater ease. It implies greater resilience for exporting firms with longer quality ladders in facing volatile and unpredictable changes in their country’s real exchange rate. It is consistent with the earlier finding by Yang (1997) that more ‘differentiated’ industries have higher pass-through, albeit potentially for different reasons. Yang (1997) estimates higher pass-through in highly differentiated industries and those with a lower elasticity of marginal cost to output.³² Here, quality differentiation has a more precise definition, which can be seen as an improvement over the advertising intensity and R&D proxy measures used by Yang (1997); it is unclear whether the latter proxy for the horizontal or vertical dimension of differentiation, or both. Moreover, these results are in the same spirit as those in Khandelwal (2008), in which output and employment in long quality ladder industries are less vulnerable to low-wage import competition.

³²The model in Yang (1997) also predicts a negative relationship between market share and pass-through, though no evidence was found to support that prediction. In a quality-differentiated model, market share is high for high quality products in quality industries and high for low quality/low cost products in cost industries. As such, an average relationship between market share and pass-through would be difficult to disentangle.

5 Conclusions

From an empirical viewpoint, it has long been recognized that average prices are imperfect measures of both price and quality. This paper takes a step forward in overcoming the difficulties of quality inference from average prices by disentangling their relationship transaction by transaction. Exploring the distribution of transaction prices within narrow product groups introduces a new dimension to our understanding of firm pricing behavior and adds texture to our observations of average trade patterns.

In particular, the upper moments in prices reveal not only the scope for differentiation across products, but the countries that specialize in quality and the dynamics of pricing due to upgrading. I have found evidence that observations of an average relation between product price and exporter productivity nets out highly disparate prices: high prices in quality differentiated industries and low prices in more homogeneous industries. Moreover, process and product upgrading have exacerbated this disparity over time, which adds importance to attaining a deeper understanding of the productivity-quality nexus.

This work also highlights the distinction between two different stories of quality composition: the short-run effects on prices of changes in existing varieties in the import basket, as well as long-run trends in innovation which simultaneously introduce varieties of higher quality/price and constant quality/lower price. In this paper, the short-run story is illustrated by evidence of firm sorting and the effect of entry and exit on average prices following exchange rate movements: the basket of products changes in a predictable manner, with corresponding changes in prices. There long-run story is evidenced by the inverse trends in the high and low tails of the price distribution. The model of quality choice above is surprisingly powerful in distinguishing these two versions of the quality story.

Finally, it is important to view the results herein in context. Perhaps the future of trade price data promises a global census of transaction quantities and prices and perfect information about product specifications. In such a world, it would be feasible and straightforward to estimate the marginal value of product characteristics and there would be no need to infer quality from composition-contaminated average prices. In the meantime, this paper presents an intermediate rung on the data quality ladder.

Appendix: Theoretical Moments

1. Mean:

Within exporting country k , the average quality-inclusive price of product j at time t is:

$$\begin{aligned}
 \overline{\ln p_{jkt}} &= \int_{i \in \omega_{jkt}} \ln p_{ijkt} f(\varphi) d\varphi \\
 &= \int_i \left[\ln \theta_j^p + \ln w_{jkt} + \left(\frac{b}{a-b} \right) \ln \varphi_{ijkt} \right] f(\varphi | \varphi \in \omega_{jkt}) d\varphi \\
 &= \ln \theta_j^p + \ln w_{jkt} + \left(\frac{b}{a-b} \right) \int_i \ln \varphi_{ijkt} f(\varphi | \varphi \in \omega_{jkt}) d\varphi \\
 &= \ln \theta_j^p + \ln w_{jkt} + \left(\frac{b}{a-b} \right) \overline{\ln \varphi_{jkt}}
 \end{aligned}$$

where ω_{jkt} is the range of active firms and $\overline{\ln \varphi_{jkt}}$ is their average productivity level. For product j in year t , the average quality-inclusive price is a simple average across countries:

$$\begin{aligned}
 \overline{\ln p_{jt}} &= \sum_k \frac{1}{k} \overline{\ln p_{jkt}} \\
 &= \ln \theta_j^p + \sum_k \frac{1}{k} \ln w_{jkt} + \left(\frac{b}{a-b} \right) \sum_k \frac{1}{k} \overline{\ln \varphi_{jkt}} \\
 &= \ln \theta_j^p + \overline{\ln w_{jt}} + \left(\frac{b}{a-b} \right) \overline{\ln \varphi_{jt}}
 \end{aligned}$$

2. Variance:

Within country k , the variance of quality-inclusive prices for product j at time t is:

$$\begin{aligned}
 Var_{jkt}(\ln p_{ijkt}) &= \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jkt}}]^2 f(\varphi) d\varphi \\
 &= \left(\frac{b}{a-b} \right)^2 \int_{i \in \omega_{kt}} [\ln \varphi_{ijkt} - \overline{\ln \varphi_{jkt}}]^2 f(\varphi) d\varphi \\
 &= \left(\frac{b}{a-b} \right)^2 Var_k(\ln \varphi_{ijkt})
 \end{aligned}$$

For product j (all export countries), the variance of quality-inclusive prices additionally

depends on the variance of wages across countries:

$$\begin{aligned}
Var_{jt}(\ln p_{ijkt}) &= \sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jt}}]^2 f(\varphi) d\varphi \right\} \\
&= \sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} \left[(\ln w_{jkt} - \overline{\ln w_{jt}}) + \left(\frac{b}{a-b} \right) (\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}}) \right]^2 f(\varphi) d\varphi \right\} \\
&= \sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} \left[(\ln w_{jkt} - \overline{\ln w_{jt}})^2 + \left(\frac{b}{a-b} \right)^2 (\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}})^2 \right. \right. \\
&\quad \left. \left. + 2 \left(\frac{b}{a-b} \right) (\ln w_{jkt} - \overline{\ln w_{jt}}) (\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}}) \right] f(\varphi) d\varphi \right\} \\
&= \sum_k \frac{1}{k} (\ln w_{jkt} - \overline{\ln w_{jt}})^2 \\
&\quad + \left(\frac{b}{a-b} \right)^2 \sum_k \frac{1}{k} \left[\int_{i \in \omega_{kt}} (\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}})^2 f(\varphi) d\varphi \right] \\
&= Var_{jt}(\ln w_{jkt}) + \left(\frac{b}{a-b} \right)^2 Var_{jt}(\ln \varphi_{ijkt}) \tag{21}
\end{aligned}$$

In the fourth line, the covariance between item productivity and country wage is assumed to be zero.

3. Skewness:

Assuming uniform wage across countries, the skewness of quality-inclusive prices for product j is:

$$\begin{aligned}
Skew_{jt}(\ln p_{ijkt}) &= \frac{\sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jt}}]^3 f(\varphi) d\varphi \right\}}{\sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jt}}]^2 f(\varphi) d\varphi \right\}^{\frac{3}{2}}} \\
&= \left(\frac{\frac{b}{a-b}}{\left| \frac{b}{a-b} \right|} \right)^3 \frac{\sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}}]^3 f(\varphi) d\varphi \right\}}{\sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}}]^2 f(\varphi) d\varphi \right\}^{\frac{3}{2}}} \\
&= \left(\frac{\frac{b}{a-b}}{\left| \frac{b}{a-b} \right|} \right)^3 Skew_{jt}(\ln \varphi_{ijkt})
\end{aligned}$$

This means that the skewness of prices has the same sign as the skewness of firm productivity if $\frac{b}{a-b} > 0$. That is, if prices are increasing in firm productivity and productivity has positive skewness (high outliers), then price skewness will be positive; if prices are decreasing in productivity and productivity has positive skewness, then price skewness will be negative. Interestingly, the skewness of prices always has the same magnitude as the skewness of productivity.

