The Long and Short (of) Quality Ladders*

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Abstract

I develop a model predicting that the exposure of firms to low-wage country competition decreases with a product market's degree of quality differentiation. The model's predictions are verified using measures of countries' export quality that exploit both price and market share information, which contrasts to earlier work that uses only price data. The quality estimates reveal that the "quality ladder" lengths, measured by the range of qualities, vary considerably across product markets, indicating that quality specialization is more feasible in some product markets than in others. Empirical estimates confirm that the impact of low-wage import penetration on U.S. manufacturing employment is weaker in industries characterized by longer quality ladders. The results indicate that product quality is an important factor for understanding how international trade affects firms and workers.

Keywords: Quality Ladders; Import Competition; Quality Specialization; Product Differentiation

JEL Classification: F1, F2, L1

1 Introduction

The fear of globalization's impact on employment is rooted in the vulnerability or, to use Leamer's terminology, the contestability of jobs (Leamer, 2006). As Leamer puts it, the contestable jobs are those whose "wages in Los Angeles are set in Shanghai."[1] Recent attention in the media and political arena has elevated

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[1] Leamer (2006), page 5.

these fears by arguing that increased economic integration would result in today's American jobs being "exported abroad" tomorrow. This argument implicitly appeals to a factor price equalization argument: Wage arbitrage is possible when workers abroad can replicate–at a fraction of the cost–identical tasks performed in the United States. From a policy perspective, it is important to identify the types of industries that are likely to be contested by emerging economies.

But how does one identify the contestable jobs? Between 1980 and the mid-1990s, manufacturing's share of total U.S. employment fell from 21 to 14.5 percent while the share of low-wage imports simultaneously increased from .8 to 4 percent. Studies by Sachs and Shatz (1994) and Bernard, Jensen, and Schott (2006) provide formal evidence that contestability increases with the degree of import penetration, particularly from low-wage countries.[2] However, simple correlations suggest that some product markets are more vulnerable to foreign competition than others. For example, between 1980 and the mid-1990s, employment in both fabricated metals and electronics has declined at the same rate despite four times faster low-wage import penetration in electronics.

The hypothesis advanced here is that the extent of quality specialization, as opposed to product specialization, allows U.S. firms to reduce exposure to foreign competition. In a textbook Heckscher-Ohlin framework, factor prices equate through trade when countries produce identical goods using identical technologies. However, many studies reject this simple view of the world in favor of an equilibrium where countries specialize in goods tailored to their endowments (e.g., see Leamer (1987), Davis and Weinstein (2001) and Schott (2003)). Schott (2004) has found evidence against across-product specialization–62 percent of U.S. products in 1994 originated from trading partners that spanned the income distribution–in favor of within-product specialization because the export prices vary substantially within products. Like Flam and Helpman (1987) and Schott (2004), this paper demonstrates that specialization occurs in the vertical (i.e., quality) dimension. However, due to exogenous technology constraints, at least in the short- and medium-run, the ability to differentiate quality varies across product markets. A product's quality ladder–the range of qualities within a product (Grossman and Helpman, 1991)–therefore may be *long* or *short*.

I develop a model where heterogenous firms compete by differentiating products in the vertical and horizontal dimensions. Like Flam and Helpman (1987), developed countries have a comparative advantage in producing higher-quality goods, and like Krugman (1980), differentiating in the horizontal dimension is costless. That is, I assume that moving up the quality ladder requires comparative advantage factors while moving across the ladder rung does not. The Northern firms have a comparative advantage in higher-quality manufactures but there exists a range of qualities along the exogenous ladder that overlaps with the low-cost Southern producers. This generates the "vulnerability" hypothesis: Northern firms that lie within this overlap are most exposed to Southern competition and this fraction of exposed firms increases when the

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[2] Other studies studying the negative relationships between trade and employment include Freeman and Katz (1991) and Revenga (1992). Bernard et al. (2006) explicitly connect employment losses to exposure to low income countries, defined as countries with less than 5 percent of U.S. per capita GDP. The low-wage countries used in this paper are listed in Table 1.

ladder shortens. It is the *interaction* of comparative advantage with a long quality ladder that insulates the North from low-wage competition.

Testing the implications of the model requires empirical measures of product quality. Since quality is unobserved, most studies in the international trade literature invoke a convenient vertical-market assumption so that observed unit values can perfectly proxy unobserved quality (e.g., see Schott (2004), Hummels and Skiba (2004) and Hallak (2006)). However, the vertical-market assumption is inconsistent with the reality that most products possess both vertical and horizontal attributes. Horizontal differentiation allows products with high quality-adjusted manufacturing costs to remain in equilibrium because consumers have idiosyncratic preferences for such products. For example, some consumers may trade off comfort (a vertical attribute) for an expensive shoe style (a horizontal attribute). The existence of horizontal differentiation therefore invalidates the "price = quality" assumption.

The empirical quality measures follow from the theoretical model's demand structure, which embeds preferences for horizontal and vertical attributes. I identify the quality of U.S. imports by estimating demand functions for about 1,000 manufacturing sectors via a nested-logit framework. Quality is the vertical component of the model and is structurally defined as the mean valuation that U.S. consumers attach to an imported product. The intuition behind this approach is similar to Hallak and Schott (2006): conditional on price, the product with higher market share is assigned higher quality. A key advantage is that the procedure here recovers qualities at the finest level of aggregation available.

The inferred qualities reveal that developed countries, on average, sit atop the quality ladder, defined as the range of estimated qualities within a product. However, for some products like apparel and footwear, the resulting quality ladders are compressed despite large difference in observed prices. The average U.S. consumer attaches a low valuation for these expensive imports that do not offer a substantially superior vertical attribute relative to cheaper substitutes. Horizontal differentiation keeps the expensive imports in short ladder markets. I also find a negative correlation between the quality ladders and the elasticities of substitution estimated from Broda and Weinstein (2006), which is consistent with the hypothesis that developed countries are more susceptible to inexpensive, but similar quality imports from low-wage countries in short ladder markets.

I aggregate the product-level quality ladders to match U.S. industry data to test the vulnerability predictions of the model. Consistent with Bernard et al. (2006), I find that industry employment is negatively associated with exposure to imports, particularly from low-wage countries. The model here, however, predicts a differential impact across product markets according to ladder length. The empirical results confirm that import penetration has a weaker impact on employment in industries with long quality ladders: a ten percentage point increase in low-wage penetration is associated with a 8 percent employment decline in average ladder industry while employment in a long-ladder industry (one standard deviation above the mean) declines by 2 percent. The results are robust to a number of robustness checks and as well as instrumenting for endogenous import competition.

The results here stress the importance of understanding how quality specialization affects both workers and firms. From the firm perspective, quality ladders provide an avenue for firms to respond to increased globalization. This is the subject of a growing literature in international trade, e.g., Nocke and Yeaple (2005) and Bernard, Redding, and Schott (2006). A key contribution here is the emphasis on vertical versus horizontal differentiation, a feature that has been typically been ignored in the literature.[3] From the perspective of workers, quality specialization as a response to globalization can have important implications for rising inequality in both developed and developing countries.[4]

The remainder of the paper is organized as follows. Section 2 uses a simply model to illustrate that exposure to low-wage competition is greater in markets with short quality ladders. The empirical method used to identify quality in the data is discussed in Section 3. The data and quality estimation results are presented in Section 4. Section 5 applies the quality ladders to U.S. industry data to test the implications of quality specialization for employment. Section 6 concludes.

2 Theoretical Model

2.1 Model Setup

The following assumptions are maintained throughout the model. There are two regions, North and South, with wages higher in the North: $w^N > w^S$. Ricardian comparative advantage has Northern firms draw from an ability distribution that stochastically dominates the South and has a higher bounded support: $\lambda^N_{\max} > \lambda^S_{\max}$.

2.1.1 Firms

Firms in the two regions compete by producing vertically and horizontally differentiated varieties within a monopolistically competitive product market. I assume, as in Krugman (1980) and Melitz (2003), that horizontal differentiation is costless and orthogonal to comparative advantage factors so in equilibrium, all firms produce horizontally distinct varieties. Like Flam and Helpman (1987), vertical differentiation depends on the Ricardian comparative advantage. Heterogenous firms are modeled as a draw from an ability distribution $G(\lambda)$, with associated pdf $g(\lambda)$, on the bounded support $[1, \lambda^{\max}]$. This draw enables a firm λ to design a quality, $\xi(\lambda)$, via the function[5]

$$\xi(\lambda) = \lambda^{\gamma}, \qquad \gamma \in [0, 1). \tag{1}$$

In this setup, quality is isomorphic with entrepreneurial ability. The firm requires 1 unit of labor and incurs a per unit cost of $c(\xi)$, with $c' > 0$, to manufacture the variety.

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[3] Two exceptions are Young (1998) and Hallak and Schott (2006).

[4] For example, see Feenstra and Hanson (1999), Zhu and Trefler (2005), Verhoogen (2006) and Goldberg and Pavcnik (2007).

[5] The quality production function is a simplified version of that considered by Verhoogen (2006). This function could easily be extended to include several inputs such as skilled labor and capital.

The exogenous and fixed parameter γ plays an important role in the model. It controls the returns to quality and is assumed to be less than one to ensure an interior solution. As is shown below, γ controls the "length" of the quality ladder.

