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# IMPORT COMPETITION AND QUALITY UPGRADING

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**ABSTRACT**

It is important to understand the factors that influence a country's transition from the production of low-quality to high-quality products since the production of high-quality goods is often viewed as a pre-condition for export success and, ultimately, for economic development. In this paper, we provide the first evidence that countries' import tariffs affect the rate at which they upgrade the quality of their products. We analyze the effect of import competition on quality upgrading using highly disaggregated export data to the U.S. from fifty-six countries in 10,000 products using a novel approach to measure quality. As predicted by recent distance to the frontier models, we find that lower tariffs are associated with quality upgrading for products close to the world quality frontier, whereas lower tariffs discourage quality upgrading for products distant from the frontier.

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## 1. Introduction

A fundamental question facing governments is how policy can promote economic growth. It is generally accepted that innovation is a key channel to fostering growth, however, it is less clear how to create the right incentives to encourage innovation. Empirical studies have found that innovation increases with competition (see Geroski 1995, Nickell 1996 and Blundell, Griffith, and Van Reenen 1999), yet these findings were at odds with theories from industrial organization that suggest that competition could actually discourage innovation. According to theory, pro-competitive policies may cause firms to under-invest if they are able to capture only a fraction of the benefits of innovation while incurring the full investment costs. This appropriation argument dates back to a negative relationship between competition and innovation suggested by Schumpeter (1943). Policies that protect innovation rents could therefore encourage incumbent firms to increase investment. More recent theories, though, suggest that the relationship between competition and growth need not be monotonic. Hausmann and Rodrik (2003), Aghion and Howitt (2005), and Acemoglu, Aghion, and Zilibotti (2006) show that policies that initially facilitate growth could in fact inhibit growth at later stages of economic development. Aghion, Blundell, Griffith, Howitt, and Prantil (henceforth, ABGHP, 2009) develops an industry model in which a firm's response of innovation to competition policy or increased entry threat depends on how far it is from the world technology frontier.

Subsequent empirical studies have found support for this nonmonotonic relationship between competition and innovation (see, for example, Aghion, Bloom, Blundell, Griffith, and Howitt, henceforth, ABBGH 2005, ABGHP 2009, and Vandenbussche, Aghion, and Meghir 2004). However, all these studies have been confined to either single country analysis or aggregate cross-country studies. Empirically investigating these theories with aggregate country data is difficult because competition policy can take many forms and is likely to be correlated with other country characteristics, such as relative factor endowments. While industry studies within countries circumvent problems associated with cross-country analysis, the findings are difficult to generalize across countries that span a wide income distribution. The lack of internationally comparable measures of growth at a micro level has prevented previous studies from adopting a hybrid approach that takes account of cross country and within country characteristics.

In this paper, we analyze the nonmonotonic relationship between competition policy and innovation formalized in these theories using highly disaggregate data. Our sample comprises 10,000 products across fifty-six countries. We are able to circumvent some of the problems that have plagued previous studies by using a novel approach that measures product quality, which serves as our proxy for innovation. We infer a product's quality based on the approach by Khandelwal (forthcoming). In our framework, we estimate the quality of each product exported to the U.S. by using both price and quantity information, where, conditional on price, higher quality is assigned to products with higher market shares. The framework provides quality measures that are internationally comparable across countries and over time. We can therefore exploit very detailed information on countries' quality performance to address potential endogeneity concerns in cross-country studies. To measure competition in each country, we use detailed industry-level tariffs on its imports, which, again, are comparable across industries and countries. Thus, countries with high tariff barriers are those where competitive forces are weaker. Moreover, since tariffs are a policy instrument, they may be less subject to endogeneity concerns compared to other measures of competition, such as the Herfindahl index, a measure that summarizes the concentration of firms, used in many studies. The high level of disaggregation of both the tariff and the quality measures is crucial for isolating the effects of competition on innovation that are distinct from other channels, such as changes in a countries' relative endowments, product-specific productivity shocks, changes in consumer demands, or changes in countries' institutional structures.

To allow for the possibility of a nonmonotonic relationship between competition and quality upgrading, we draw on models by Aghion and Howitt (2005), ABBGH (2005) and ABGHP (2009) to guide our empirical analysis. The key idea behind these models is that the effect of competition on innovation activity depends on firms' proximity to the world technology frontier. These models highlight two forces. First, for firms far from the technology frontier, an increase in competition reduces incentives to innovate because ex post rents from innovation are eroded by new entrants; this idea is similar to the Schumpeterian appropriability effect of competition. Following ABGHP (2009), we refer to this as the discouragement effect. As firms approach the frontier, however, competition can increase incentives to innovate because it reduces firms' pre-innovation rents by more than it reduces its post-innovation rents. We refer to this force as the escape competition effect.[1]

We examine predictions of these models by allowing the effect of competition on quality upgrading, our measure of innovation, to depend on a product's proximity to the world frontier, defined as the highest-quality product exported to the U.S. in a given year. Our empirical results provide support for the nonmonotonic relationship between competition and quality upgrading predicted by the theory. Products that face a relatively high degree of competition in their home market (i.e., low import tariffs) exhibit relatively slower quality upgrading when they are distant from the world frontier. In contrast, for products close to the world frontier, a competitive home market is associated with faster quality upgrading.

Our results are consistent with the nonmonotonic relationship between competition and innovation found in the industrial organization literature. Moreover, our disaggregated

[1] ABGHP (2009) refer to this as the "escape-entry" effect which dominates when incumbent firms are in a neck-and-neck industry. In Acemgolu, Aghion and Zilibotti (2006), it is referred to as a "selection effect"; in their model, pro-competitive policies stimulate innovation when firms are close to the technology frontier due to a selection effect of more talented entrepreneurs.

approach enables us to study the effects of competition on quality upgrading across a wide income distribution. We show that the theory has support in both high and low income per capita countries provided there is a minimum level of institutional quality.[2] This result is intuitive given that, in countries with multi-dimensional sources of market frictions, changes in import tariffs are likely to have limited effects on the competitive pressures faced by domestic firms. Thus, the results suggest that a minimum institutional "quality" may be needed for the mechanisms of the model to operate.

Within the trade literature, there are a number of studies that have analyzed the relationship between tariffs and productivity. For instance, firm-level studies by Pavcnik (2002), Amiti and Konings (2007) and Topalova (2007), and cross-country studies by Romalis (2006) have found a positive relationship between trade liberalizations and productivity. Other studies, such as Bustos (2008), find a relationship between trade liberalization and technology adoption. However, our study is the first to allow for the potential nonmonotonic relationship depending on proximity to the frontier using tariffs as the competition measure. Our results suggests that understanding where industries are located along the world frontier is important for understanding its future performance following a trade liberalization.