Allowing wages to differ across countries, the skewness of quality-inclusive prices for product j is:

$$\begin{aligned}
Skew_{jt}(\ln p_{ijkt}) &= \frac{\sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jkt}}]^3 f(\varphi) d\varphi \right\}}{[Var_j(\ln p_{ijkt})]^{\frac{3}{2}}} \\
\frac{Skew_{jt}(\ln p_{ijkt})}{[Var_{jt}(\ln p_{ijkt})]^{-\frac{3}{2}}} &= \sum_k \frac{1}{k} \left\{ \int_{i \in \omega_{kt}} [\ln p_{ijkt} - \overline{\ln p_{jkt}}]^3 f(\varphi) d\varphi \right\} \\
&= \sum_k \frac{1}{k} (\ln w_{jkt} - \overline{\ln w_{jt}})^3 + \text{covariance terms} \\
&\quad + \left(\frac{b}{a-b} \right)^3 \sum_k \frac{1}{k} \left[\int_{i \in \omega_{kt}} (\ln \varphi_{ijkt} - \overline{\ln \varphi_{jt}})^3 f(\varphi) d\varphi \right] \quad (22) \\
&= \frac{Skew_{jt}(\ln w_{jkt})}{[Var_{jt}(\ln w_{jkt})]^{-\frac{3}{2}}} + \left(\frac{b}{a-b} \right)^3 \frac{Skew_{jt}(\ln \varphi_{ijkt})}{[Var_{jt}(\ln \varphi_{ijkt})]^{-\frac{3}{2}}} \quad (23)
\end{aligned}$$

Again, assuming that the covariance terms of industry productivity and country wage are zero, (22) reduces to an expression which states that quality-inclusive price skewness (non-standardized) is a function of cross-country wage skewness and average industry productivity skewness.

References

- [1] Alterman, William (1991) "Price Trends in U.S. Trade: New Data, New Insights," in Peter Hooper and J. David Richardson, eds. *International Economic Transactions. Studies in Income and Wealth*, no. 55. Chicago: Univ. of Chicago Press and NBER, 109-139.
- [2] Auer, Raphael and Thomas Chaney (2007): "How do the Prices of Different Goods Respond to Exchange Rate Shocks? A Model of Quality Pricing-to-Market," Manuscript.
- [3] Aw, Bee Yan & Roberts, Mark J. (1986): "Measuring Quality Change in Quota-Constrained Import Markets: The Case of U.S. Footwear," *Journal of International Economics*, Elsevier, vol. 21(1-2), pages 45-60, August.
- [4] Baldwin, Richard and James Harrigan (2007): "Zeros, Quality and Space: Trade Theory and Trade Evidence," NBER Working Papers 13214, National Bureau of Economic Research, Inc.
- [5] Bergin, Paul R. and Robert C. Feenstra (2007): "Pass-through of Exchange Rates and Competition Between Floaters and Fixers," NBER Working Papers 13620, National Bureau of Economic Research.
- [6] Bergin, P., R. Glick and A. Taylor (2004): "Productivity, Tradability and the Long-Run Price Puzzle." NBER Working Paper 10569, National Bureau of Economic Research.
- [7] Bils, Mark (2004): "Measuring the Growth from Better and Better Goods." NBER Working Papers 10606, National Bureau of Economic Research.
- [8] Boskin M.J., E.R. Dulberger, R.J. Gordon, Z. Griliches and D.W. Jorgenson (1997): "The CPI Commission: Findings and Recommendations" *American Economic Review*, Vol. 87, No. 2, Papers and Proceedings of the Hundred and Fourth Annual Meeting of the American Economic Association (May), pp. 78-83.
- [9] Broda, C. & D.E. Weinstein (2006): "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, MIT Press, vol. 121(2), pages 541-585, May.

- [10] Campa, José Manuel and Linda S. Goldberg (2005): "Exchange Rate Pass-Through into Import Prices," *Review of Economics and Statistics*, 87(4): 679-690.
- [11] Choi, Yo Chul, David Hummels and Chong Xiang (2006): "Explaining Import Variety and Quality: The Role of the Income Distribution," NBER Working Papers 12531, National Bureau of Economic Research.
- [12] Feenstra, Robert C. (1996): "U.S. Imports, 1972-1994: Data and Concordances," NBER Working Paper 5515.
- [13] Feenstra, Robert C. (1988): "Quality Change under Trade Restraints in Japanese Autos," *Quarterly Journal of Economics*, 103(1): 131-46.
- [14] Feenstra, Robert C., Romalis, John and Peter K. Schott (2002): "U.S. Imports, Exports and Tariff Data, 1989-2001," NBER Working Paper 9387, National Bureau of Economic Research.
- [15] Ghironi, Fabio & Marc J. Melitz (2005): "International Trade and Macroeconomic Dynamics with Heterogeneous Firms," *Quarterly Journal of Economics*, Vol. 120, No. 6 Pg. 1695 1725.
- [16] Goldberg, Pinelope and Michael Knetter (1997): "Goods Prices and Exchange Rates: What Have We Learned?" *Journal of Economic Literature*, 35, 1243-1272.
- [17] Gopinath, Gita and Roberto Rigobon (forthcoming): "Sticky Borders," *Quarterly Journal of Economics*.
- [18] Gopinath, Gita, Oleg Itskhoki and Roberto Rigobon (2007): "Currency Choice and Exchange Rate Pass-Through," manuscript.
- [19] Gust, Christopher, Sylvain Leduc and Robert J. Vigfusson (2006): "Trade Integration, Competition, and the Decline in Exchange-Rate Pass-Through," Board of Governors of the Federal Reserve System International Finance Discussion Paper #864.
- [20] Hallak, Juan Carlos (2006): "Product Quality and the Direction of Trade," *Journal of International Economics*, 68, 238-265.

- [21] Hallak, Juan Carlos and Peter K. Schott (2008): "Estimating Cross-Country Differences in Product Quality," Working paper.
- [22] Harrigan, James and Geoffrey Barrows (2006): "Testing the Theory of Trade Policy: Evidence from the Abrupt End of the Multifibre Arrangement," NBER Working Papers 12579, National Bureau of Economic Research.
- [23] Hummels, David and Peter J. Klenow (2005): "The Variety and Quality of a Nation's Exports," *American Economic Review*, 95(3): 704-723.
- [24] Johnson, Robert C. (2008): "Trade and Prices with Heterogeneous Firms," mimeo.
- [25] Khandelwal, Amit (2008): "The Long and Short (of) Quality Ladders," mimeo, Columbia University.
- [26] Kremer, Michael R. (1993): "The O-ring Theory of Economic Development." *The Quarterly Journal of Economics*, Vol. 108, No. 3, pg. 551-575, August.
- [27] Kugler, Maurice and Eric A. Verhoogen (2007): "Product Quality at the Plant Level: Plant Size, Exports, Output Prices and Input Prices in Colombia," Discussion Papers 0708-12, Columbia University, Department of Economics.
- [28] Marazzi, Mario, Nathan Sheets, Robert J. Vigfusson, Jon Faust, Joseph E. Gagnon, Jaime Marquez, Robert F. Martin, Trevor A. Reeve and John H. Rogers (2005): "Exchange Rate Pass-through to U.S. Import Prices: Some New Evidence," Board of Governors of the Federal Reserve System International Finance Discussion Paper #833.
- [29] Melitz, Marc J. (2003): "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica*, Vol. 71, No. 6., pp. 1695-1725, November.
- [30] Melitz, Marc J. & G. Ottaviano (2005): "Market Size, Trade, and Productivity," Mimeo, Harvard University.
- [31] Moulton, Brent R. & Moses, Karin E. (1997): "Addressing the Quality Change Issue in the Consumer Price Index" Brookings Papers on Economic Activity 1, 305-349.
- [32] Olivei, G. (2002): "Exchange Rates and the Prices of Manufacturing Products Imported into the United States," *New England Economic Review*, First Quarter, 3-18.