2.1.2 Consumers

Northern consumers have unit demands and choose the variety that provides them with the highest utility. The (indirect) utility that consumer n obtains from choosing variety λ is

$$V_n(\lambda) = \bar{\theta}\xi(\lambda) - \alpha p(\lambda) + \mu_n \xi(\lambda) + \epsilon_n(\lambda). \tag{2}$$

Consumers have a random taste for quality that is drawn from a distribution $P_\mu(\mu)$. This taste is decomposed into the mean component $\bar{\theta}$ and a consumer-specific-random deviation μ_n. There are several interpretations of the vertical component, ξ. It can measure physical characteristics like the clarity or sharpness of a television screen. Or, it can capture the increase in perceived quality that results from marketing or advertising. In either case, the vertical component captures any attribute that enhances consumers' willingness-to-pay for this variety as opposed to competitor varieties. An alternative interpretation is that ξ represents a shift parameter in the variety demand schedule such that an increase induces a rightward shift in the demand curve (Sutton, 1991). The empirical identification of quality relies on this latter intuition (see below).

Horizontal differentiation is introduced through the consumer-variety-specific term, $\epsilon_n(\lambda)$, that is assumed to be independent and identically distributed type-I extreme value. This term explains why some consumers purchase varieties with high quality-adjusted prices. The inclusion of both $\xi(\lambda)$ and $\epsilon_n(\lambda)$ is what differentiates this approach from a purely horizontal model (e.g, Krugman (1980)) or a purely vertical model (e.g., Flam and Helpman (1987)).

A great feature of the random coefficients model is that it alleviates the Independence of Irrelevant Alternatives (IIA) property that plagues standard logit and CES frameworks. IIA has the undesirable property that forces substitution patterns to be driven by market shares. For example, suppose the market shares for a high-quality plasma television variety and a low-quality tube variety were the same. Under IIA, the varieties would have the same cross-price elasticity with respect to *any* third alternative. This would mean that a decrease in the price of another tube television would necessarily generate equal percentage declines in the demand for both varieties. IIA occurs because the covariance between the error components for two varieties, $\mathrm{Cov}[\mu_n\xi(\lambda) + \epsilon_n(\lambda), \mu_n\xi(\lambda') + \epsilon_n(\lambda')]$, is equal to zero if $\mu_n \equiv 0$ because the ϵ draws are i.i.d. Allowing for consumer-taste interactions (i.e., $\mu_n \neq 0$) with quality implies that preferences for two similar quality goods are more highly correlated than varieties at two different quality segments.

The standard logit distributional assumption an exact aggregation of the individual purchases in the economy. Conditional on the μ_n draw, the probability that an individual chooses variety λ is given by the familiar logit formula

$$f_n(p, \xi, \bar{\theta}, \mu_n; \lambda) = \frac{e^{\left(\bar{\theta}+\mu_n\right)\xi(\lambda) - \alpha p(\lambda)}}{\int_\Lambda e^{\left(\bar{\theta}+\mu_n\right)\xi(\lambda) - \alpha p(\lambda)} \phi(\lambda) d\lambda}, \tag{3}$$

where $\phi(\lambda)$ denotes the *ex post* ability distribution of the firms that remain in the market and Λ denotes the support of this distribution. The overall market shares for variety λ are obtained by integrating over the distribution of the random coefficient

$$s(p, \xi, \bar{\theta}; \lambda) = \int f_n dP_\mu(\mu). \tag{4}$$

2.2 Autarky in the North

The Northern firms draw their managerial ability from the distribution function $g^N(\lambda^N)$. Conditional on this draw, they choose the skilled labor and price to maximize profits, given the demand in (4). Under monopolistic competition, the behavior of competitors is taken as given so the denominator in (3) is fixed. The firm's maximization problem is given by

$$\pi^N = \max_{p^N}(p^N - w^N - c(\xi^N))s - F^N, \tag{5}$$

where F^N is the fixed cost of production. A Northern firm of ability λ^N charges a price marked up over marginal cost, $p^N(\lambda^N) = \frac{1}{\alpha} + w^N + c(\xi^N(\lambda^N))$.

Profits are increasing in the firms' ability so free entry implies that there is a unique cut-off, λ^N_{min}, that determines the lowest ability firm that remains in the market. The zero-profit condition that defines this cutoff is

$$\pi^N(\lambda^N_{\text{min}}) = 0 \Rightarrow \frac{1}{\alpha} \int \frac{e^{\left(\bar{\theta}+\mu_n\right)\xi^N(\lambda^N_{\text{min}})-\alpha p^N(\lambda^N_{\text{min}})}}{\int_{\lambda^N_{\text{min}}}^{\lambda^N_{\text{max}}} e^{\left(\bar{\theta}+\mu_n\right)\xi^N(\lambda^N)-\alpha p^N(\lambda^N)}\phi^N(\lambda^N)d\lambda^N} dP_\mu(\mu) = F^N. \tag{6}$$

Firms that draw below this ability exit the market. The *ex ante* probability of successful entry is given by $1 - G^N(\lambda^N_{\text{min}})$ so the *ex post* distribution of abilities, truncated at the zero-profit ability cutoff, is

$$\phi^N(\lambda^N) = \begin{cases} \frac{g^N(\lambda^N)}{1-G^N\left(\lambda^N_{\text{min}}\right)} & \text{if} \qquad \lambda^N \geq \lambda^N_{\text{min}} \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

A firm must pay a sunk cost of entry, F^N_e, to obtain its ability draw. Upon learning λ^N, the firm decides whether to produce or exit the market. The free-entry condition is therefore

$$\left[1 - G^N(\lambda^N_{\text{min}})\right] \bar{\pi}^N = F^N_e, \tag{8}$$

where $\left[1 - G^N(\lambda^N_{\text{min}})\right]$ denotes the probability of survival and $\bar{\pi}^N$, the expected profit conditional on survival, is given by

$$\bar{\pi}^N = \int_{\lambda^N_{\text{min}}}^{\lambda^N_{\text{max}}} \pi^N(\lambda^N)\phi^N(\lambda^N)d\lambda^N. \tag{9}$$

The bounded support determines the length of the market's quality ladder, defined as the range of qualities within the market

$$\begin{aligned} Ladder(\gamma; \lambda_{\text{min}}, \lambda_{\text{max}}) &\equiv \xi(\lambda_{\text{max}}) - \xi(\lambda_{\text{min}}) \\ &= \lambda_{\text{max}}^{\frac{1}{1-\gamma}} - \lambda_{\text{min}}^{\frac{1}{1-\gamma}}. \qquad (10) \\ \frac{\partial Ladder(\gamma; \lambda_{\text{min}}, \lambda_{\text{max}})}{\partial \gamma} &> 0 \qquad (11) \end{aligned}$$

The quality ladder length is increasing in γ. The γ parameter dictates the effectiveness of inputs in raising variety quality. For product markets with faster diminishing returns, the quality ladder is short and concentrated. Therefore, low γ markets are those with a relatively higher degree of horizontal to vertical differentiation.

This model treats the quality ladder length as fixed and therefore excludes the possibility that the quality ladder endogenously "lengthens" in response to competition, as in Sutton (1998) or Klette and Kortum (2004). This assumption is reasonable in the short- and medium-term where technology determines the range of potential qualities. The empirical analysis deals with this potential problem by fixing the product's quality ladder its initial or baseline length.

2.3 Free Trade

Now suppose the North allows Southern exporters to enter its market. The Southern firms costlessly differentiate their varieties in the horizontal space and locate along the quality ladder according to their entrepreneurial ability. Southern entrepreneurs draw their ability from the distribution $g^S(\lambda^S)$ on the bounded support $[1, \lambda^S_{\max}]$. The Southern exporter faces the consumer demand functions given in (4). The firm receives its ability draw λ^S, and conditional on exporting, it sets the price at $p^S(\lambda^S) = \frac{1}{\alpha} + w^S + c(\xi^S(\lambda^S))$. Conditional on quality, the lower wage provides the South with a cost advantage.

When Southern exporters enter the market, all Northern firms lose some market share because of the increased competition.[6] But the lower the manufacturing wages in the South, the larger the decline in Northern market shares: $\frac{\partial s(\lambda^N)}{\partial w^S} > 0$. Empirical evidence for this derivative has been shown by Bernard et al. (2006): U.S. plant survival is negatively correlated with import competition, but the impact is much stronger from low-wage competition.

This model shows that the intensity of competition within a market depends on the quality ladder. Under the assumption that $\lambda^S_{\max} > \lambda^N_{\min}$, there exists a set of qualities that overlaps between the two regions. The random-coefficients utility implies that consumers of a Northern variety with a relatively high quality-adjusted price are now more likely to substitute towards the Southern variety with identical quality but lower quality-adjusted price. As a result, the Northern firms that manufacture qualities within this overlapping set suffer the largest decline in market shares.

Denote the ability of the Northern firm that manufactures the quality of the most able Southern firm as $\tilde{\lambda}^N$ $(= \lambda^S_{\max})$. The South can produce all qualities at or below $\xi^N(\tilde{\lambda}^N)$. The fraction of vulnerable Northern firms lies in the range[7]

$$\Omega(\gamma; \lambda^N_{\min}, \lambda^N_{\max}) = \frac{\xi^N(\tilde{\lambda}^N) - \xi^N(\lambda^N_{\min})}{\xi^N(\lambda^N_{\max}) - \xi^N(\lambda^N_{\min})}. \tag{12}$$

Vulnerable Firms: *The fraction of vulnerable firms decreases with the ladder length:* $\frac{\partial \Omega(\gamma; \lambda^N_{\min}, \lambda^N_{\max})}{\partial \gamma} < 0$. *Proof:* See Appendix. $\square$

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[6] Horizontal differentiation prevents any firm from exiting the market.

[7] The expression assumes that the mass of firms is uniformly distributed along the quality ladder.