The support we find for a nonmonotonic relationship between import tariffs and quality growth can also help shed light on why the trade and income growth literature has produced mixed results. In a survey of this literature, Rodriguez and Rodrik (2002) discuss how the results are often sensitive to identification strategies and controls, and explain the difficulty of disentangling the mechanisms through which trade affects income growth using cross-country regressions. In this paper, we show that omitting country-year fixed effects, which of course cannot be included in aggregate cross-country regressions, can change the sign on the tariff coefficient; and how allowing for a more flexible nonmonotonic relationship can also alter the conclusions. Although we focus on the link between tariff liberalization and one particular channel of growth - quality growth - to the extent that quality growth has implications for income (see, for instance, Hausmann, Hwang, and Rodrik 2006), our results offer a lens into the mechanism for the relationship between trade and income growth.

The remainder of the paper is as follows. In Section 2, we provide a sketch of the model in ABGHP (2009) which serves as the basis for our empirical specification. In Section 3, we outline our empirical strategy and the methodology used to infer product quality. In Section 4, we present the results, and in Section 5, we conclude.

[2] As discussed in more detailed below, we rely on the World Bank's Doing Business Report to infer a country's business climate.

## 2. Model

We draw on the model in ABGHP(2009) to guide our empirical specification.[3] It is a multisector Shumpeterian growth model where entry threat affects innovation by incumbents. A final good, $y_t$, is produced under perfect competition with a continuum of intermediate inputs, $x_t(i)$:

$$y_t = \int_0^1 A_t(i)^{1-\alpha} x_t(i)^{\alpha} \, di, \qquad \alpha \in (0,1), \tag{1}$$

where $A_t(i)$ is the productivity associated with input $i$. The final good is used as capital in producing intermediates. Only two firms are capable of producing an innovation for each intermediate input. The model assumes Bertrand competition, so that if two firms have equal technology, then profits are zero; and if the two technologies differ, then the leader has positive profits. It is assumed that the world technology frontier, $\overline{A}_t$ grows at an exogenous rate, $\gamma > 1$.

There are three possible types of firms: type 1 firms are at the frontier, with $A_{t-1}(i) = \overline{A}_{t-1}$; type 2 firms are one step behind the frontier, with $A_{t-1}(i) = \overline{A}_{t-2}$; and type 3 firms are two steps behind the frontier, with $A_{t-1}(i) = \overline{A}_{t-3}$. Innovation allows the incumbent to increase productivity by $\gamma$ and keep up with the growth of the frontier, but technological progress is step-by-step. The last firm type is automatically upgraded by $\gamma$ (the model does not allow for leapfrogging).

In each period and in each of the intermediate sectors, there is only one potential entrant that can pay an entry cost to enter. It is assumed that when entry occurs, it takes place at the frontier. Thus, an entrant captures the entire market and becomes the new leading firm unless the incumbent leader is also at the frontier after innovation, in which case the new entrant chooses not to enter. The entrant observes post-innovation technology, thus would not pay the entry cost if the incumbent was at the frontier because Bertrand competition would drive profits to zero. An incumbent laggard never invests in innovation because at best it would catch up to its rival and earn zero profits. Thus in steady state, there are never two type 1 or type 2 firms. ABGHP(2009) demonstrate that in equilibrium there are only three possible states: (1) type 1 leader; (2) type 2 leader; and (3) two type 3 incumbents.

To solve for equilibrium, ABGHP (2009) shows that a firm chooses its investment $z$ to maximize the expected net profit gain from innovation less the cost of research and development. Noting that it is never profitable for a laggard to innovate, they solve the first-order conditions for a state 1 and a state 2 leader. Denote $prob_j$ as the probability that the potential entrant pays the cost of entry in sector $j$, which depends negatively on an exogenous common cost parameter, $\Lambda$, so $prob_j'(\Lambda) < 0$. This cost parameter can be

[3] We refer the reader to ABGHP (2009) for the full model and to Aghion and Howitt (2005) for an overview of models that provide similar insights under different assumptions.

interpreted as a measure of competition, with a higher $\Lambda$ implying less competition. Then in state 2 sectors, they show that the probability of increasing innovation, $\partial z_2/\partial\Lambda$, is positive due to the "discouragement effect." That is, firms behind the frontier know they cannot survive entry even if they successfully innovate; thus any policies that reduce the cost of entry will discourage innovation for firms behind the frontier. In contrast, in state 1 sectors where the leader is at the frontier, a reduction in $\Lambda$ that increases the entry threat increases innovation: $\partial z_1/\partial\Lambda < 0$. A larger entry threat increases the incumbent leader's losses from entry if it does not innovate, thus increasing the incentive to escape entry by innovating.

Expected productivity growth, $g_i$, in each sector is proportional to innovative investment, thus:

$$\frac{dg_1}{d\Lambda} = \frac{\partial z_1}{\partial\Lambda}(\gamma - 1) < 0; \qquad \frac{dg_2}{d\Lambda} = \frac{\partial z_2}{\partial\Lambda}(\gamma - 1) > 0. \tag{2}$$

This implies that for firms at the frontier (sector 1 firms), a reduction in the entry cost (tougher competition) increases innovation and growth. Conversely, for firms behind the frontier (sector 2 firms), a reduction in the entry cost decreases innovation and growth.

## 3. Empirical Specification

The implications of the model are that innovation is a nonmonotonic function of competition that depends on the firm's proximity to the world technology frontier:

$$\textit{innovation} = f(\textit{competition},\ \textit{proximity to the frontier}). \tag{3}$$

To explore this relationship, we need to obtain a measure of innovative activity, proximity to the frontier, and competition.

### *3.1. Innovation*

Innovative activity may involve developing new production techniques, new products or upgrading the quality of existing products. Measuring all of these aspects is challenging because of the complexity of these different attributes and the dearth of data that is comparable across countries. We overcome some of these difficulties by focusing on the quality element of innovation using a novel approach developed in Khandelwal (forthcoming). We measure a product's quality using export data to the United States. We rely on a country's exports to the United States rather than its production to infer quality because the trade data are available at a highly disaggregate level, which is important for our analysis, and because these data are comparable across countries and time. Moreover, we are likely to capture the highest quality products within a country given the evidence that exporting firms tend to be more productive, employ higher skilled workers, more likely to obtain International Organization Standard (ISO) certifications, and produce higher unit value products relative to nonexporters (e.g., see Bernard et al. 2007, Verhoogen 2008, Kugler and Verhoogen 2008). There is also evidence that higher unit value goods are exported to higher income countries (e.g., see Hallak 2006, Bastos and Silva 2009, and Manova and Zhang 2009).