- [33] Schott, Peter K. (2004): "Across-product Versus Within-product Specialization in International Trade," *Quarterly Journal of Economics*, MIT Press, 119(2): 646-677.
- [34] Verhoogen, Eric A. (2007): "Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector," IZA Discussion Papers 2913, Institute for the Study of Labor (IZA).
- [35] Yang, Jiawen (1997): "Exchange Rate Pass-Through in U.S. Manufacturing Industries," *Review of Economics and Statistics*, 79(1): 95-104.

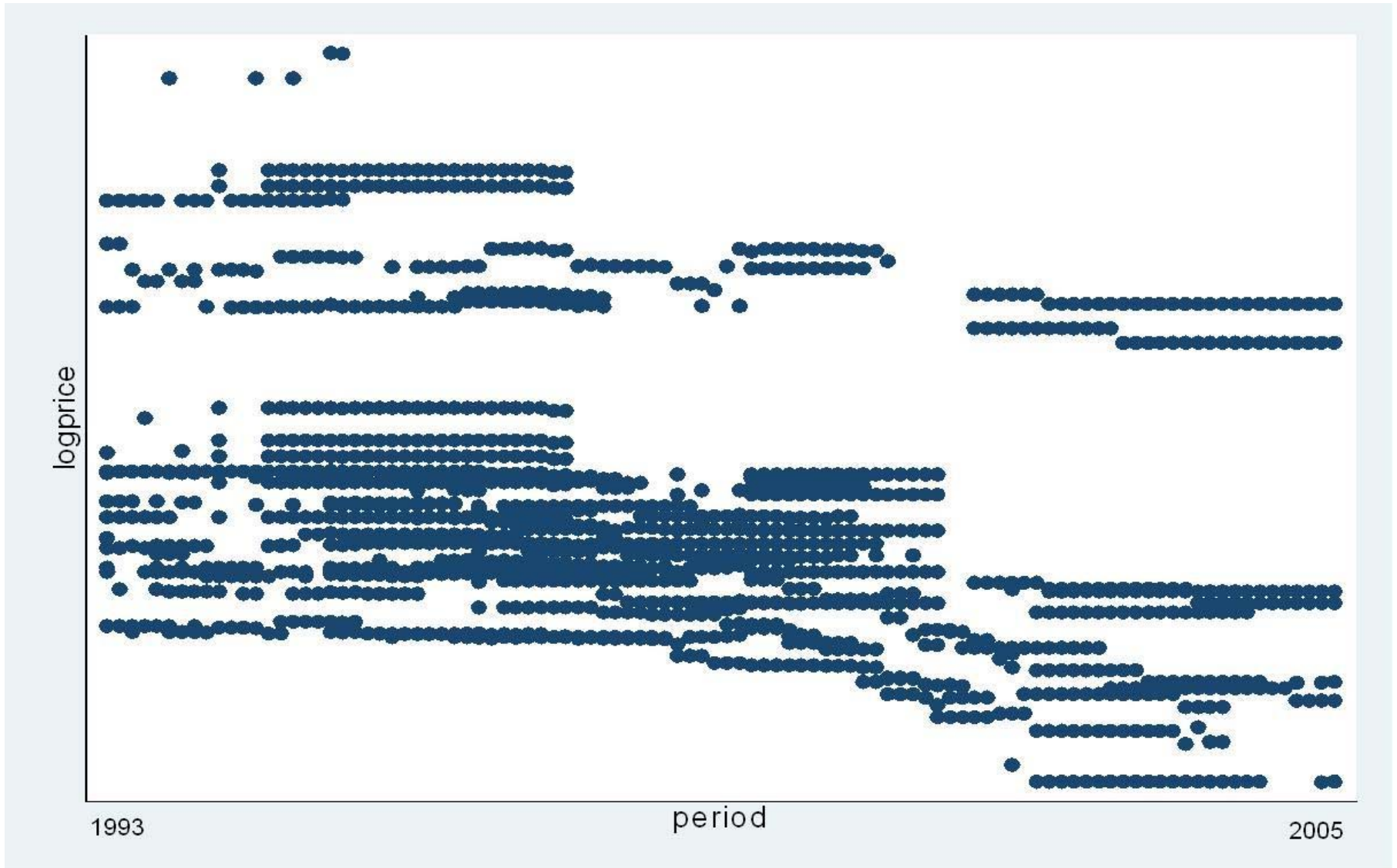


Figure 1: Monthly transaction price levels within a HS10 category

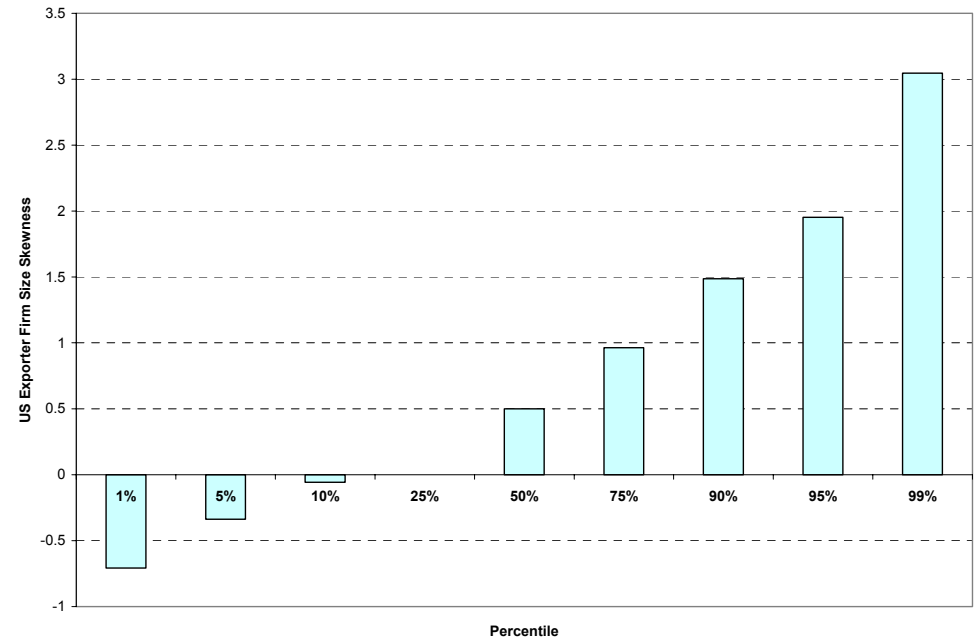
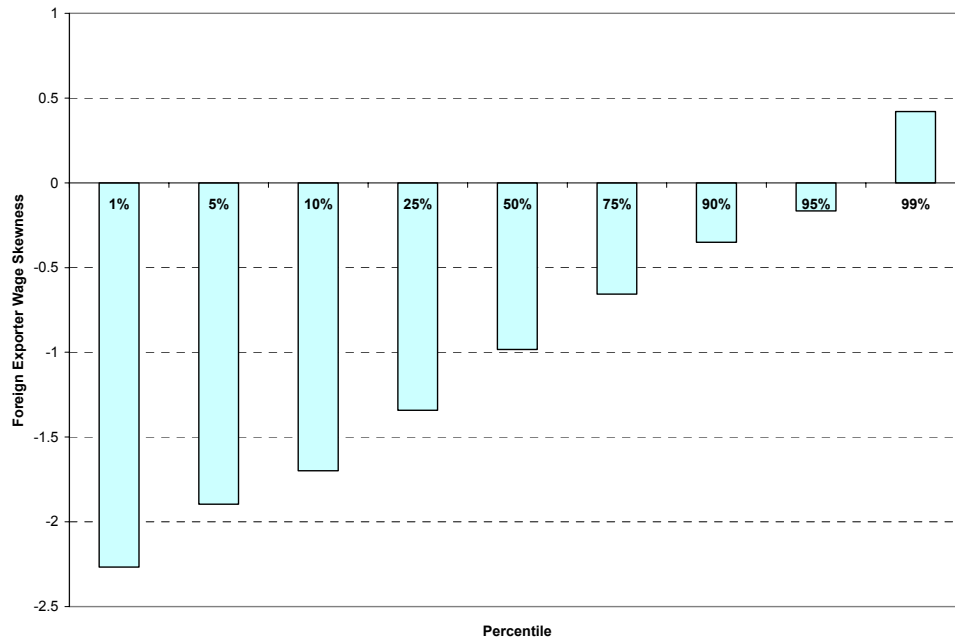
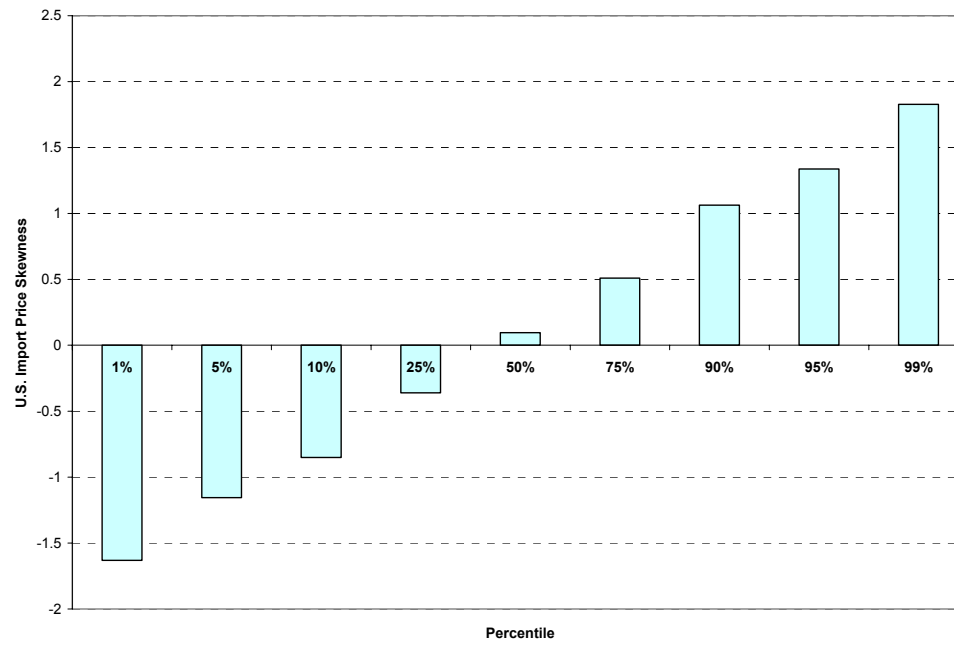
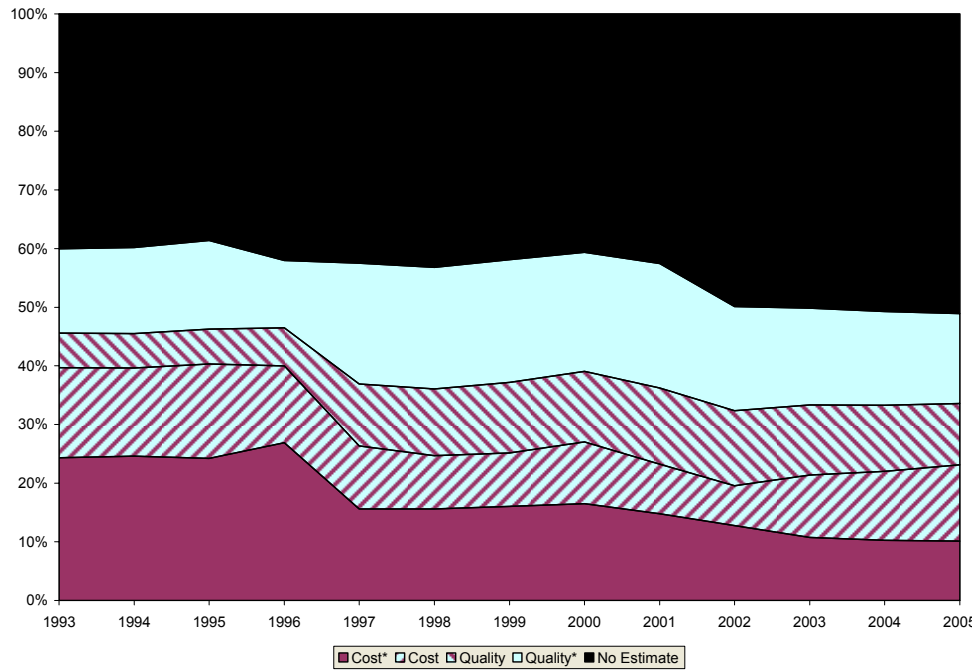
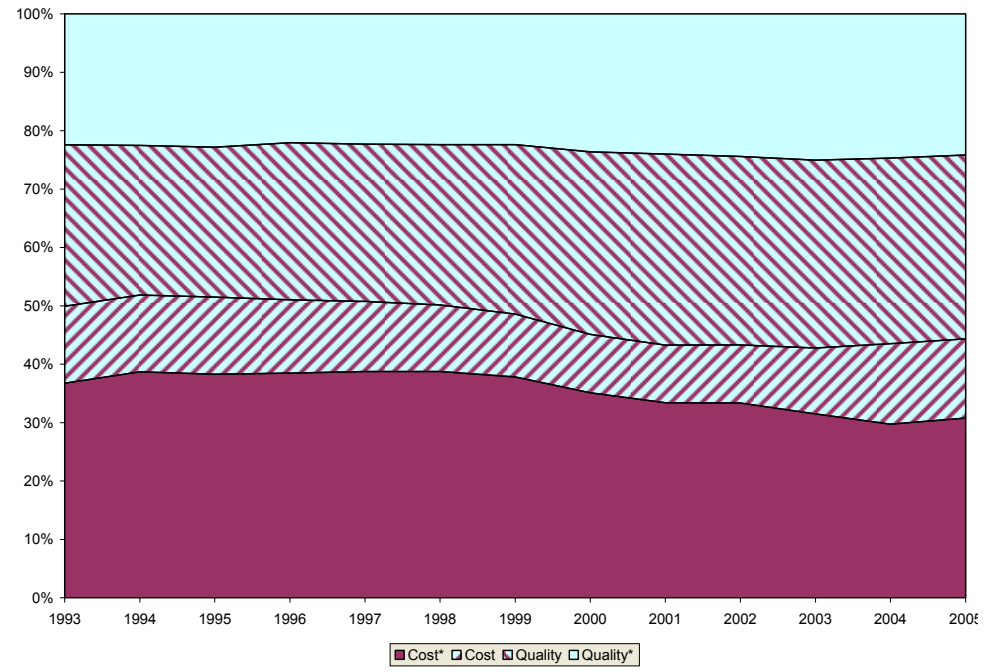