In this model, free trade with the South generates a differential impact on two markets that are otherwise identical but vary according to γ. The result is related to more general trade models that predict a breakdown of factor price equalization when countries are fully specialized in production. In contrast to a single-cone equilibrium, where endowments are such that all countries produce all goods, the conditions required for factor price equalization are not met in multi-cone equilibrium because countries specialize in varieties tailored to their endowments.[8] Schott (2004) has extended this analysis to *within* product specialization in the quality dimension. In this environment, endowments are such that countries specialize in different parts of a product's quality ladder.

This model sharpens this prediction by arguing that quality specialization is more feasible in some markets rather than others. For example, multiple cones may not arise in the clothing market but could arise in the television market with developed countries specializing in plasma screen receivers and developing countries manufacturing tube receivers. This would imply that U.S. apparel producers compete directly with their Chinese counterparts while U.S. electronics firms reduce exposure because they inhabit a higher rung of the television quality ladder.

3 Empirical Implementation

To test the implications of the model, I first estimate the quality of U.S imports by estimating the above demand system for manufacturing import data. However, due to computational intensity, it is not feasible to estimate random coefficients demand systems (e.g., see Berry et al. (1995)), for approximately 1,000 manufacturing markets. I therefore use a version of the nested-logit model that is a slightly restricted version of the random coefficients framework in (2). The nested logit partially relaxes the IIA property by allowing preferences for alternatives within a nest, such as the type of clothing material, to be more correlated with each other.

Accounting for IIA is important because I infer quality from both price and market share data. To understand why, suppose a consumer chooses between a Japanese wool shirt and an Italian cotton shirt. Under a standard logit or CES framework, the market shares and inferred consumer valuation of both imports fall by an equal percentage if a Chinese cotton shirt enters the market. However, the Chinese shirt's "location" should be closer to the Italian shirt because of the similarity in material. The market share of the Italian shirt should adjust by more than the Japanese wool shirt. The nested logit allows for more appropriate substitution patterns by placing varieties into appropriate nests.

I estimate separate demand curves at the five-digit Standard Industrial Trade Classification (SITC, Revision 2) level, which are referred to as *sectors*. Sectors are aggregates of ten-digit Harmonized System (HS) *products*. For example, within the men's knit-shirts sector (SITC 84632) there are different types of

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[8] For evidence in favor of the hypothesis that countries inhabit multiple cones of diversification, see Leamer (1987), Davis and Weinstein (2001) and Schott (2003).

shirt materials such as cotton, wool, and silk. The HS codes provide a natural delineation for the nests because the product descriptions classify imports along similar characteristics. A country's (c) export within a product k is referred to as a *variety* and is indexed by j in this section.

The empirical specification follows Berry (1994). The following derives the estimation model for a single sector so the sector subscript is suppressed to reduce clutter. Consumer n seeks to purchase a variety in the sector and obtains utility from variety j, which is classified in product k, at time t

$$V_{njkt} = \xi_{1j} + \xi_{2t} + \xi_{3jt} - \alpha p_{jt} + \sum_{k=1}^{K} \mu_{nkt} d_{jk} + (1-\sigma)\epsilon_{njt}. \tag{13}$$

The ξ terms represent the variety's valuation that is common across consumers. This is the empirical analog to quality in the theoretical model and is decomposed into three components. The first term, ξ_{1j}, is the time-invariant valuation that the consumers' attach to variety j. The second term, ξ_{2t}, controls for secular time trends common across all varieties. The ξ_{3jt} term is a variety-time deviation that is observed by the consumer but not the econometrician. This term is potentially correlated with the variety's unit value, p_{jt}, which includes transportation and tariff costs.[9] Define $\delta_{jt} \equiv \xi_{1j} + \xi_{2t} + \xi_{3jt} - \alpha p_{jt}$.

The horizontal component of the model is captured by the expression $\sum_{k=1}^{K} \mu_{nkt} d_{jk}$ and the logit error ϵ_{njt}. The summation term is similar to the random consumer tastes specified in the theoretical model. It interacts the valuation that consumer n places on product k, μ_{nkt}, with a dummy variable d_{jk} that takes a value of 1 if variety j lies in product k. This term enables correlations among consumer n's preferences for all varieties within product k. Cardell (1997) has shown that the distribution of $\sum_{k=1}^{K} \mu_{nkt} d_{jk}$ is the unique distribution such that if ϵ is distributed extreme value, then the sum is also distributed type-I extreme value.[10]

The consumer chooses variety j if $V_{njkt} > V_{nj'kt}$, $\forall\, j' \neq j, \forall k$. The distributional assumptions imply the usual logit formulas: the conditional market share for variety j is

$$\bar{s}_{jt/k}(\delta, \sigma) = \frac{\exp[\frac{\delta_{jt}}{1-\sigma}]}{D_{kt}}, \tag{14}$$

where $\bar{s}_{jt/k}$ is variety j's share within product k and $D_{kt} = \sum_{j \in \mathcal{J}_{kt}} \exp[\frac{\delta_{jt}}{1-\sigma}]$. The notation $\mathcal{J}_{kt}$ denotes the total number of varieties within product k.

The probability of choosing product k amongst the set of all possible products within the sector (the product share) is given by

$$\bar{s}_{kt}(\delta, \sigma) = \frac{D_{kt}^{(1-\sigma)}}{\left[\sum_k D_{kt}^{(1-\sigma)}\right]}. \tag{15}$$

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[9] Information on non-tariff barriers are unavailable at the HS level.

[10] The degree of within nest correlation is controlled by $\sigma \in (0, 1]$ and is assumed to be identical across all products. As σ approaches one, the correlation in consumer tastes for varieties within a nest approaches one and as σ tends to zero, the nested logit converges to the standard logit model since the within group correlation converges to zero.

The unconditional market share for variety j is the product of (14) and (15)

$$\begin{aligned} s_j(\delta,\sigma) &= \bar{s}_{jt/k}(\delta,\sigma)\bar{s}_{kt}(\delta,\sigma) \\ &= \frac{\exp[\frac{\delta_{jt}}{1-\sigma}]}{D_{kt}^{\sigma}\left[\sum_k D_{kt}^{(1-\sigma)}\right]}. \end{aligned} \tag{16}$$

The denominator is composed of a product value, D_{kt}, which is common to all varieties within product k, and the total market value, $\sum_k D_{kt}$, which is common to all varieties in the sector.

An outside variety is required to complete the demand system. The consumer chooses the outside option if his or her utility is greater than all the inside varieties. For example, the outside option captures the utility for purchasing a domestic U.S. variety or not purchasing. The utility of the outside option is given by

$$u_{n0t} = \delta_{0t} + \mu_{n0t} + (1-\sigma)\epsilon_{n0t}, \tag{17}$$

and is normalized to zero by setting $\delta_0 = 0$ and $D_0 = 1$. The outside market share is

$$s_{0t}(\delta,\sigma) = \frac{1}{\left[\sum_k D_{kt}^{(1-\sigma)}\right]}. \tag{18}$$

Since the outside variety market share is unobserved, I proxy it by using import penetration measures at the four-digit Standard Industrial Classification (SIC, Revision 1987), which are taken from Bernard et al. (2006) and mapped to the SITC sectors using a concordance provided by Feenstra et al. (2002). The outside variety market share is defined as one minus the import penetration ratio. It is important to note that the way the outside good market share is derived will not affect the results below because the specification includes year fixed effects. In other words, while the outside good market share affects the absolute growth rate of quality, the relative quality growth rate is unaffected. From here, the the total market size for the sector can be obtained from $MKT_t = \sum_{j\in\mathcal{J}_{kt}, j\neq 0} m_{jt}/(1-s_{0t})$, where m_{jt} denotes the import quantity of variety j. The imported variety market shares are computed as $s_{jt} = m_{jt}/MKT_t$.

Dividing (16) by (18) removes the market value term that is common across all varieties. Taking logs gives

$$\ln(s_{jt}) - \ln(s_{0t}) = \frac{\delta_{jt}}{1-\sigma} - \sigma \ln D_{kt}. \tag{19}$$

Dividing (15) by (18) and taking logs simplifies to $\ln D_{kt} = \left[\ln(\bar{s}_{kt}) - \ln(s_{0t})\right]/(1-\sigma)$. Substituting this expression into (19) gives

$$\delta_{jt} = \ln(s_{jt}) - \sigma\ln(\bar{s}_{jt/k}) - \ln(s_{0t}). \tag{20}$$

Using the definition of δ, the equation can be rewritten as

$$\ln(s_{jt}) - \ln(s_{0t}) = \xi_{1j} + \xi_{2t} - \alpha p_{jt} + \sigma\ln(\bar{s}_{jt/k}) + \xi_{3jt}. \tag{21}$$

The expression in (21) states that the relative market share of the variety will equal its mean valuation plus its significance within the nest it occupies, less its price. Typically, $\xi_{1j} + \xi_{2t}$ are approximated using the variety's characteristics but the trade data do not record characteristics. I therefore exploit the panel dimension of the data by estimating variety (country-product) and year fixed effects. The third component of quality, ξ_{3jt}, is not observed and plays the role of the estimation error. Both this term and the nest share ($\bar{s}_{jt/k}$) are potentially correlated with the variety's price, so instrumental variables are required to identify the parameters.