### *3.2. Methodology for Measuring Quality*

Following Khandelwal (forthcoming), we use a procedure to estimate a product's quality from both export prices and market share information. This is in contrast to the literature in international trade that often uses prices or unit values (value divided by quantity) as a proxy for quality (e.g., Schott 2004, Hallak 2006). The obvious advantage of using unit values is that they are easily calculated in the trade data. However, if products possess both vertical (e.g., comfort) and horizontal (e.g., style) attributes, unit values may be inappropriate proxies for quality. For example, consider women's trousers, defined at the HS 10-digit level (HS 6204624020), exported to the U.S. in 2005 by India and Venezuela. The unit values (inclusive of transportation and tariff costs) associated with these imports were \$140 and \$163, respectively. Under the price-equals-quality assumption, Venezuelan trousers would be assigned higher quality. However, the income per capita of Venezuela exceeds India's by ten-fold and so it is possible that the differences in unit values also reflect, in part, the wage differential. Our measure of quality also takes into account differences in market shares; thus for two products with identical unit values, the product with a higher market share is assigned higher quality (how much higher quality depends, as seen below, on the slope of the demand schedule). Indeed, India exported over 1 million units more than Venezuela; and after accounting for these differences in market shares, the methodology described below assigns a higher quality to Indian trousers, despite lower prices.

To estimate quality, we use a nested logit demand framework, based on Berry (1994). In this framework, quality is defined as the vertical component of the model and has a structural definition as the mean valuation that U.S. consumers attach to an imported product. The intuition behind this approach is that higher quality is assigned to products that have higher market shares, *conditional* on prices. We closely follow the set up in Khandelwal (forthcoming) and summarize the estimation procedure here.

To understand the nested logit structure, first we need to describe how the data are classified. We define products as the HS 10-digit codes, which is the most disaggregated U.S. trade data classification. A U.S. import from a country within a product is called a *variety*. All products can be mapped into a coarser 5-digit SITC (revision 3) classification code, which we refer to as the *industry*. For example, an industry may be men's knit shirts, and within this industry, shirts are classified into products that can vary by fabric material (e.g., cotton, wool, etc.). Chinese cotton and Japanese wool shirts are examples of varieties. We use the HS 10-digit products as the nests for our application. As shown below, the nested logit allows for more plausible substitution patterns than the logit by allowing differences in the correlation among consumer preferences for varieties within a nest than for varieties across nests.

We derive the structural equation for a single SITC industry, comprising many varieties, and then estimate this equation separately for each industry (thus we suppress industry subscripts). Consumer $n$ has preferences for HS product $h$ imported from country $c$ (e.g., variety $ch$) at time $t$. The consumer purchases the one variety that provides her with the highest indirect utility, given by

$$V_{ncht} = \lambda_{1,ch} + \lambda_{2,t} + \lambda_{3,cht} - \alpha p_{cht} + \sum_{h=1}^{H} \mu_{nht} d_{ch} + (1-\sigma)\epsilon_{ncht}. \tag{4}$$

The $\lambda$ terms represent the variety's valuation that is common across consumers (notice that these terms are not subscripted by $n$). The first term, $\lambda_{1,ch}$, is the time-invariant valuation that the consumer attaches to variety $ch$. The second term, $\lambda_{2,t}$, controls for secular time trends common across all varieties. The $\lambda_{3,cht}$ term is a variety-time deviation from the fixed effect that consumers observe but that we as the econometricians do not. Consequently, this last component of quality is potentially correlated with the variety's unit value inclusive of transportation and tariff costs, $p_{cht}$.

The horizontal component of the model is captured by the random component, $\sum_{h=1}^{H} \mu_{nht} d_{ch} + \epsilon_{ncht}$. The term $\epsilon_{ncht}$ is assumed to be distributed Type-I extreme value and explains why a low-quality variety that is expensive is ever purchased. The former term interacts the common valuation that consumer $n$ places on all varieties within product $h$, $\mu_{nht}$, with a dummy variable $d_{ch}$ that takes a value of 1 if country $c$'s export lies in product $h$. This term generates the nesting framework because it allows consumer $n$'s preferences to be more correlated for varieties within product $h$ than for varieties across products.[4] For instance, a consumer who prefers Japanese wool shirts is more likely to prefer other wool shirts rather than cotton shirts. The nested logit is designed to capture this preference structure.

An outside-variety completes the demand system. The outside option allows consumers to choose a domestically produced variety instead of any imported variety. The consumer chooses this outside option if the utility derived from the outside-variety exceeds that from purchasing any inside option. The utility of the outside-variety is given by

$$u_{n0t} = \lambda_{1,0} + \lambda_{2,t} + \lambda_{3,0t} - \alpha p_{0t} + \mu_{n0t} + (1-\sigma)\epsilon_{n0t}. \tag{5}$$

The mean utility of the outside variety is normalized to zero; this normalization anchors the valuations of the inside varieties. In the context here, one can think of the outside

[4] As discussed in Berry (1994), Cardell (1997) has shown that the distribution of $\sum_{h=1}^{H} \mu_{nht} d_{ch}$ is the unique distribution such that if $\epsilon$ is distributed extreme value, then the sum is also distributed type-I extreme value. The degree of within nest correlation is controlled by $\sigma \in (0, 1]$ and is assumed to be identical across all products. As $\sigma$ approaches one, the correlation in consumer tastes for varieties within a nest approaches one; as $\sigma$ tends to zero, the nested logit converges to the standard logit model.

variety as the domestic substitute for imports, and we therefore set the outside variety market share to one minus the industry's import penetration. Note that the choice of the outside variety proxy affects the absolute growth rate of import qualities but not the relative growth rate because our analysis includes year fixed effects that are common to all varieties. Once the outside variety market share $s_{0t}$ is known, we can compute the industry size: $MKT_t = \frac{\sum_{ch \neq 0} q_{cht}}{1-s_{0t}}$, where $q_{cht}$ denotes the import quantity of variety $ch$. The market shares for imported varieties are then calculated as $s_{cht} = q_{cht}/MKT_t$.

The consumer chooses variety $ch$ if $V_{ncht} > V_{nc'h't}$. Under the distributional assumptions for the random component of consumer utility, Berry (1994) has shown that the demand curve from the preferences in equation (4) is

$$\ln(s_{cht}) - \ln(s_{0t}) = \lambda_{1,ch} + \lambda_{2,t} - \alpha p_{cht} + \sigma \ln(vs_{cht}) + \lambda_{3,cht}, \tag{6}$$

where $vs_{cht}$ is variety $ch$'s share within product $h$ at time $t$ (the nest share).[5]

Since the trade data do not record detailed characteristics of varieties, we exploit the panel dimension of the data by specifying a time-invariant component of quality ($\lambda_{1,ch}$) with variety fixed effects, and the common quality component ($\lambda_{2,t}$) with year fixed effects. The third component of quality, $\lambda_{3,cht}$, is not observed and plays the role of the estimation error.