Figure 2: U.S. import price, foreign wage and U.S. export size distributions (HS10 statistics, averaged over products and time)



a. Aggregate imports; unbalanced



b. Subset of imports; balanced

Figure 3: Estimated value share of cost and quality industries over time

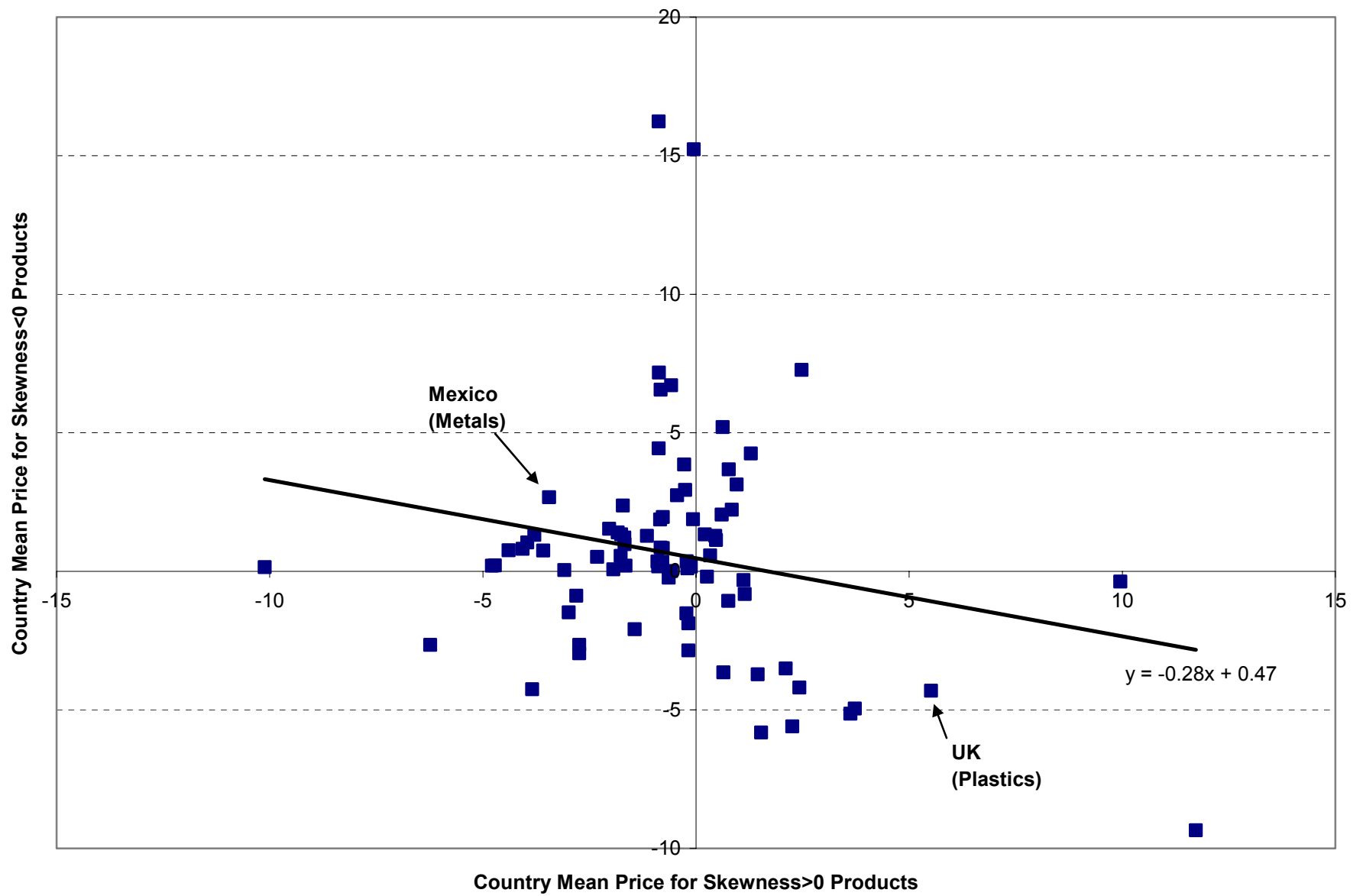


Figure 4: Estimated mean country-sector relative prices in the tail of the price distribution

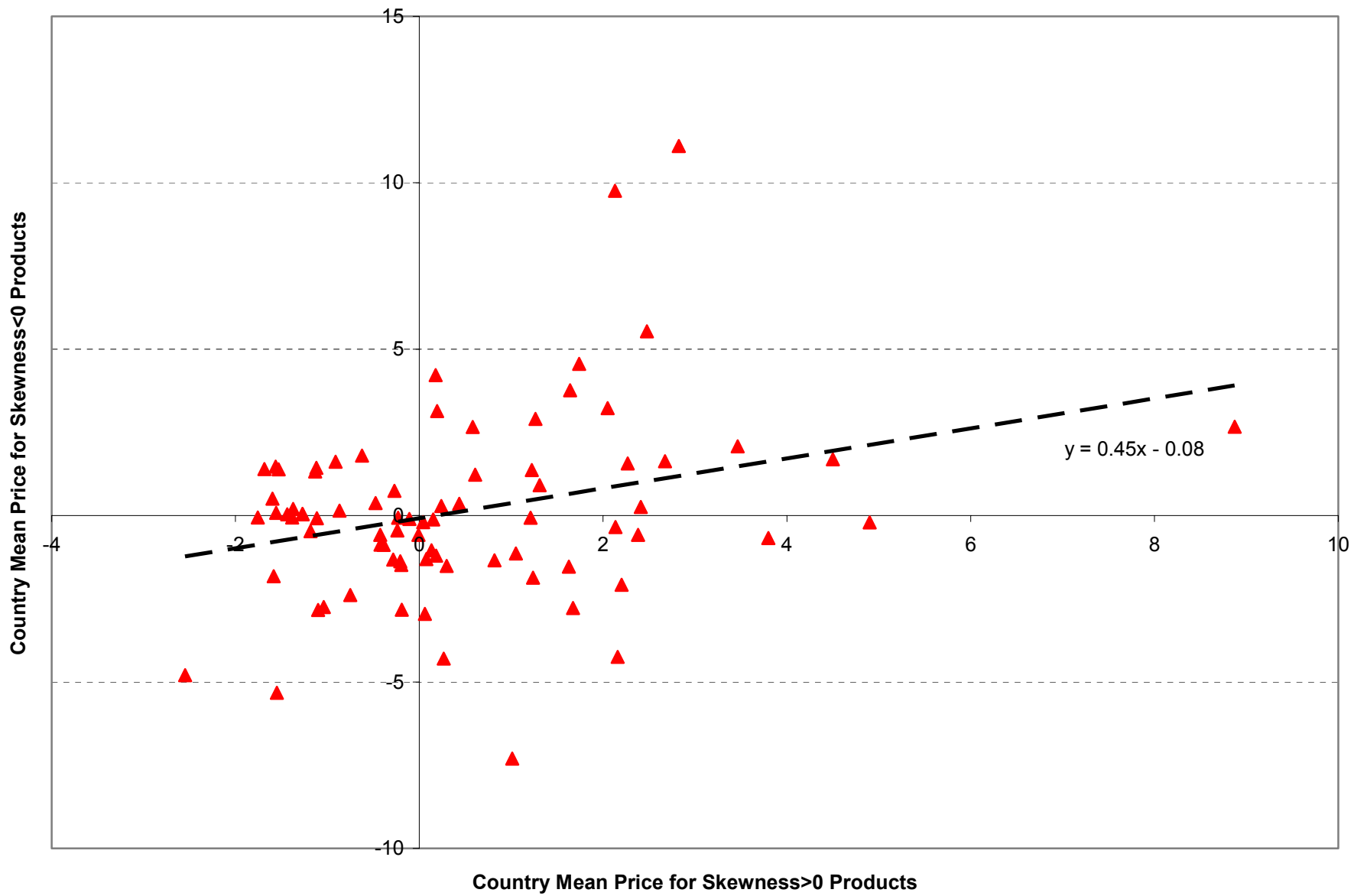


Figure 5: Estimated mean country-sector relative prices in the body of the price distribution