3.1 Identification

One set of cost shifters used to identify the demand parameters are exchange rates and the interaction of distance to the U.S. with the price of oil.[11] However, there is insufficient variation in these instruments to identify the parameters, even when interacted with product dummies. Additional cost shifters that vary at the HS level for all countries, years and industries spanned by the trade data are not available. For example, country-specific raw cotton prices could instrument the price of cotton shirts. However, the detail of trade data is such that many knit-shirt products contain some amount of cotton material. As a result, country-specific instruments have insufficient variation to shift the price of each individual variety.

I therefore also use lagged competitor prices as instruments for variety j's current price. Specifically, I use lagged average prices within the sector, within the product and within the country's exports in that sector as the instruments. The use of lagged prices assumes that there is serially correlation in marginal cost but that the unobserved consumer valuation ξ_{3jt} is serially uncorrelated.[12] One justification for lagged competitor prices serving as instruments is that the utility structure in (13) does not include characteristics or prices of rival goods and is therefore uncorrelated with ξ_{3jt} by construction. This justification is analogous to that used by Berry et al. (1995) who use rival varieties' characteristics as instruments for price.

Since characteristics data are unavailable, the number of varieties within the product nest and the number of observed varieties exported by the country are included as instruments to identify σ. Note that using the number of varieties is less restrictive than using product characteristics as instruments, which is a standard practice in the discrete choice literature (see Berry et al. (1995)). Validity of these instruments only requires that entry and exit occur prior to the revelation of the consumers' unobserved valuation.

3.2 Hidden Varieties

A second issue that arises in estimating (21) is that the market shares are likely to be an aggregation of even more finely classified imports. A country's large market share may simply reflect the fact that it exports more *unobserved* or *hidden* varieties within a product.

To illustrate this potential problem, suppose that China and Italy export identical varieties at identical prices and split the market equally at the (unobserved) twelve-digit level. But suppose that China

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[11] The great-circle distance data are obtained from http://www.eiit.org/.

[12] Hausman (1996), Nevo (2001) and Thomas (2005) are also examples of discrete choice demand models that also rely on competitor prices as instrumental variables to identify demand parameters.

exports more twelve-digit varieties. Aggregation to the observed ten-digit level would assign a larger market share to China, which from (21) would cause an upward bias in the fixed effects and an overstatement of Chinese quality. Allowing the mean of the logit error distribution to vary across countries can control for the unobserved varieties. But because country fixed effects are not identified in (21), I follow theoretical predictions in Krugman (1980) and use a country's population as a proxy for the number of hidden varieties within an HS code. Allowing the (log of) population to shift the logit error mean implies that it becomes an additional covariate in (21).A broader measure of quality might include the number of hidden varieties, in which case controlling for population is not required. Yet since the theory emphasizes the importance of vertical, rather than horizontal, specialization, it is necessary to control for within-product horizontal differentiation in this context.

A fixed effect IV approach is used to estimate the following regression separately for each of the manufacturing sectors

$$\ln(s_{jt}) - \ln(s_{0t}) = \xi_{1j} + \xi_{2t} - \alpha p_{jt} + \sigma \ln(\bar{s}_{jt/k}) + \gamma \ln pop_{ct} + \xi_{3jt}, \tag{22}$$

where pop_{ct} is the population in country c at time t. Quality is defined as

$$\xi_{jt} \equiv \hat{\xi}_{1j} + \hat{\xi}_{2t} + \hat{\xi}_{3jt}. \tag{23}$$

The quality measures are residuals of the demand systems and measures the consumers' willingness-to-pay; an increase in a product's quality allows its price to rise without losing market share. The lack of characteristics data implies that many factors could influence this measure, but it is important to note that this set is much smaller by controlling for prices. For example, a variety may have a large market share if the exporting country is geographically close to U.S. However, the price includes transportation costs and therefore the quality estimate is not capturing purely "gravity" effects such as distance. A similar argument can be made regarding free trade agreements. Even though Mexican and Canadian import shares are high because of NAFTA, this effect will operate through prices, which are inclusive of tariffs. Likewise, a low-wage country may have high market shares, but by conditioning on its low export price, the quality measures will not just reflect market shares.

4 Data and Quality Estimation Results

I estimate the model on U.S. product-level import data compiled by Feenstra et al. (2002). The sample is restricted to the manufacturing sectors (SITC 5-8) and homogenous goods, as defined by Rauch (1999), are excluded. The data record the quantity, value, transportation costs and duties paid for imports into ten-digit HS product codes from 1989-2001. The unit value is defined as the sum of the three components divided by the quantity and deflated to real values using the CPI.

The import data are extremely noisy (General Accounting Office, 1995), so the data are trimmed along two dimensions. All varieties that report a quantity of one or a total value of less than $10,000 are excluded. I also exclude varieties with extreme unit values below the 5th percentile and above the 95th percentile within the sector.[13] Table 2 reports basic summary statistics by two-digit SIC industry. The apparel and leather industries have the lowest average per capita GDP while imports into transportation, industrial machinery and chemicals are dominated by relatively richer countries. Notice also that there is little variation in the number of countries present at the two-digit level.

The estimating equation in (22) is run separately on 1,047 manufacturing sectors. Summary statistics of the regressions are shown in Table 3. Approximately 71 percent of the 1.2 million observations are associated with a negative and statistically significant price coefficient. The average p-value testing the overidentifying restrictions passes conventional levels and the IV price coefficient is more than twice the magnitude of the OLS coefficient (rows 2 and 3); this suggests that the instruments are working in the intuitive direction. The average own-price elasticity (row 4) is low but not surprising given that the regressions exclude all across-variety variation. Approximately 80 percent of the estimations report σ parameter statistically significant at the 5 percent level which suggests that the nested structure is important. In addition, 90 percent of the estimations indicate that σ lies within the unit interval; this is a necessary and sufficient condition for random utility maximization (McFadden, 1978). The standard errors for the quality estimates are obtained by simulating draws from the asymptotic distribution of the estimated parameters ($\hat{\alpha}$, $\hat{\sigma}$ and $\hat{\gamma}$); the average t-statistic is 4.6.[14]

4.0.1 Factor Endowments and Quality Specialization

The inferred qualities offer support for previous studies that have found, using prices to proxy for quality, that more capital- and skill-intensive countries export higher quality varieties (e.g., see Schott (2004)). The relationship between export quality and level of development is assessed by regressing variety quality on GDP per capita

$$\xi_{ckt} = \alpha_{kt} + \beta \ln Y_{ct} + \nu_{ckt}, \tag{24}$$

where ξ_{ckt} is the estimated quality of country c's export in product k at time t and Y_{ct} is country c's per capita GDP. The inclusion of a product-year dummy, α_{kt}, indicates that the regression considers the cross-sectional relationship between quality and income within products. Table 4 reports that the coefficient on exporter income is positive and significant. Richer countries, on average, export higher quality products within narrowly defined industries.

Columns two and three re-run (24) using capital-labor ratios and the fraction of a country's workforce with tertiary education, which provides a more appropriate test of the factor proportions hypothesis.[15] The coefficients are also positive (and for capital-labor, statistically significant); countries abundant in skill and

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[13] 12 percent of the sectors record imports in multiple units. For these sectors, the products of the majority unit are kept which comprise about 80 percent of the observations within a multiple-unit sector.

[14] The bootstrap is an alternative method to obtain the standard errors but is inappropriate in this context since sampling varieties alters the market equilibrium.

[15] Capital-labor ratios and tertiary education percentages are obtained from the World Bank's World Development Indicators.

capital export higher quality varieties within the narrowly classified products. Thus, the quality measures inferred from a model that allows products to possess both vertical and horizontal attributes indicate evidence of within-product quality specialization.

4.0.2 Quality Ladders

Regression (24) provides evidence that richer countries sit atop the quality ladder within products. The quality ladder is defined as the range of the estimated qualities within a product. I mitigate concerns of the endogenous lengthening of the quality ladder by using the product's *initial* quality ladder[16]

$$Ladder_{k0} = \xi_{k0}^{\max} - \xi_{k0}^{\min}. \tag{25}$$

It is important to note that there is a strong persistence in a product's ladder length over the sample; the correlation coefficient between a product's initial and final baseline is .91. This is important because it implies that, on average, initially short-ladder products do not become long-ladders products by the end of the sample period. This also provides support for assuming a fixed quality ladder in the theoretical analysis.

To what extent are the qualities reflected by observable prices? In a vertical product market, prices and quality are isomorphic since consumers agree on the rankings of goods. The mapping between prices and quality is less clear in horizontal markets because idiosyncratic preferences influence purchasing behavior. The following specification assesses the relationship between the inferred qualities and prices across products of varying ladder lengths

$$\xi_{ckt} = \alpha_{kt} + \beta_1 \ln p_{ckt} + \beta_2 \left(\ln p_{ckt} \times \ln Ladder_{k0}\right) + \nu_{ckt}. \tag{26}$$

Product-year fixed effects are denoted by α_{kt}, and p_{ckt} is the unit value of country c's export in product k at time t. The coefficient of interest is β_2; a positive β_2 suggests that a more positive correlation between price and quality in long ladders. Table 5 reports that the interaction coefficient is positive, but only significant at the 16 percent level.[17] Nevertheless, specification (26) casts doubt on the vertical-market assumption that is commonly used in the international trade literature.

Regression (26) indicates that the *average* consumer does not attach a high valuation to expensive imports in short-ladder products. For example, although Canadian footwear is 29 percent more expensive than average imported footwear, it has a lower than average estimated quality. Horizontal differentiation explains why these high quality-adjusted varieties remain in the product market. A fraction of consumers purchase Canadian footwear not because of a high ξ, the common valuation over all consumers, but because this fraction obtains a high logit draw for Canadian shoes. In the aggregate, however, the *average* U.S.