Since $\lambda_{3,cht}$ and the nest share are potentially correlated with the variety's price, instrumental variables are required to identify the parameters. We instrument the price with the variety's transportation costs, which are obviously correlated with prices but may also be correlated with quality if firms ship higher-quality goods in order to lower per unit transport costs. This practice potentially raises concerns that trade costs may be correlated with a variety's quality (Hummels and Skiba 2004). However, the exclusion restriction remains valid as long as transport costs do not affect *deviations* from average quality, $\lambda_{3,cht}$. In other words, if an Australian firm chooses to export higher-quality varieties to the United States because of distance, the instruments remain valid as long as shocks to transportation costs do not affect deviations from the firm's average quality choice. Indeed, the Washington Apples phenomenon discussed in Hummels and Skiba (2004) identify the impact of distance on prices using cross-country variation in distance rather than shocks to transport costs over time. We also include exchange rates and the interaction of distance to the United States

[5] If one adopts a logit demand system, the nest share disappears from equation (6). To understand why this nest share term is important for inferring quality, consider the following example. Imagine there are two shirts–Japanese wool and Italian cotton–that are identical in every dimension (including prices) and evenly split the market. We would infer their qualities also to be equal. Now suppose an identical Chinese cotton shirt enters and the market shares for the cotton shirts are 1/4 each and the wool shirt captures the remaining 1/2. Without the nesting structure, we would infer that the quality of the Italian cotton shirt has fallen in half (since its market share has fallen while its price remains the same), even though its underlying attributes have not changed. The nested logit takes into account the correlated preferences within nests. So although the market share for the Italian cotton shirt falls, its nest share ($vs_{cht}$) also falls and so its inferred quality would remain unchanged.

with oil prices as additional instruments; these instruments vary at the country-year level. Finally, $vs_{cht}$ is also endogenous, and so we instrument this term with the number of varieties within product $h$ and the number of varieties exported by country $c$. As is frequently assumed in the discrete choice literature (e.g., see Berry, Levinsohn and Pakes 1995), the identification assumption is that entry and exit of other varieties will be correlated with $ch$'s share within the nest, but uncorrelated with quality shocks. This would occur in a model of monopolistic competition where all varieties are atomistic, or in an oligopoly model where entry and exit decisions occur in the first stage and Nash prices and qualities are chosen in the second stage of game.[6]

A second issue that arises in estimating (6), first noted by Feenstra (1994) and also by Hallak and Schott (2008), is the problem of unobserved or "hidden" varieties. To understand how hidden varieties could confound the measurement of quality, suppose that the reason India exported far more women's trousers than Venezuela was simply that India exported more unobserved twelve-digit HS varieties (for instance, more colors). If the Venezuelan and Indian varieties were identically priced with equal market share, then when aggregating to the observed ten-digit HS level, we would assign a larger market share to the Indian varieties. From equation (6), India's estimated quality would be biased upward simply due to the hidden varieties. Drawing on standard models (e.g., Krugman 1980) that predict that a the number of varieties produced is increasing in a country's population, we use the (log of) population as an additional covariate in (6).

The demand curve that controls for the hidden-varieties problem is given by

$$\ln(s_{cht}) - \ln(s_{0t}) = \lambda_{1,ch} + \lambda_{2,t} - \alpha p_{cht} + \sigma \ln(ns_{cht}) + \gamma \ln pop_{ct} + \lambda_{3,cht}, \tag{7}$$

where $pop_{ct}$ is the population in country $c$. The estimated parameters and the residual of the regression define the quality of variety $ch$ at time $t$ as:

$$\lambda_{cht} \equiv \hat{\lambda}_{1,ch} + \hat{\lambda}_{2,t} + \hat{\lambda}_{3,cht}. \tag{8}$$

From equation (7), we see that the quality of an imported variety is defined relative to its market share after controlling for exporter size and price. More generally, our notion of quality is an attribute that allows a variety's price to rise without it losing market share. One potential concern about this interpretation is that many factors unrelated to quality could affect market shares and therefore confound our measure of quality. However,

[6] We note that the validity of using a count of varieties to instrument for $vs_{cht}$ relies on weaker assumptions than those typically made in the discrete choice literature. The discrete choice literature typically instruments $vs_{cht}$ with the average characteristics of varieties (e.g., Berry, Levinsohn and Pakes 1995). This practice assumes that the firms' quality choices are fixed (or chosen before prices). Here, we only need that the number of varieties is uncorrelated with the deviation from average quality, $\lambda_{3,cht}$. This will be the case in a model where entry and exit occur *prior* to the firms' quality choice. For example, this occurs in models where firms choose quality in the final stage of a multi-stage game of location, price, and quality decisions (e.g., Vogel 2008).

it is important to note that this set of factors is made much smaller by conditioning on prices. For example, a variety may have a large market share if the exporting country is geographically close to the United States. However, since the price includes transportation costs the quality estimate is not capturing purely gravity effects such as distance.[7]

*3.2.1. Proximity to Frontier*

We estimate equation 7 separately for each SITC (revision 3) industry and use the estimated parameters of the regressions to define the qualities according to (8).[8] We construct the frontier measures by first taking a monotonic transformation of the quality measures to ensure that all qualities are non-negative: $\lambda^F_{cht} = \exp[\lambda_{cht}]$. We define a variety's *proximity* to the frontier as the ratio of its (transformed) quality to the highest quality within each HS product:

$$PF_{cht} = \frac{\lambda^F_{cht}}{\max_{c \in ht}(\lambda^F_{cht})}, \tag{9}$$

where the max operator chooses the maximum $\lambda^F_{cht}$ within a product-year and $PF_{cht} \in (0, 1]$. For varieties close to the frontier, this measure is close to one. For varieties far from the frontier, this measure is close to zero.

*3.3. Competition*

To measure a country's competitive environment, we collect disaggregated import tariffs for each country in our sample. The tariff data are obtained from WITS and are specified at the HS 6-digit level and over time. That is, we measure the competitive environment of an HS6 industry in South Korea by South Korea's tariffs on imports in that industry. The advantage of using tariffs as our measure for competition within a country is that they are readily available at a disaggregate level and comparable across countries and time. Importantly, there is widespread evidence that tariff reductions result in pro-competitive pressures in the liberalizing countries which result in both a reallocation of resources towards more competitive firms and exit of inefficient firms.[9] An alternative measure of competition often used in studies is a Herfindahl concentration index, however these measures are unavailable across a large sample of countries necessary for our study. Moreover, while concentration measures have the advantage of encompassing a broader concept of competition, it is not possible to discern what policies are causing the differences in concentration across industries, since it is an outcome of many policies.