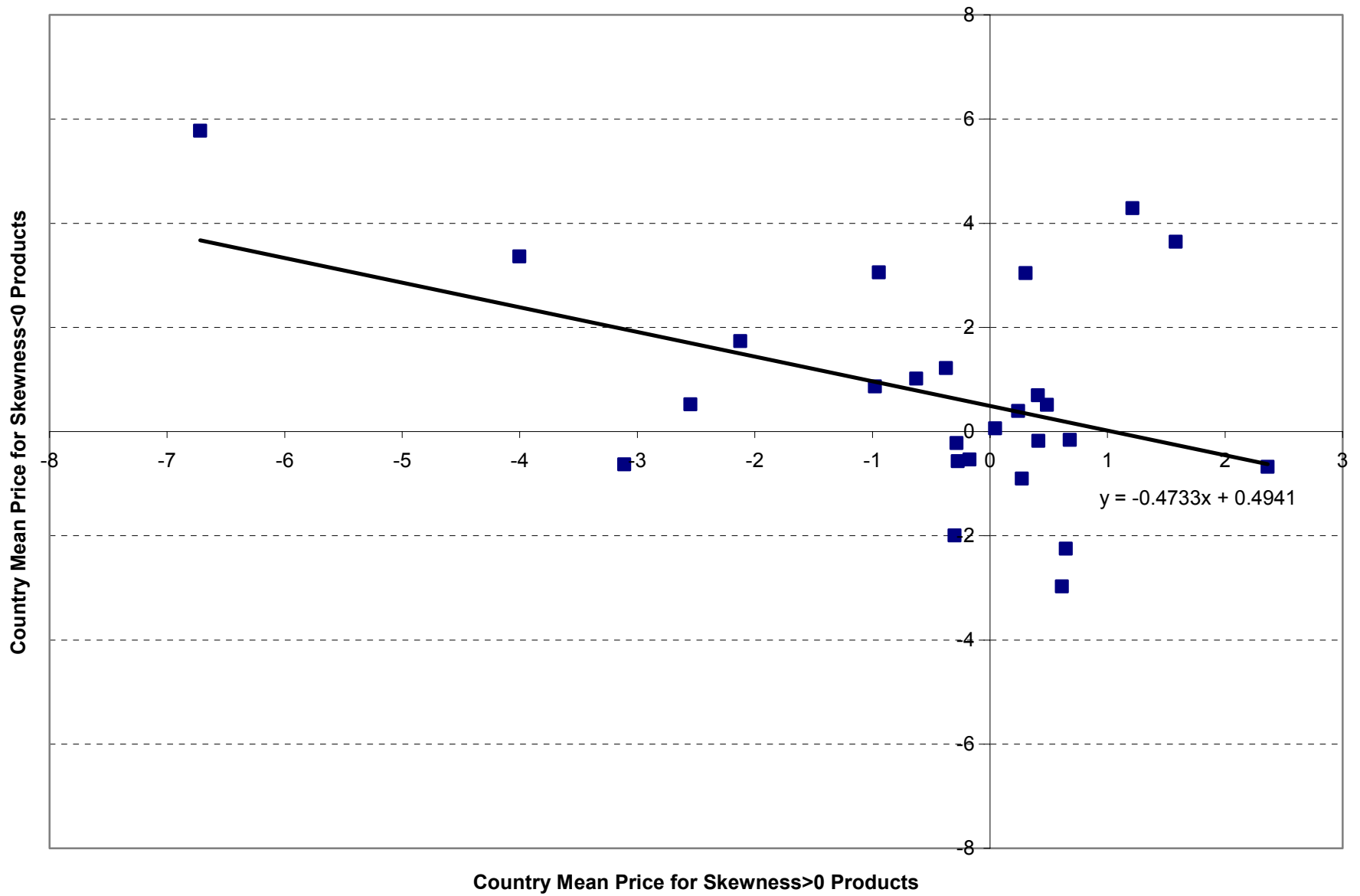


Figure 6: Estimated mean country-sector relative prices in the tail of the price distribution (w/ additional control variables)

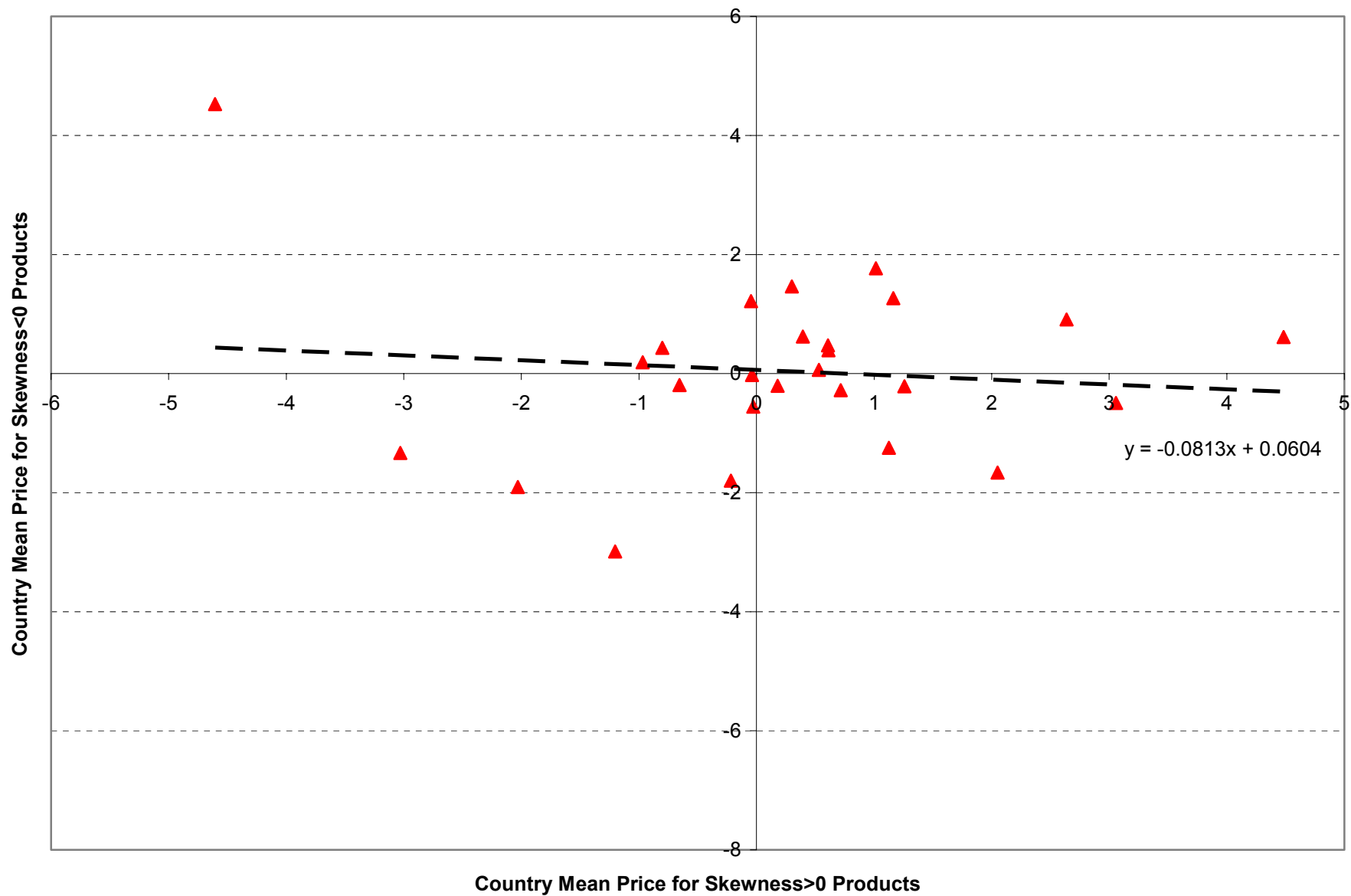
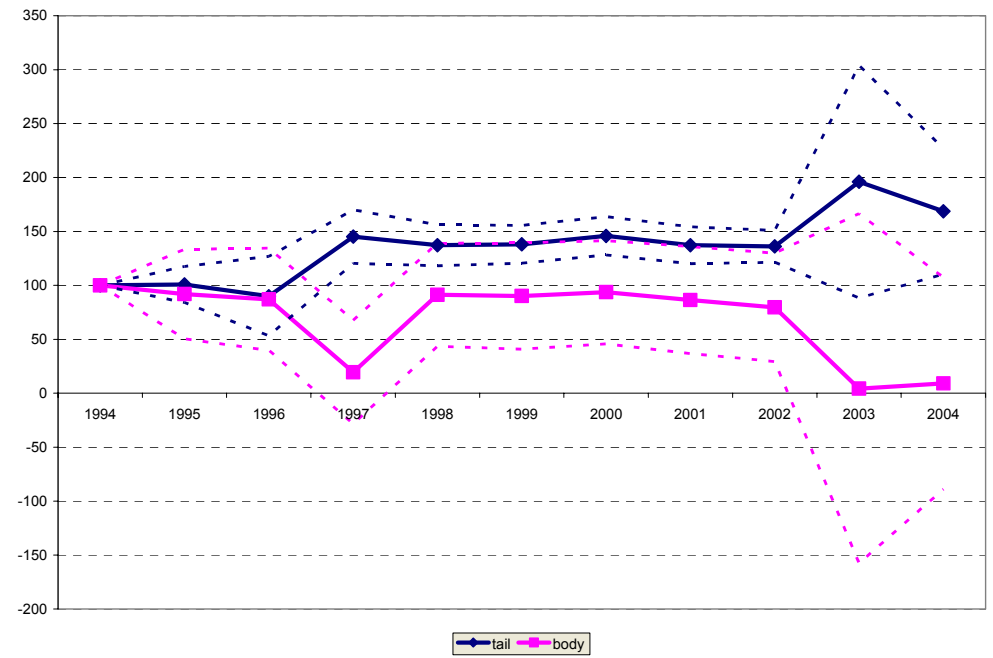