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[16] The main results of the paper actually rely on the inter-decile range which is more robust to outliers than the range. However, the sensitivity checks reveal that results are robust alternative measures including the full range, the inter-quartile range or the standard deviation of qualities within a product (see below).

[17] Note that the negative β_1 coefficient is a consequence of how quality is defined (see (22)): *conditional* on market shares, price and the estimated quality measures are positively correlated.

consumer attaches a low valuation to the expensive Canadian shoes because these imports do not offer better vertical attributes to justify its high price. Inferring quality from prices alone would instead attach a high quality rank for Canadian footwear.

Two graphs further illustrate this point. Figure 1 plots the relationship between quantities, unit values and the estimated qualities for two products: "Transmission Receivers Exceeding 400 MHZ" (HS 8525203080) and "Footwear with Plastic Soles, Leather Uppers" (HS 6403999065). The figures are ordered by unit values, which also roughly correspond to exporter per capita GDP. For transmission receivers (top panel), unit values and quality are positively correlated, indicating that the average consumer assigns a higher valuation to more expensive varieties. For this product, it appears that the vertical market assumption is tenable.

The bottom panel plots leather shoes. Here, exporters of expensive varieties, like Belgium, are associated with relatively low quality. The reason lies in the export quantities (square dots). Belgium has a very low market share, even conditioning on its price. Taking into account Belgium's market share and export price, the quality estimates indicate that the average consumer attaches a low valuation to Belgian leather shoes. On the other hand, France exported the second most expensive variety in this HS classification and obtained a relatively high market share given its price. It is therefore assigned a high quality estimate. China's exceptionally large market share, conditional on its price, results in the highest export quality for this HS code. There are other examples that do accord with intuition. Spain, Italy and Germany export expensive footwear, but they also secure large market shares given their export prices. As a result, these countries are associated with relatively high quality shoes. So the vertical market assumption typically invoked in the trade literature may be salient for some product markets.

The model predicts that developed countries are more susceptible to competition in short-ladder products. This also implies that varieties in short-ladder products should have relatively higher elasticities of substitution. I examine the correlation between the quality ladders and the product-level elasticities of substitution provided by Broda and Weinstein (2006), which are estimated for the U.S. trade data using a method developed by Feenstra (1995). Table 6 reports that the correlation is negative and statistical significant: a ten percent increase in the quality ladder is associated with a .3 percent lower elasticity of substitution. This means that varieties in long-ladder products are less substitutable with one another than imports into short ladders. This is initial evidence that the scope for vertical differentiation has implications for the vulnerability of developed countries to low-wage imports.

In the next section, the quality ladders are explicitly linked to employment outcomes in the U.S. It should be noted that although the quality ladder is inferred from only imported varieties, it is reasonable to assume U.S. firms fall within this technological frontier since the ladders are constructed from imports of highly developed countries similar to the U.S. like Japan, Germany and Canada. One potential caveat is that non-tariff barriers, such as voluntary export restraints or quotas, may induce higher quality imports but not domestic varieties. The major non-tariff barriers during this period were quotas imposed on textile and apparel imports under the Multifiber Arrangement (MFA) and its successor, the Agreement on Textile and Clothing (ATC).However, since the quotas were levied on developing countries, they should not have directly influenced developed countries' clothing and textile quality.

5 Long and Short Quality Ladders

5.1 Quality Ladders and U.S. Manufacturing Employment

This section examines the vulnerability hypothesis outlined in Section 2 by linking the impact of import competition on U.S. manufacturing employment with industry ladder lengths. The industry's quality ladder, $IndLadder_m$, is defined to be the weighted average of the *baseline* product ladders within the four-digit SIC industry:

$$IndLadder_m = \sum_{k=1}^{K_m} w_{0k} Ladder_{k0}, \tag{27}$$

where K_m denotes the number of ten-digit HS products in SIC industry m, $Ladder_{k0}$ is the product's baseline ladder (defined in (25) and w_{0k} is its baseline weight of product k within the four-digit SIC industry m. Note that the industry ladder is a time invariant measure.

The industry ladders are matched to the NBER manufacturing database from 1989-96 (Bartelsman et al., 1996). Summary statistics for the quality ladders are shown in the final column of Table 2. The ladders broadly conform to intuition: chemicals, industrial machinery, transportation and instruments are characterized by relatively long quality ladders while apparel, leather and furniture are short-ladder industries. Notice also that there are some counterintuitive findings; lumber is associated with a long ladder while electronics is relatively short. Table 7 decomposes the ladder measure according to observable industry characteristics: skill intensity, capital intensity and total factor productivity.[18] Higher capital-labor ratios and total factor productivity are correlated with a longer quality ladder, but the regression R-squared is quite low suggesting that much of the variation in the quality ladder cannot be explained by these variables.

Following Bernard et al. (2006), I link employment outcomes with two measures of import competition: imports originating from countries with less than 5 percent of U.S. per capita GDP ($LWPEN$) and the rest of the world ($OTHPEN$). Total import penetration is defined as $I_{mt}/(I_{mt} + Q_{mt} - X_{mt})$, where I_{mt} is the value of imports in four-digit SIC industry m at time t, Q_{mt} is the industry's domestic production and X_{mt} represents U.S. exports. $LWPEN$ is the product of total import penetration and the value share of imports originating from low-wage countries

$$LWPEN_{mt} = \frac{I_{mt}^{\text{low}}}{I_{mt} + Q_{mt} - X_{mt}}.$$

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[18] Skill intensity is measured as the ratio of non-production to production workers. Capital intensity is the ratio of capital stock to total employment. Total factor productivity is obtained from a five-factor model (Bartelsman et al., 1996).

$OTHPEN$ is defined analogously as

$$OTHPEN_{mt} = \frac{I_{mt} - I_{mt}^{\text{low}}}{I_{mt} + Q_{mt} - X_{mt}}.$$

The following specification regresses industry employment outcomes on the industry quality ladder and the import penetration measures

$$\ln Emp_{mt} = \alpha_m + \alpha_t + \beta_1 OTHPEN_{mt} + \beta_2 LWPEN_{mt} + \beta_3 \left(LWPEN_{mt} \times \ln IndLadder_m\right) + \nu_{mt}. \quad (28)$$

Note that the specification includes both industry (α_m) and year (α_t) fixed effects. The regression should find $\beta_1, \beta_2 < 0$; higher import penetration is negatively correlated with industry employment. The coefficient of interest is the interaction between $LWPEN$ and $IndLadder$, which measures the differential impact of low-wage penetration on employment across industries of varying ladder lengths. The vulnerability hypothesis predicts $\beta_3 > 0$; long-ladder industries with high exposure to low-wage countries suffer smaller employment declines.

Column one of Table 8 reports the baseline results. The coefficients are statistically significant and have the predicted signs. Import penetration negatively affects employment, and the impact of low-wage penetration is stronger. The interaction coefficient is positive and precisely estimated, supporting the model's prediction that vulnerability to low-wage penetration declines in industries with longer quality ladders.

The point estimates are also economically significant. If low-wage penetration increases by ten percentage points, employment in an average ladder industry declines by 7.6 percent. In contrast, low-wage penetration is associated with only a 2.2 percent employment loss in a long-ladder industry (one standard deviation above the mean). For a specific example, if $LWPEN$ were to increase by ten percentage points in the household audio and video equipment industry (SIC 365), employment would fall 10.7 percent compared to a 15 percent decline in footwear (SIC 314), an industry with one-third the ladder length.

The point estimates are consistent with a point emphasized by Leamer (2000) that even low import volumes can have a significant impact on U.S. firms if international trade equalizes product prices, and this is particularly salient for short-ladder products. Indeed, the extent to which domestic goods overlap with foreign goods, and the source of the foreign imports, is precisely what determines which industries are vulnerable to competition in the framework here. The magnitude of the employment effects are also consistent with Bernard et al. (2006), whose conservative estimates indicate that a ten percentage point increase in $LWPEN$ raises the probability of U.S. plant death by 17 percent.

In column two, I include a ladder-$OTHPEN$ interaction to determine if the effects of imports originating from more-advanced countries are also dampened in long ladders. This does not appear to be the case; the ladder-$OTHPEN$ interaction is not significant. But the ladder-$LWPEN$ interaction remains statistically significant.

Given that the quality ladder is related to capital intensity and TFP (see Table 7), one concern is that the quality ladder might simply proxy these observable factors. If this were true, then the results in columns one and two simply confirm the findings of previous studies that have argued that more productive and capital-intensive industries are less susceptible to import competition. To address this concern, I include interactions of an industry's TFP, skill- and capital-intensities with $LWPEN$ in columns three and four.[19] More capital-intensive industries are less vulnerable to low-wage imports, although the effect does not vary with skill or TFP. The coefficient on the quality ladder interaction remains statistically significant implying that the quality dimension is a relevant metric in assessing an industry's vulnerability beyond observable industry characteristics. Using the point estimates in column three, *ceteris paribus*, a ten percentage point increase in $LWPEN$ results in a 5 percent larger employment decline in a short-ladder industry (one standard deviation below the mean). Similarly, a low capital-intensive industry (one standard deviation below the mean) suffers a 8 percent larger decline relative to an industry that uses the average capital intensity.