[7] Note that defining quality to be inclusive of a residual is analogous to the productivity literature that interprets total factor productivity as the residual from conditioning output on observable inputs.

[8] Note that separate industry regressions imply that quality cannot be compared across industries. We include appropriate fixed effects in our analysis below to account for this.

[9] For instance, see Levinsohn (1993), Pavcnik (2002), and the comprehensive survey article by Tybout (2003).

## 4. Data Description

To estimate quality, we use U.S. import data from 1990 to 2005 at the HS 10-digit level. Since unit values are notoriously noisy (GAO 1995), prior to estimating the demand systems in equation (7), we trim the data along three dimensions: we drop variety-year observations above or below the 1st and 99th percentile of unit values, exclude varieties with annual price increases of more than 200 percent or price declines of more than 66 percent, and drop varieties with export quantities of fewer than ten. The quality estimates obtained from equation (8) are also noisy and so we trim the qualities at the 5th and 95th percentiles. We also drop any observations with five-year quality growth outside the 1st and 99th percentiles. We trim along five year growth intervals since our dependent variable below will be defined as quality growth over 5-year intervals.

We obtain six-digit HS import tariffs for fifty-six countries for 1990, 1995, and 2000 from the World Bank's World Integrated Trade Solution (WITS) database. The sample of countries is limited by the availability of tariff data for those years.[10] The world quality frontier for each product in each year is defined from the set of countries for which we have tariff data. The proximity to the frontier for each country's products in each year is then matched to its import tariffs. Table 1 reports summary statistics of the change in quality, proximity to frontier, and tariff levels for OECD and non-OECD countries,[11] as well as statistics for countries classified as having strong and weak business environments, high DB and low DB, which we define below. The table shows that non-OECD countries have faster quality growth than OECD countries, and they also have higher rates of protection. The table also shows that non-OECD countries have slightly higher proximity to frontier measures than OECD countries, but this is related to product composition. Controlling for product-year fixed effects, there is a positive and statistically significant correlation between proximity to the frontier and income per capita.

As would be expected, the quality estimates indicate that richer countries export higher quality varieties within products.[12] Thus, on average, more advanced countries sit atop a product's quality ladder while developing countries are further from the frontier. The relationship between income and quality in 2005 is seen in Figure 1. The left panel of Figure 1 plots the proportion of the total number of products a country exports for which it is the quality "leader", $PF_{cht} = 1$, against its income per capita, showing there is a positive and statistically significant relationship.[13] Similarly, there is a positive relationship between

[10]If tariff data were unavailable for a particular year, we included the data for the preceding year. Note that tariffs are common for all countries within the European Union.

[11]OECD countries include all those that joined the OECD before our sample period in 1990. Countries in our sample that joined the OECD after 1990 include Mexico in 1994, and South Korea and Poland in 1996. Taiwan is a member but cannot vote.

[12]This was shown in Khandelwal (forthcoming) and consistent with findings in the previous literature.

[13]The income per capita and population variables are obtained from the the World Development Indicators

income and the fraction of highest-priced varieties in the right panel of the figure. Notice in this panel that the positive relationship is steeper than the quality-based measure. In particular, China is a clear outlier; although China exported the highest-priced variety in 9 percent of products in 2005, the quality-based measure indicates that China was the leader in 44 percent of the total number of products it exported to the U.S. There are several reasons for this discrepancy. First, although China exports low-priced varieties, it has exceptionally high market shares (it has the highest quantity in 59 percent of the products it exports), particularly for labor-intensive products. That is, the procedure above yields high quality estimates for China because its market shares are larger than the predicted market shares given its price and the estimated elasticity of demand. Thus, the methodology will record higher quality for China in these products. Second, trade statistics are recorded on a total value basis rather than a value-added basis. Given the importance of processing trade for Chinese exports, its value added will vary across sectors. For example, the Apple iPod is "made in China" even though China's value added accounts for a fraction of the production (Linden, Kraemer, and Dedrick 2007). More generally, Koopman, Wang and Wei (2008) estimate that China's value added in computers may be as low 5 percent. If the U.S. Census collected value-added trade data, China's inferred quality would presumably be much lower. Note that in Section 5.3, we will adopt several robustness checks in our analysis, including using unit values as a proxy for quality, and excluding China from the analysis and frontier definition.

## 5. Quality Upgrading and Competition Results

With the import tariffs and quality measures in hand, we can analyze the effect of competition on quality upgrading as in equation 3, allowing for the discouragement and escape-competition forces. We use the following empirical specification to relate quality growth to import tariffs, proximity to the frontier, and the interaction of the two, which allows for a nonmonotonic relationship highlighted in ABGHP (2009):[14]

$$\Delta \ln \lambda_{cht}^{F} = \alpha_{ht} + \alpha_{ct} + \beta_1 PF_{cht-5} + \beta_2 \text{tariff}_{ch,t-5} + \beta_3 (PF_{ch,t-5} * \text{tariff}_{ch,t-5}) + \varepsilon_{cht}. \quad (10)$$

The dependent variable, $\Delta \ln \lambda_{cht}^{F}$, is the change in a variety's quality between period $t$ and $t-5$. All the explanatory variables are in levels for the period $t-5$. Our specification includes both product-year fixed effects ($\alpha_{ht}$) and country-year fixed effects ($\alpha_{ct}$) which are critical to the analysis. The product-year fixed effects deal with two issues. One, because the qualities are estimated separately across industries, the quality estimates are only comparable within the industry or product. Including the product-year effects ensure*s* that the estimation only exploits the variation between comparable qualities. Two, product-year fixed effects control

database.

[14] ABGHP (2009) specifies a similar estimating equation in their context.

for shocks that are common to all varieties within a product such as demand shocks or world-wide technology shocks that could also influence quality upgrading. The country-year fixed effects sweep out country-level shocks such as technological shocks, changes in relative endowments, and changes in institutions that affect competition. Thus, this specification flexibly controls for different shocks that may be correlated with tariff changes and affect quality growth.

The ABGHP model suggest that $\beta_2 > 0$ and $\beta_3 < 0$ (see equation 2). Thus, a fall in tariffs would spur a variety's quality growth in subsequent periods only if the product variety is close to the world quality frontier ($PF_{cht-5}$ close to 1); this is consistent with the escape competition effect discussed above. In contrast, if a product variety is a long way from the frontier, a fall in tariffs could reduce quality upgrading due to the discouragement effect. That is, products a long way from the frontier need high tariffs to protect rents in order to promote quality upgrading. Note that $\beta_1 < 0$ implies that varieties that are far from the frontier ($PF_{cht-5}$ close to 0) experience faster quality upgrading, implying convergence in quality.