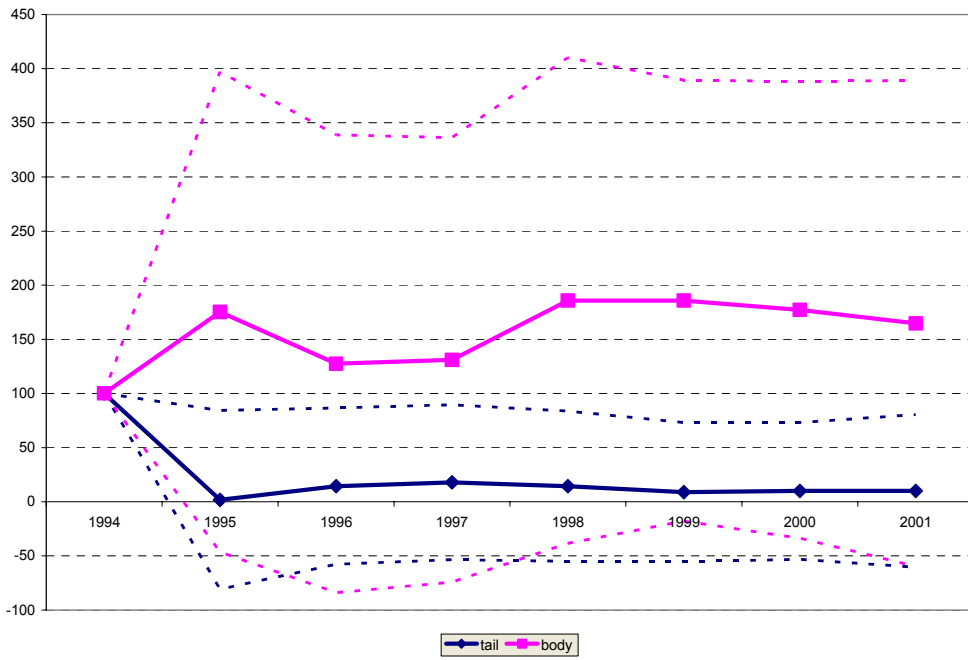
Figure 7: Estimated mean country-sector relative prices in the body of the price distribution (w/ additional control variables)



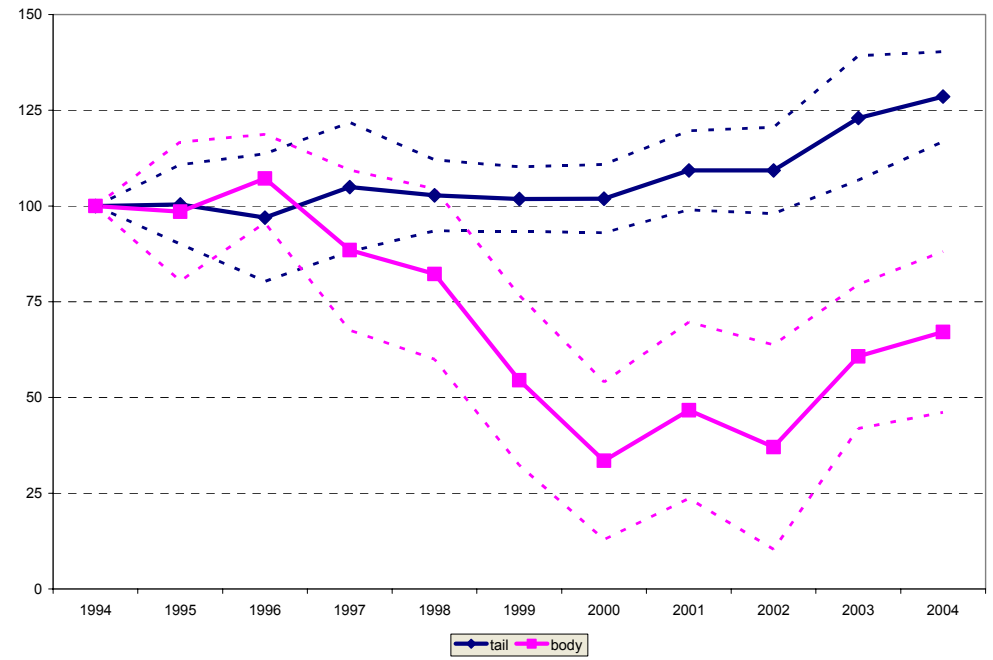
a. Mechanical & Computers (Skewness<0)



b. Mechanical & Computers (Skewness>0)