While using the baseline ladder and factor intensities mitigate endogeneity concerns, import penetration is likely to be endogenous. For instance, international trade may be filling a void created by a decline in domestic industries caused by other factors, such as structural changes in the economy. The simultaneity would bias the import penetration coefficients downward in (28). I therefore instrument the penetration measures with industry-year weighted averages of exchange rates, tariffs and freight rates for low-wage countries and the rest of the world.[20]

Table 9 presents the IV results. The first column shows the baseline specification. Instrumenting actually causes the coefficient on $LWPEN$ to increase in magnitude, which suggests measurement error in the variable.[21] The quality ladder now becomes even more important. For example, a ten percentage point increase in $LWPEN$ leads to a 14 percent employment decline in a short-ladder industry (one standard deviation below the mean) compared to a 6 percent employment *gain* in the average industry.

These magnitudes are large but again are plausible if trade leads to a convergence in product prices. For example, the raw data reveal that low-wage import penetration into the footwear industry (SIC 314) increased by 35 percentage points and employment simultaneously fell by almost 50 percent between 1989 and 1996. Import competition therefore can have large impacts on domestic firms in short-ladder industries, particularly those at the competitive fringe.

Column two includes the interaction of the ladder with $OTHPEN$, and the main results do not change. Columns three and four add the interactions of industry characteristics but the ladder-$LWPEN$ interaction remains robust to these additional controls. These two columns indicate that even industries with similar observable characteristics may still exhibit heterogenous impacts from international trade because of inherent differences in vertical specialization.

Results also confirm a differential impact of foreign competition on industry output across the quality ladders (not reported). This finding confirms that highly exposed short-ladder industries are indeed

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[19] Since these variables are endogenous, the regression fixes the three variables at their 1989 values. This also means that the levels are not identified because of the industry fixed effects.

[20] The weights are the country's share of industry value in 1989.

[21] Bernard et al. (2006) also find that instrumenting import penetration causes the magnitude of the coefficients to increase.

contracting rather than substituting employment with other input factors.

5.1.1 Robustness Checks

I perform a number of robustness exercises to check the sensitivity of the results. Table 10 re-runs the IV specification with two-digit SIC interacted with year fixed effects to control for time-varying unobservables. For example, these control for technological changes over the sample which might be correlated with the initial quality ladder. As shown in the table, the magnitude of the coefficients decline, not surprisingly, but the interaction remains statistically significant.

Constructing the quality ladders hinges on the disaggregate detail of U.S. import data. One concern might be that the ladder lengths simply reflect aggregation differences if products in some industries are defined more coarsely than others. Another worry could be that the product-level ladders just proxy the number of countries exporting that product code. To ensure that the results are not sensitive to these concerns, I re-run the employment regressions using alternative definitions for the ladder in Table 11. The first row defines the product-level ladder as the number of countries (i.e., varieties) within the product and then aggregates to the industry level according to (27). The second measure counts the number of products within the four-digit industry code and uses that as the industry-level ladder. This measure proxies potential differences in the coarseness of product definitions across industries. The coefficients on the ladder-$LWPEN$ interactions are displayed in the first two rows. The OLS and IV coefficients on both measures are extremely imprecisely measured. This provides evidence that the quality ladder is not identified off of the coarseness of data, but rather is based on meaningful prices and market share information.

Section 4 provides evidence that prices may not be equivalent to quality in some markets, particularly those with a high degree of horizontal product differentiation. But what if the quality ladder is measured using just prices? Row three replicates the employment regressions with a quality ladder constructed by aggregating the standard deviation of prices within products. The table reports that both the OLS and IV coefficients are not statistically significant. Thus, by measuring an quality differentiation through prices alone, one would not find a differential impact of import penetration across industries. This is because quality based on prices alone ignores horizontal differentiation. For instance, the apparel quality ladder, using the method above, is below average but the price-based ladder is above the average industry. Thus, testing the vulnerability hypothesis using a price-based ladder is not consistent with the apparel industry which has experienced large declines in employment and high import penetration.

Row four of Table 11 takes the opposite approach and measures the ladder using just market shares. While the OLS coefficient is statistically significant, the IV coefficient is very imprecisely estimated. This ensures that the quality ladder is not simply a measure of just market shares, but rather incorporates both prices and market share information.

Row five defines quality exclusive of the residual from the estimating equation in (22), $\xi_{jt} = \xi_{1j} + \xi_{2t}$, and then constructs the industry ladder using (25) and (27). This addresses concerns that the residual term

(ξ_{3jt}) may be capturing factors other than quality since it is a residual of the estimating equation. However, the table shows that the results are robust to defining quality without this term.

Variety quality defined in (23) is measured in utils relative to that particular sector's outside good. Row six indicates that the results are not sensitive to converting the qualities into dollar-denominated measures by dividing by the sector's price coefficient.[22]

Row seven of Table 11 constructs the quality ladder for quality estimates obtained from specification (22) where population is replaced by GDP as the proxy for hidden varieties. While the OLS interaction coefficient is insignificant, the IV result is statistically significant at conventional levels.

Rows eight through ten measure the product-ladder quality ladder as the full range, inter-quartile range and the standard deviation of qualities within products, respectively, and re-run (28). All coefficients in both the OLS and IV regressions are positive and statistically significant, so the quality ladder measure is not sensitive to alternative measures of within-product quality dispersion.

Finally, while virtually all countries in the sample export apparel and leather products, fewer developing countries source more factor intensive industries like instruments and transportation. This creates a selection bias which arguably biases the quality ladder downwards.[23] Accounting for the selection bias (e.g., see Helpman et al. (2006)) would increase the quality ladders in more factor-intensive industries, so the selection bias works against the results here and is therefore not a major concern.

6 Conclusion

Product specialization can weaken the convergence in goods and factor prices predicted to result from international trade. Departing from traditional use of prices as sufficient statistics for quality, I provide estimates of product quality using both price and market share information. Like quality measures inferred from just prices, these alternative measures reveal that factor-abundant countries export higher-quality varieties within products. However, unlike prices, the scope for quality differentiation varies substantially across products.

This variation in quality ladder lengths has important implications for future trade patterns. If developed countries are unable to exploit comparative-advantage factors to manufacture vertically superior goods, employment and output in products will shift towards lower cost countries. I find support for this theory by matching the quality ladders to U.S. industry employment outcomes resulting from international trade. Consistent with the model, the impact of low-wage import penetration on employment inversely varies with the ladder length.

The analysis treats the quality ladder as time invariant, which is a reasonable assumption in the

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[22] The price coefficient α is an exchange rate between dollars and utils. ξ/α is therefore measured in dollars relative to the good.

[23] The virtual price in a discrete choice model is infinite and this can be interpreted as the import possessing infinitely negative quality.

short and medium run. Given the technological frontier, firms sort along the quality ladder. In the long run, the ladder is, of course, endogenous as firms respond to competition through investment and innovation to lengthen the quality ladder. This paper ignores the product cycling through which developed countries innovate new products that eventually migrate to the South (Vernon, 1966). Although research and development (R&D) is likely to mitigate the impact of low-wage countries, the R&D expenditures vary across industries.[24] This suggests that lengthening the quality ladder may not be feasible for some industries, and these industries are likely to continue losing output and employment due to trade. Addressing the dynamics of import competition and innovation activity is an important extension to this research that will continue to merge developments in the international trade and industrial organization literatures.

In addition to the effects on firm survival, quality upgrading in response to import competition may have implications for rising income inequality within developed and developing countries. Climbing the existing quality ladder, or investing in innovative resources to lengthen the quality ladder, presumably raises the demand for skilled labor. If so, this would suggest an additional channel through which globalization increases income inequality in addition to other factors, such as the offshoring of manufacturing activity to developing countries (Feenstra and Hanson, 1999). Understanding the firm-level mechanisms of quality specialization resulting from more intense import competition, and its subsequent impact on workers, is left for future research.

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[24] For example, in 1995 R&D expenditure as a fraction of domestic net sales for fabricated metals was 1% compared to 6% for transportation equipment (see www.nsf.gov).

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A Appendix

Vulnerable Firms: *The fraction of vulnerable firms is decreasing in the ladder length:* $\frac{\partial\Omega(\gamma;\lambda_{\min},\lambda_{\max})}{\partial\gamma} < 0$. Suppress the superscript N to reduce clutter. The fraction of vulnerable Northern firms is

$$\Omega(\gamma;\lambda_{\min},\lambda_{\max}) = \frac{\xi(\tilde{\lambda}) - \xi(\lambda_{\min})}{\xi(\lambda_{\max}) - \xi(\lambda_{\min})}. \tag{A-1}$$

where $\lambda_{\min} < \tilde{\lambda} < \lambda_{\max}$. The expression can be rewritten as

$$\begin{aligned} \Omega(\gamma;\lambda_{\min},\lambda_{\max}) &= \frac{\tilde{\lambda}^{\gamma} - \lambda_{\min}^{\gamma}}{\lambda_{\max}^{\gamma} - \lambda_{\min}^{\gamma}} && \text{(A-2)} \\ &= \frac{\lambda_1^{\gamma} - 1}{\lambda_2^{\gamma} - 1}, && \text{(A-3)} \end{aligned}$$

where $\lambda_1 = \frac{\tilde{\lambda}}{\lambda_{\min}}, \lambda_2 = \frac{\lambda_{\max}}{\lambda_{\min}}$ and $\lambda_1 < \lambda_2$. The derivative of $\Omega(\gamma)$ with respect to γ is

$$\frac{\partial\Omega}{\partial\gamma} = \frac{(\ln\lambda_2 - 1)(\ln\lambda_1 * \lambda_1^{\gamma}) - (\ln\lambda_1 - 1)(\ln\lambda_2 * \lambda_2^{\gamma})}{(\lambda_2^{\gamma} - 1)^2} \tag{A-4}$$