### *5.1. Results*

Before estimating equation (10), we first look for a monotonic relationship between competition and quality growth by regressing the growth in a variety's quality on the home market's import tariffs and product-year fixed effects, as in the trade and growth literature. The first column of Table 2 shows that a fall in tariffs is associated with slower quality upgrading. However, once we include country-year fixed effects in column 2, to control for factors such as changes in a country's relative factor endowments or technology shocks, the sign on the tariff coefficient switches sign, and is now negative indicating that a fall in tariffs is associated with faster quality upgrading. These results highlight the importance of controlling for country-year effects that may be correlated with industry level competition measures such as tariffs. In all subsequent regressions, we therefore include both country-year and product-year fixed effects.

Next, we examine whether the relationship between quality upgrading and tariffs depends on a variety's proximity to the frontier according to the baseline regression in (10). Column 3 shows there is a negative coefficient on the lag proximity to the frontier, which implies a faster catch-up for varieties far from the frontier. The positive coefficient on tariffs and the negative coefficient on the interaction of tariffs with the proximity to frontier provide support for the effects highlighted in ABGHP (2009). The negative coefficient on the interaction implies that the varieties close to the world frontier are more likely to upgrade quality in response to tougher competition in the domestic market (the escape-competition effect). And the positive coefficient on the linear tariff variable implies that tariffs are likely to have the opposite effect for varieties distant from the world frontier (the discouragement effect). Thus, the results support the theory of a non-monotonic relationship between tariffs and quality upgrading.

In column 4, we examine heterogeneity in the discouragement and escape-competition effects by allowing for separate effects for OECD and non-OECD countries. The results hold across both groups but the magnitudes of the tariff coefficients are much larger for OECD countries. For OECD varieties that are distant from the frontier ($PF_{cht-5}$ close to 0), a 10 percentage-point fall in tariffs is associated with a 4.2 percent fall in quality upgrading. However, for OECD varieties close to the frontier, a fall in tariffs has the opposite effect: a 10 percentage-point fall in tariffs is associated with a 5.6 percent increase in quality upgrading. For non-OECD varieties far from the frontier, a 10 percentage-point fall in tariffs is associated with a 1.1 percent fall in quality upgrading; and for varieties close to the frontier a 10 percentage-point fall in tariffs is associated with a 1.3 percent growth in quality.

### *5.2. Institutions and Quality Upgrading*

The results in column 4 of Table 2 raise the question as to why there are larger quality responses in OECD countries than in non-OECD countries as tariffs change. For the effects in the theory to be present, market forces need to be able to operate. In particular, the potential for entry and exit of firms is crucial for tariffs to invoke more competition in the home market. However, nontariff barriers, bureaucratic red tape, and other entry regulations are likely to imply heterogeneity in the impact of tariffs on the competitive environment across countries. In countries with more regulation, additional domestic reforms may be needed so that lower tariffs induce further competition in the market.

We test for heterogenous effects in the tariff-frontier interaction coefficient according to institutional quality in the first column of Table 3. To assess the quality of a country's institutions, we rely on a measure of the regulatory environment from the World Bank's Doing Business Survey.[15] The index ranges from 0 to 1, with a higher value indicating a better business environment. We separate countries into two groups, with $HDB$ comprising countries with a doing-business indicator greater than the median, and $LDB$ comprising countries with a doing business indicator lower than the median.[16] Column 1 shows that for countries with weak business environments, the magnitudes and significance on the tariff variables are much lower than for countries with strong business environments, with the coefficient on the linear tariff term insignificant.

[15] We construct an aggregate Doing Business Index by following the procedure outlined in World Bank (2005). The Doing Business database tracks constraints along several dimensions, including the ease of starting a business, enforcing contracts, obtaining credit, hiring and firing, etc. We compute each country's percentile ranking for each outcome. The aggregate Doing Business measure takes the (simple) average of a country's percentile rankings across the outcomes. A higher value indicates an environment more conducive to conducting business.

[16] See Table 1 for the list of countries classified as above and below the median Doing Business index.

Interestingly, the business environment indicator is picking up an effect beyond differences in income per capita. To see this, we allow for additional flexibility in the coefficients for strong and weak business environments further broken down by OECD and non-OECD countries in the middle panel of Table 3 (columns 2a and 2b). The results indicate that even non-OECD countries characterized by strong business environments display both the discouragement and the escape-competition forces (see upper panel of column 2b). Yet, for countries characterized by weak doing business indicators the coefficients on the tariff variables are insignificant on both tariff terms for both OECD countries and non-OECD countries, and the coefficient on the tariff term for non-OECD countries becomes negative (see lower panel).[17] This result suggests that a minimum institutional "quality," and not simply differences in income per capita, is required for the two forces to operate. In particular, the lack of support for the models among weaker business-climate countries appears consistent with a variant on the Acemoglu, Aghion, and Zilibotti (2006) model that discusses how political economy factors can inhibit the escape-competition effect from operating (see section 5.2 of Acemoglu et al. 2006). Since countries with poorer business climates are unlikely to fit the theory, we restrict the subsequent analysis to the set of countries characterized by a relatively stronger business environment.

In column 3, we therefore reestimate equation (10) with only the sample of countries with business environments above the median. The results indicate that for varieties far from the frontier, a 10 percentage point fall in tariffs is associated with a 5.2 percent decline in quality growth, while an equivalent tariff decline for varieties close to the frontier is associated with a 3.8 percent increase in quality growth. To get a sense of the economic significance of these point estimates, we evaluate what a 10 percentage point change in tariffs implies for varieties close to the frontier and for those distant from the frontier, and compare these predicted changes to the actual change in quality for these varieties. Thus, for varieties close to the frontier ($PF > 0.9$), the predicted mean change in quality is 3 percent, whereas the actual mean change in quality for these varieties is 13 percent. This calculation implies that a 10 percentage point change in tariffs can account for around 20 percent of the actual change in quality. An analogous calculation for varieties distant from the frontier ($PF < 0.1$), implies that a 10 percentage point change in tariffs can account for around 10 percent of the actual change in quality.