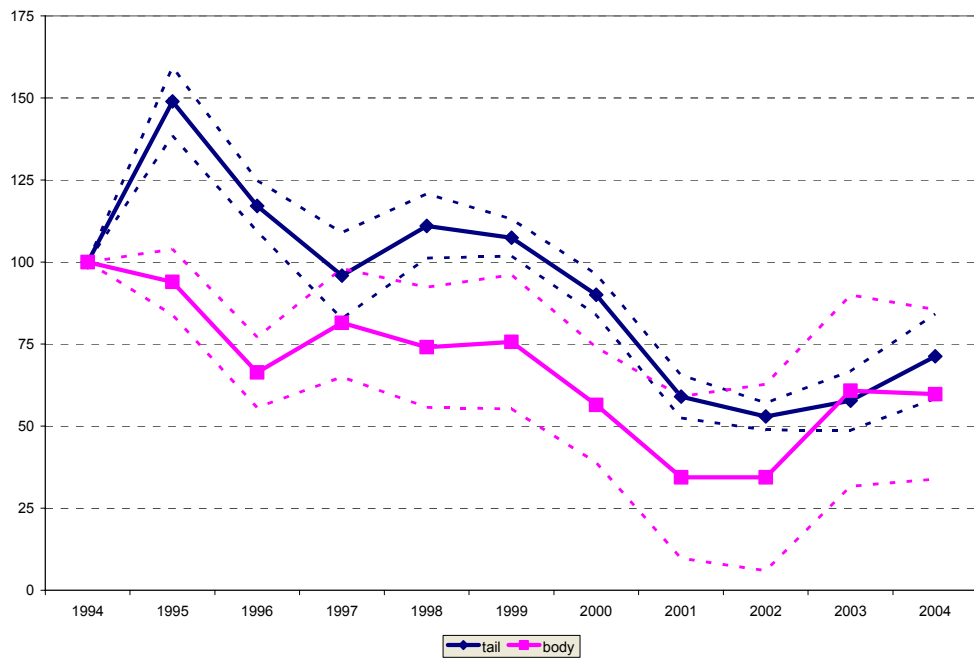


c. Transportation (Skewness<0)

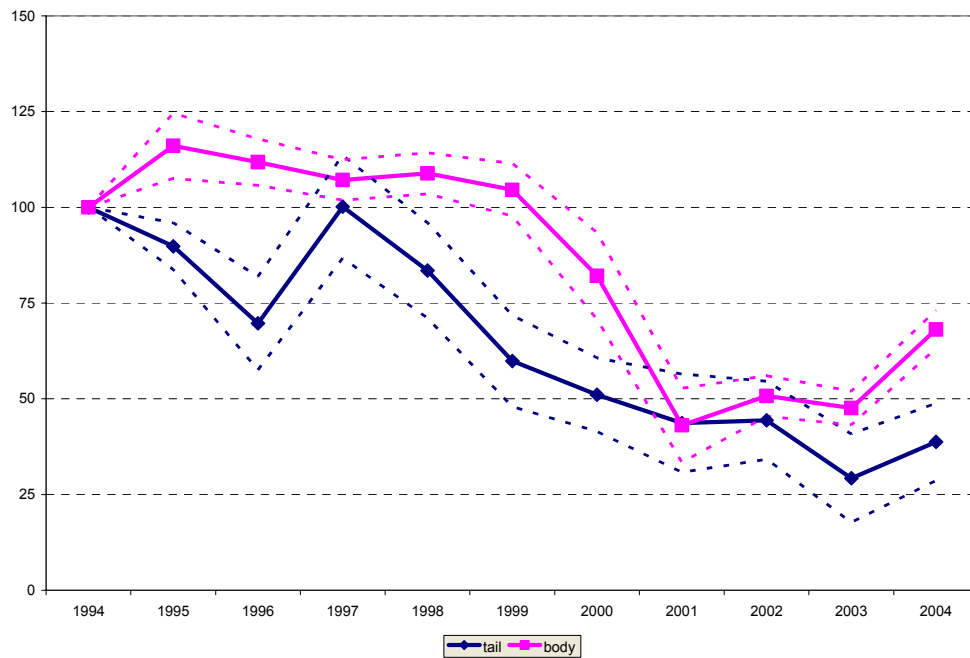


d. Transportation (Skewness>0)

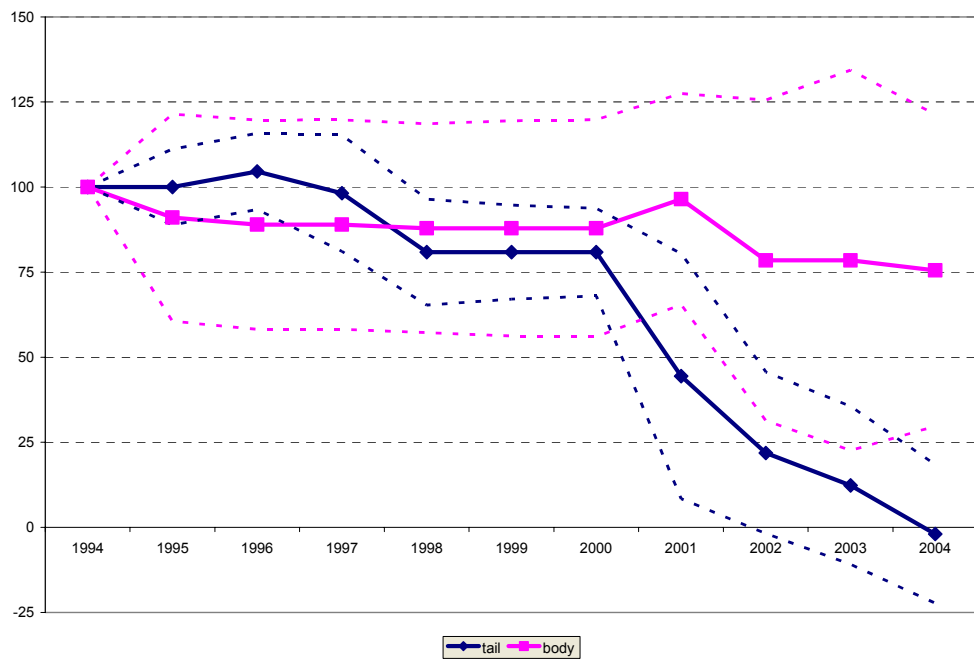
Figure 8: Estimated import price indexes by skewness (mechanical & computers and transportation)



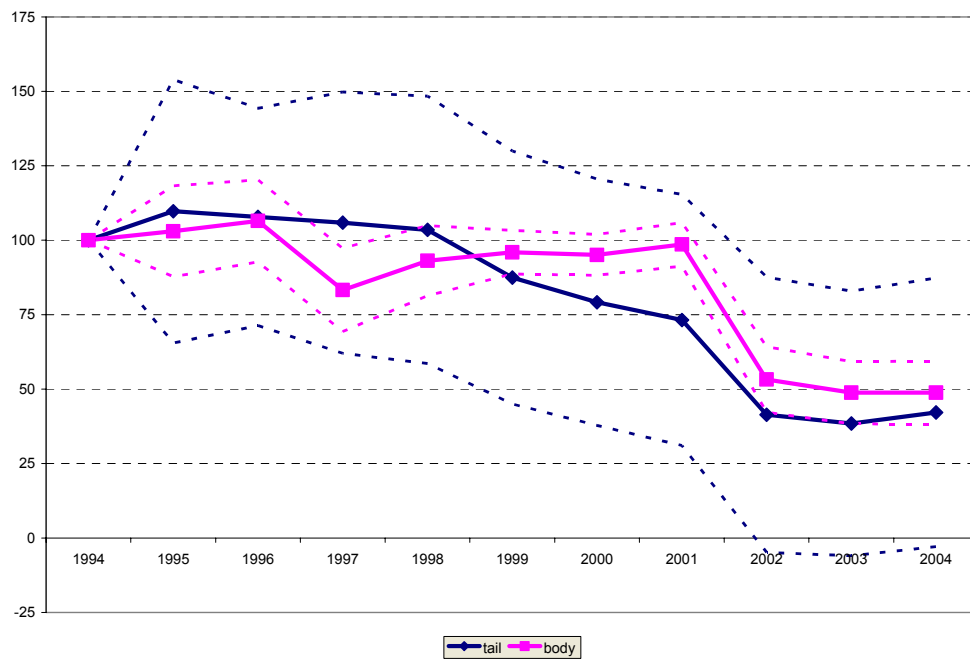
e. Vegetables (Skewness<0)



f. Vegetables (Skewness>0)



g. Textiles (Skewness<0)



h. Textiles (Skewness>0)

Figure 9: Estimated import price indexes by skewness (vegetables and textiles)