It remains to be shown that the numerator in (A-4) is less than zero. Denote the numerator as $N(\lambda_1,\lambda_2;\gamma)$. Note that for $\lambda_1 = \lambda_2$, the numerator is equal to zero. To show that this expression is less than zero, I exploit the fact that $\lambda_2 > \lambda_1 > 1$. The derivative of $N(\lambda_1,\lambda_2;\gamma)$ with respect to λ_2 and evaluated at $\lambda_2 = \lambda_1$ is

$$\begin{aligned} \frac{\partial N}{\partial\lambda_2}\,|_{\lambda_2=\lambda_1} &= \lambda_2^{\gamma-1}\left\{1 + \gamma\ln\lambda_2 + \lambda_1^{\gamma}\left[\gamma\left(\ln\lambda_1 - \ln\lambda_2\right) - 1\right]\right\}|_{\lambda_2=\lambda_1} && \text{(A-5)} \\ &= 1 + \gamma\ln\lambda_1 - \lambda_1^{\gamma} < 0 && \text{(A-6)} \end{aligned}$$

Since $N(\lambda_1,\lambda_2;\gamma) = 0$ and $\frac{\partial N}{\partial\lambda_2}\,|_{\lambda_2=\lambda_1} < 0$, the numerator in (A-4) is less than zero so it is decreasing away from 0. Therefore, $\frac{\partial\Omega}{\partial\gamma} < 0$. □

B Tables

Table 1: Low-wage Countries

Afghanistan	Chad	Haiti	Niger
Albania	China	India	Pakistan
Angola	Congo	Kenya	Rwanda
Armenia	Equitorial Guinea	Lao PDR	Samoa
Azerbaijan	Ethiopia	Madagascar	Sierra Leone
Bangladesh	Gambia	Malawi	Sri Lanka
Benin	Georgia	Mali	Sudan
Burkina Faso	Ghana	Mauritania	Togo
Burundi	Guinea	Moldova	Uganda
Cambodia	Guinea-Bissau	Mozambique	Vietnam
Central African Republic	Guyana	Nepal	Yemen

Notes: The table provides the list of low-wage countries used in the paper. Low-wage countries are defined as countries with a less than 5 percent of US per capita GDP.

Source: Bernard et al. (2006).

Table 2: Summary Statistics

Two-Digit SIC Industry	Sectors (SITC-5)	Products (HS codes)	Countries	Varieties	Varieties/ Product	Share	Average GDP	Ladder Length
20 Food	8	37	69	588	15.9	0.1%	16,828	2.17
22 Textile	85	1,639	128	23,658	14.4	1.4%	13,175	2.16
23 Apparel	68	2,539	139	52,060	20.5	9.1%	6,996	1.80
24 Lumber	20	262	110	3,931	15.0	0.7%	12,768	2.81
25 Furniture	5	72	104	2,496	34.7	0.7%	11,673	1.61
26 Paper	38	216	104	4,284	19.8	2.4%	19,737	2.04
27 Printing	16	55	114	2,237	40.7	0.5%	17,404	1.41
28 Chemicals	228	2,548	133	33,918	13.3	6.8%	20,041	2.61
29 Petroleum	7	21	81	448	21.3	0.2%	10,758	3.06
30 Rubber & Plastic	45	514	112	9,234	18.0	2.4%	13,990	2.36
31 Leather	17	403	122	9,295	23.1	2.8%	5,931	1.88
32 Stone & Ceramic	57	357	122	8,698	24.4	1.4%	14,976	2.37
33 Primary Metal	96	1,369	112	21,575	15.8	3.9%	16,697	2.18
34 Fabricated Metal	78	599	126	15,372	25.7	2.8%	17,224	1.83
35 Industrial Machinery	167	1,638	130	31,921	19.5	14.7%	20,334	2.37
36 Electronic	100	1,334	135	29,627	22.2	18.3%	15,134	1.85
37 Transportation	39	363	111	5,868	16.2	25.2%	22,960	2.17
38 Instruments	60	715	111	10,785	15.1	3.0%	21,624	2.60
39 Miscellaneous	75	374	132	8,032	21.5	3.6%	10,690	2.26

Notes: The table provides summary statistics for the two-digit SIC (1987 revision) industries. Column seven reports the weighted average of exporter per capita GDP. Column eight reports the (log) weighted average industry ladder (see equation (27)).

Source: Feenstra et al. (2002) and author's calculations. Dollar-denominated GDP per capita, population and real exchange rate data are taken from World Bank's World Development Indicators.

Table 3: Quality Estimation Results

Remark	Statistic
Obs. with price coefficient significant at 10 percent	71%
OLS price coefficient	-0.05
IV price coefficient	-0.11
*Own price elasticity	-1.51
T-statistic of quality estimates	4.4
Within-product correlation	0.47
Overidentifying restrictions p-value	0.14
1st stage F-stat, price	2.00
1st stage F-stat, nest share	2.68
Within R-squared	0.65
Total Estimations	1,047
Total Number of Products	15,055
Total Observations	1,232,188

Notes: Table reports estimation statistics of running equation (22) separately for each of the 1,047 manufacturing sectors. All statistics are mean values. * denotes the mean elasticity conditional on a negative price coefficient and $\sigma \in (0, 1]$.

Table 4: Quality and Factor Endowments

	Quality_{ckt}		
	(1)	(2)	(3)
Log (PCGDP_{ct})	0.28 ***		
	(0.06)		
Log (KL_{ct})		0.27 ***	
		(0.06)	
Log (Education_{ct})			0.12
			(0.08)
Product x Year FEs	yes	yes	yes
R-squared	0.18	0.18	0.36
Observations	1,231,677	1,162,244	511,438

Notes: Table regresses the quality estimates on (log) per capita GDP, (log) capital-labor ratios and percentage of workforce with tertiary education. Regressions include product-year fixed effects. Robust standard errors are clustered by exporting country. Significance levels: *** .01 ** .05 * .1.

Source: The World Bank's World Development Indicators.

Table 5: Relationship between Quality and Price

	Quality_{ckt}
Price_{ckt}	-0.46 ***
	(0.19)
Price_{ckt} x Log (Ladder_{0k})	0.17
	(0.12)
Product x Year FEs	yes
R-squared	0.18
Observations	1,232,188

Notes: Table regresses variety quality on (log) price and its interaction with the product's baseline quality ladder. Robust standard errors are clustered by exporting country. Significance levels: * .1 ** .05 *** .01.

Table 6: Ladders and Elasticity of Substitutions

	Log (BW Sigma_k)
Log (Ladder_{0k})	-0.03 ***
	(0.01)
Constant	1.50
	(0.02)
R-squared	0.00
Observations	11,311

Notes: Table regresses the (log) quality ladder (defined in equation (25)) on product-level (log) elasticities of substitutions provided by Broda and Weinstein (2006). Significance levels: * .1 ** .05 *** .01.

Table 7: Quality Ladder Decomposition

	Log (Industry Ladder_m)
Log (K/L_m)	0.16 ***
	(0.06)
Log (Skill_m)	0.04
	(0.07)
Log (TFP_m)	0.96
	(0.65)
Constant	1.58 ***
	(0.25)
F-test for joint significance	4.51
R-squared	0.04
Observations	325

Notes: Table regresses the industry quality ladder (defined in 27) on four-digit SIC factor intensities: capital intensity, skill intensity and total factor productivity. Capital intensity is the ratio of capital stock to total employment. Skill intensity is measured as the ratio of non-production to production workers. Total factor productivity is obtained from a five-factor model (see Bartelsman et al. (1996)). Factor inputs measured at 1989 values.

Source: Factor intensities obtained from Bartelsman et al. (1996)

Table 8: Employment Regressions: OLS

	OLS - Log (Employment$_{m}$)			
	(1)	(2)	(3)	(4)
OTHPEN$_{mt}$	-0.46 ***	-0.56	-0.42 ***	-0.37
	(0.10)	(0.35)	(0.10)	(0.31)
Log (IndLadder$_{m}$) x OTHPEN$_{mt}$		0.04		-0.02
		(0.14)		(0.12)
LWPEN$_{mt}$	-2.20 ***	-2.22 ***	-5.60 **	-5.64 **
	(0.46)	(0.47)	(2.36)	(2.38)
Log (IndLadder$_{m}$) x LWPEN$_{mt}$	0.66 **	0.67 **	0.65 *	0.64 *
	(0.27)	(0.27)	(0.38)	(0.38)
Log (Skill$_{m}$) x LWPEN$_{mt}$			-0.39	-0.39
			(0.57)	(0.58)
Log (K/L$_{m}$) x LWPEN$_{mt}$			0.94 *	0.95 *
			(0.48)	(0.49)
Log (TFP$_{m}$) x LWPEN$_{mt}$			-1.25	-1.26
			(2.27)	(2.28)
Industry, Year FEs	yes	yes	yes	yes
R-squared	0.99	0.99	0.99	0.99
Observations	2,585	2,585	2,585	2,585

Notes: The dependent variable for each regression is the four-digit SIC industry (log) employment. The first column regresses employment on import penetration from the rest of the world ($OTHPEN$), low-wage import penetration ($LWPEN$) and the interaction of $LWPEN$ with the industry quality ladder. Column two includes the $OTHPEN$-ladder interaction. Columns three and four include interactions of $LWPEN$ with the industry's baseline factor intensities. Robust standard errors are clustered at the three-digit SIC level. Significance levels: * .1 ** .05 *** .01. Source: Employment and factor intensities obtained from Bartelsman et al. (1996) for 1989-1996. Import penetration variables are provided by Bernard et al. (2006).