Figure 2 provides a graphical illustration of the key results of the nonmonotonic relationship between competition and quality upgrading predicted by ABGHP (2009) for the set of countries with strong business environments, highlighting the discouragement and

[17] Note that there are only two countries, Greece and Portugal, in the LDB-OECD grouping. The alternative OECD group, with all current members, would add Mexico to that subgroup, which results in significant tariff terms. One explanation for this finding is that the busines climate in the maquiladora region of Mexico, where the majority of Mexico's exports to the U.S. originate, are not accurately reflected in the DB measure. More importantly, the results for all the other three groupings are unaffected by the OECD definition.

escape-competition effects in column 3 of Table 3. The figure plots the predicted quality growth

$$\Delta \ln \hat{\lambda}^F_{cht} = \hat{\beta}_1 PF_{cht-5} + \hat{\beta}_2 \text{tariff}_{cht-5} + \hat{\beta}_3 (PF_{cht-5} * \text{tariff}_{cht-5})$$

against the $PF_{cht-5}$, evaluated at the 10th (dashed line) and 90th tariff percentiles. The downward sloping lines indicate convergence in the data; varieties far from the frontier experience faster quality upgrading than those that are proximate to the frontier. The predicted quality growth line evaluated at the 90th percentile tariff (a 20 percent tariff) is a clock-wise rotation of the 10th percentile tariff (a 0 percent tariff), and this reflects the two forces. For varieties far from the frontier, moving from a high tariff to a low tariff is associated with a decrease in the rate of quality upgrading, which is consistent with the Schumpeterian discouragement effect. However, for varieties close to the frontier, moving from a high to a low tariff is associated with a faster rate of quality upgrading, which illustrates the escape-competition effect.

Khandelwal (forthcoming) notes that products differ in their scope for quality differentiation, where some products are characterized by a large dispersion of qualities, or “long” quality ladders, while other productsare characterized by a smaller dispersion of quality, or “short” quality ladders.[18] These differences, which may be due to either technological differences or consumer preferences, imply that products will differ in their scope for quality upgrading according to their quality ladder lengths. In Table 4, we interact all the variables with an HS 10-digit product’s initial period quality “ladder” measure, which captures a product’s scope for quality differentiation (see Khandelwal, forthcoming), to see if there is more quality upgrading in products with higher quality ladders. The quality ladder is measured as the (log) difference between the best and the worst quality within a product in the baseline year, 1990. The results show that the response of quality upgrading to changes in tariffs is larger in magnitude in products that possess a higher scope for quality differentiation. This is intuitive, as we should expect limited quality upgrading in markets in which significant quality upgrading is not feasible due either to technological constraints or consumer preferences.

### *5.3. Robustness*

In the remaining tables, we check the robustness of the results. One potential concern is that the proximity variable is measured with error due to randomness or outliers of the highest quality variety. In Table 5, we demonstrate that our results are robust to alternative measures of the world frontier. In column 1, we check the sensitivity of the results by excluding varieties at the world frontier (and so exclude observations for which

[18] A market’s intrinisic scope for quality differentiation is closely related to an escalation principle developed in Sutton (1998). Other papers that rely on hetergeneity in the scope for quality differences include Kugler and Verhoogen (2008) and Johnson (2009).

$PF_{cht-5} = 1$). In column 2, we drop the top 2 varieties and redefine the frontier in equation (9) using the third highest quality variety, rather than the maximum. In column 3, we redefine the frontier based on the sample of varieties exported by HDB countries. In column 4, we redefine the frontier using qualities inferred from the data set after excluding China's exports. Recall that in Section 4, we noted that China's export quality may be overstated because of the nature of processing trade and because the export data record export values rather than value added. To check that our results are not driven by this, we exclude China's exports to the U.S. from the data, re-estimate quality using equation (7), and redefine the proximity to frontier measures excluding China. In column 4, we report the baseline specification using these (China-excluded) quality measures. Table 5 illustrates that the results are robust across all of these alternative measures of the world frontier.

In our final robustness check of the frontier measure, we reestimate equation (10) using unit values, the more common proxy for quality in international trade.[19] Specifically, we define the proximity to the frontier based on how far a variety's price is from the maximum price, and define the dependent variable as the change in log prices.[20] Column 5 shows that the magnitudes of the coefficients are similar to our baseline estimates; for varieties close to the unit value frontier, there is a negative relationship between tariffs and subsequent price growth, and for varieties far from the frontier, there is a positive association. This result shows that the discouragement and escape competition effects appear when using prices, instead of the alternative measure of quality proposed by Khandelwal (forthcoming).

In Table 6, we address issues surrounding omitted variables, endogeneity and selection. First, a potential concern is that firms are upgrading quality in response to lower tariffs on intermediate inputs rather than tariffs on final goods. As input tariffs fall, firms can access cheaper higher quality inputs, which can lead to higher quality outputs. If tariffs on intermediate inputs and final goods are correlated, this omitted variable could bias our coefficients. In column 1 of Table 6, we include input tariffs in the baseline specification and find that it has the expected negative sign, but it is insignificant.[21] More importantly, the significance and magnitudes of all the other variables are unaffected by the inclusion of input tariffs.

Second, there may be endogeneity concerns arising from countries possibly liberalizing their industries selectively based on forces that we are unable to observe. For instance, if countries receive productivity shocks that enable them to improve the quality of their products, pressures against liberalizing those markets may subside. To the extent that

[19] See Schott (2004), Hallak (2006), Baldwin and Harrigan (2007) and Johnson (2009).

[20] We exclude observations that report unit value changes above the 99th and below the1st percentiles.

[21] Interestingly, reestimating column 1 of table 5 on the countries below the median DB results in a significant negative coefficient on input tariffs. This is consistent with research on developing countries that shows lower input tariffs improves access to higher quality foreign inputs (e.g., Halpern, Koren, Szeidl 2009, and Goldberg, Khandelwal, Pavcnik, and Topalova 2008) and significantly raises productivity (see Amiti and Konings 2007) .

these shocks are country-specific, the country-year fixed effects will control for productivity shocks. Likewise, productivity (or demand) shocks that are common across all varieties within a product will be captured by the product-year fixed effects. However, productivity shocks could be market-industry specific. To address this concern, we include the change in a country's total exports to the world for each HS 6-digit industry by year. The change in industry-level exports for each country is a plausible proxy for productivity shocks: higher productivity shocks are likely to be reflected in higher export growth.[22] In column 2 of Table 6, we see that while the change in exports is positively correlated with quality upgrading, its inclusion leaves the key results unchanged. Moreover, the magnitudes are extremely close to the baseline results reported in column 3 of Table 3.