Table 9: Employment Regressions: IV

	IV - Log (Employment$_m$)			
	(1)	(2)	(3)	(4)
OTHPEN$_{mt}$	-0.30	-1.04	-0.14	-1.06
	(0.53)	(1.40)	(0.46)	(0.85)
Log (IndLadder$_m$) x OTHPEN$_{mt}$		0.42		0.51
		(0.82)		(0.35)
LWPEN$_{mt}$	-4.91 ***	-4.49 ***	-5.77	-5.52
	(1.14)	(1.45)	(4.26)	(4.32)
Log (IndLadder$_m$) x LWPEN$_{mt}$	2.56 ***	2.40 ***	1.44 *	1.43 *
	(0.82)	(0.93)	(0.79)	(0.76)
Log (Skill$_m$) x LWPEN$_{mt}$			0.52	0.23
			(1.35)	(1.29)
Log (K/L$_m$) x LWPEN$_{mt}$			1.03	0.85
			(0.90)	(0.91)
Log (TFP$_m$) x LWPEN$_{mt}$			-0.63	-0.31
			(5.00)	(4.79)
Overidentification p-value	0.09	0.07	0.37	0.26
Cragg-Donald F-statistic	3.1	2.1	3.4	2.8
Industry, Year FEs	yes	yes	yes	yes
Obs.	2,585	2,585	2,585	2,585

Notes: The dependent variable for each regression is the four-digit SIC industry (log) employment. The first column regresses employment on import penetration from the rest of the world ($OTHPEN$), low-wage import penetration ($LWPEN$) and the interaction of $LWPEN$ with the industry quality ladder. Column two includes the $OTHPEN$-ladder interaction. Columns three and four include interactions of $LWPEN$ with the industry's baseline factor intensities. The instruments are weighted average tariff rates, exchange rates and freight rates for low-wage countries and the rest of the world. Robust standard errors are clustered at the three-digit SIC level. Significance levels: * .1 ** .05 *** .01.

Source: Employment and factor intensities obtained from Bartelsman et al. (1996) for 1989-1996. Import penetration variables are provided by Bernard et al. (2006).

Table 10: Employment Regressions, SIC-Year Fixed Effects: IV

	IV - Log (Employment_m)	
	(1)	(2)
OTHPEN_{mt}	0.07	-0.08
	(1.00)	(1.55)
Log (IndLadder_m) x OTHPEN_{mt}		0.09
		(0.62)
LWPEN_{mt}	-2.42	-2.35
	(1.90)	(1.98)
Log (IndLadder_m) x LWPEN_{mt}	1.67 *	1.64 *
	(0.88)	(0.90)
Overidentification p-value	0.30	0.24
Cragg-Donald F-statistic	1.3	1.1
Two-Digit SIC x Year FEs	yes	yes
Obs.	2,585	2,585

Notes: The dependent variable for each regression is the four-digit SIC industry (log) employment. Each regression includes a full set of two-digit SIC interacted with year fixed effects. The first column regresses employment on import penetration from the rest of the world ($OTHPEN$), low-wage import penetration ($LWPEN$) and the interaction of $LWPEN$ with the industry quality ladder. Column two includes the $OTHPEN$-ladder interaction. Columns three and four include interactions of $LWPEN$ with the industry's baseline factor intensities. The instruments are weighted average tariff rates, exchange rates and freight rates for low-wage countries and the rest of the world. Robust standard errors are clustered at the three-digit SIC level. Significance levels: * .1 ** .05 *** .01.

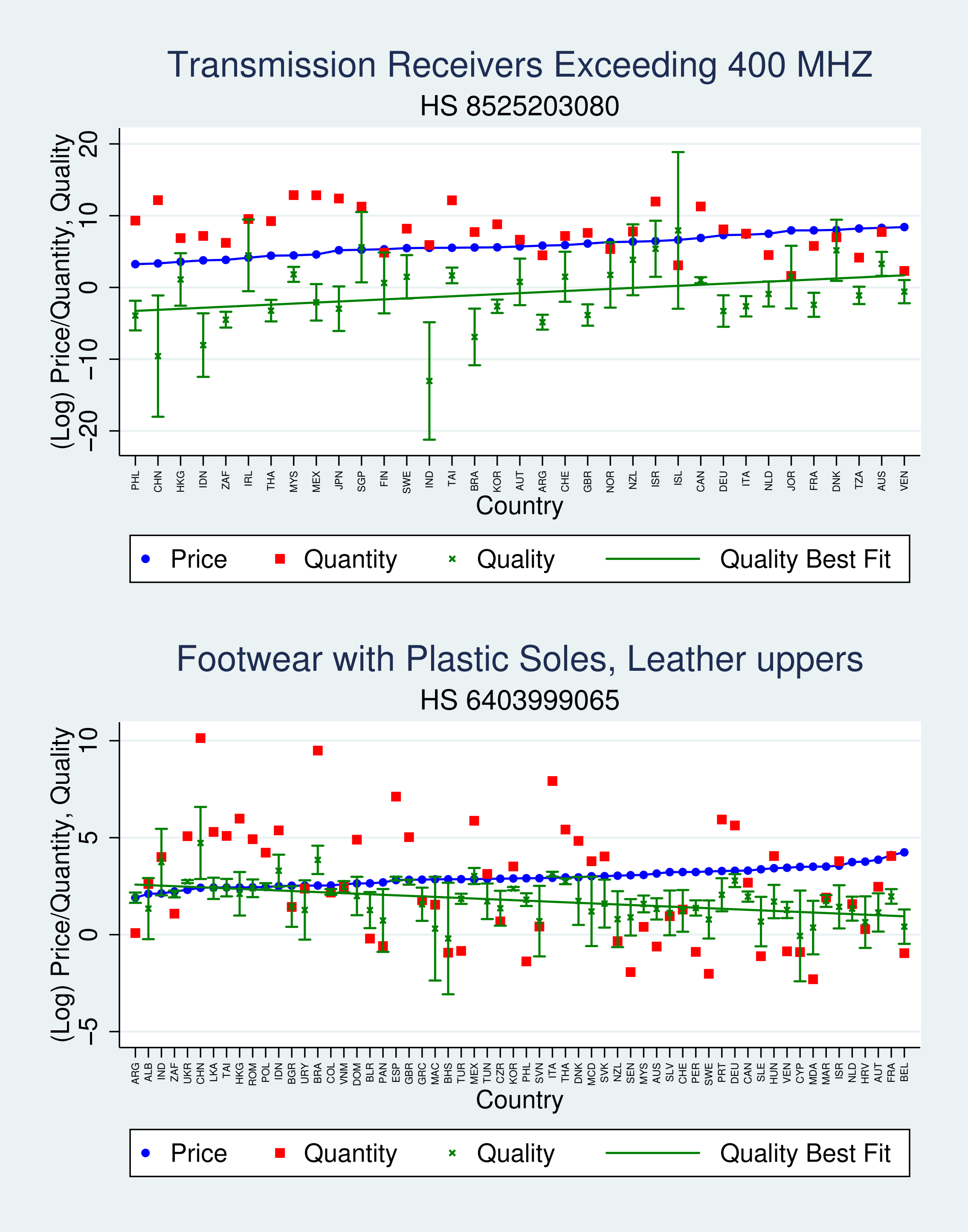
Source: Employment and factor intensities obtained from Bartelsman et al. (1996) for 1989-1996. Import penetration variables are provided by Bernard et al. (2006).

Table 11: Employment Regressions, Robustness Checks

Industry Quality Ladder	Regression Method OLS	 IV
Product Count	0.000	-0.004
	(0.001)	(0.004)
Variety Count	-0.02	0.02
	(0.02)	(0.05)
Standard Deviation Prices	0.00	0.01
	(0.01)	(0.02)
Standard Deviation Mkt Shares	10.3 *	21.0
	(5.4)	(21.6)
Quality Ladder w/out Residual	0.72 ***	2.31 ***
	(0.27)	(0.79)
$-Denominated Quality Ladder	0.23 ***	1.06 ***
	(0.09)	(0.42)
GDP-Quality Ladder	0.34	3.71 **
	(0.51)	(1.47)
Range	0.55 **	1.80 ***
	(0.25)	(0.54)
Inter-quartile Range	0.65 **	3.14 ***
	(0.30)	(1.10)
Standard Deviation	0.76 **	3.19 ***
	(0.33)	(1.04)

Notes: Table re-runs the employment regression in (28 and reports the industry ladder interaction with $LWPEN$ coefficient for various measures of the quality ladder. The first row defines the product-level ladder as the number of countries (i.e., varieties) within the product and then aggregates to the industry according to (27). The second measure counts the number of products within the four-digit industry code. Rows three and four construct the ladder from the within product standard deviation of prices and market shares, respectively (see text). Row five defines the quality ladder exclusive of the residual, $\xi_{jt} = \xi_{1j} + \xi_{2t}$, and then constructs the ladder using (25) and (27). The sixth row converts quality to a dollar-denominated measure by dividing ξ_{jt} by its estimated price coefficient. Row seven re-runs (22) but uses GDP instead of population to control for hidden varieties. The remaining rows use the full range, inter-quartile range and standard deviation of qualities within products. Robust standard errors are clustered at the three-digit SIC level for each regression. Significance levels: * .1 ** .05 *** .01.

Figure 1: **Prices, Market Shares and Quality**



The graphs show the price, quantity and estimated quality (and 95 percent confidence interval) for countries for HS 8525203080 (“Transmission Receivers Exceeding 400 MHZ”) and HS 6403999065 (“Footwear with Plastic Soles, Leather Uppers”) in 2001. Countries are ordered by unit value.