We further address potential endogeneity concerns by exploiting a specific liberalization episode: the ending of textile and clothing (T&C) quotas under the Multifiber Arrangement (MFA) in 2005. A major breakthrough in the Uruguay Round was the agreement by developed countries to end their stringent quotas on developing countries' T&C exports.While the liberalization episode was anticipated, the quota removal was plausibly exogenous for countries that exported T&C because of the WTO mandate to end the quota regime.[23] In 1995, the U.S. published the HS product schedule to phase out the quotas over ten years. Brambilla, Khandelwal and Schott (2008) show that China's T&C exports surged following MFA quota removals (it was eligible for quota removals after joining the WTO). The surge was most pronounced in the products in which China was "bound"–products in which China's quota fill-rates exceeded 90 percent. After the quotas were removed, China's exports of bounded products immediately increased by more than 450 percent. Brambilla et al. (2008) show that with few exceptions (notably Bangladesh and India), virtually all countries' T&C exports to the U.S. contracted because of China's export explosion.[24] Thus, China's exports following the end of the MFA represents a substantial increase in product market competition for T&C HS products, and especially in the set of products that China was bound.

We exploit the MFA episode by restricting our analysis to the T&C products that were covered by the MFA, and we assign an indicator variable–$B_h$– if China was subject to binding quotas in that product.[25] Based on Brambilla et al. (2008), product market competition was the most severe in the bound products. We then estimate an analog to

[22] We obtain a country's total exports to the world, by HS6, from the UN Comtrade database.

[23] Nonetheless, the U.S. did reimpose quotas on China's expots in a handful of T&C HS codes in 2006. However, the reimposition of the quotas was due to China's export surge in 2005. The lobbying for new quotas therefore precisely reflects the substantial increase in product market competition in 2005, the last year of our sample.

[24] This finding underscores the point that the quotas actually ensured gauranteed market access for many countries' textile and clothing exports.

[25] We choose 1991 as the year to determine whether or not China was binding in the product because this is the earliest year for which the binding quota information is available at the HS level. China was bound in 18 percent of the T&C products.

the baseline specification in equation (10) on the set of T&C products:

$$\Delta \ln \lambda_{cht}^{F} = \alpha_{ht} + \alpha_{ct} + \beta_1 PF_{cht-5} + \beta_2 (PF_{ch,t-5} * B_h) + \varepsilon_{cht}. \qquad (11)$$

The specification in (11) regresses quality upgrading on product-year and country-year fixed effects, the lag proximity to frontier, and its interaction with $B_h$.[26] We again restrict the analysis to the countries defined as having a relatively stronger business climate. Since China only became eligible for quota removals after it entered the WTO in December 2001, we focus on the period from 2000 to 2005. As before, we should observe $\beta_1 < 0$; varieties that are far from the frontier experience faster growth due to convergence. The coefficient of interest is $\beta_2$ which captures the differential quality upgrading in bound and unbound products according to a variety's $PF$. This coefficient should be positive; varieties that are close to the frontier should experience relatively faster quality upgrading in China's bound products. We report the results in column 3 of Table 6. Consistent with the theory and our earlier evidence, we observe that quality upgrading among high $PF$ varieties is faster in products that faced stiffer competition over this period. We also run an additional placebo test by including the earlier periods of our sample. Since China's exports remained constrained by quotas prior to 2000, product market competition should not have increased in the $B$ products in 1990-95 and 1995-00. We check this placebo test by interacting $PF$ and $PF * B$ with a PostWTO indicator that takes a value of one in period 2000-05 and a value of zero in periods 1990-95 and 1995-00. The coefficient on the triple interaction term is statistically significant implying that, as shown in the previous column, there is a differential change in quality upgrading across China's bound and unbound products after China's WTO entry. Moreover, there is no statistical difference between quality upgrading across products in the periods before China's WTO entry. These findings are entirely consistent with product market competition stiffening in the bound products in the final period of our sample, but having no differential impact in the earlier years.[27] Thus, the predictions of the model and our baseline results are verified using the MFA shock.

A related concern with the baseline specification is that the coefficients on $PF_{ch,t-5}$ and ($PF_{cht-5}$*tariff$_{cht-5}$) might be downward biased because, all else equal, a high $\lambda_{ch,t-5}$ implies a high $PF_{ch,t-5}$ but a low $\Delta \ln \lambda_{cht}$. Following Acemoglu, Aghion, and Zilibotti (2006), we therefore instrument $PF_{ch,t-5}$ (and the interactions) with its 5-year lag value. Column 5 of Table 6 shows that the results are robust, with the coefficients on the proximity to frontier and the interaction becoming a little smaller in magnitude (compare with column 3 of Table 3). The results are also unaffected by the inclusion of the growth in world exports in the instrumental variables estimation.

[26] Note that because $B_h$ is time-invariant, we are only able to identify the ineraction effect.

[27] Note that we do not report the interaction $PF$*PostWTO in the table for readibility purposes. This coefficient is insignificant which is consistent with product market competition not changing substantially in China's unbound products when the quotas were removed.

Third, an alternative source of bias could arise from selection. If a country does not export a particular product we do not observe the quality of that good. Further, the observation is only included in the estimation if the quality is observed in both periods $t$ and $t-5$. It is difficult to sign the selection bias since it is likely to depend on how tariffs affect entry and exit, and where the varieties are located on the PF distribution. For example, suppose lower tariffs result in a country-product pair exiting from our sample. While its quality change would be missing (the current period quality is not observed), one might expect its quality to have fallen (i.e., its quality-adjusted price rises to the point where no U.S. consumer chooses to import the variety). If the variety was already far away from the frontier, then our coefficient on tariff ($\beta_2$) is biased downwards (that is, it is not positive enough). If the exiting variety was close to the frontier, then the interaction coefficient ($\beta_3$) is also biased downwards implying that the estimated coefficient is "too negative". On the other hand, if lower tariffs result in more varieties entering the sample, then the selection bias implies that our coefficients are biased upwards. This is because while the quality change for entering varieties is missing (because the previous period quality is not observed), entry into our sample can be viewed as a positive change in quality. Thus, for varieties distant from the frontier, our estimate of $\beta_2$ is biased upwards (that is, it is "too positive"), while for varieties close to the frontier, the baseline estimate of $\beta_3$ is not negative enough. This makes it difficult to sign the overall bias on both coefficients due any selection issues. Nonetheless, to address this selection issue, we implement a two-step Heckman correction. For this estimation, we use freight costs that a country would have to incur if it were to export that product. This variable plausibly affects entry and exit decisions into the U.S. export market but does not affect the quality. We calculate this potential freight cost by taking the freight cost of the closest neighboring country that does export that product. The first stage probit (column 6) shows that the coefficient on the freight variable is negative and significant; this suggests that higher potential freight costs reduce the probability of being in the sample. In the second stage, we include the inverse mills ratio from the first stage regression, which is significant, implying that the error terms in both regressions are correlated. However, the results in the second step (column 7) indicate that the main coefficients of interest are unchanged from the baseline specifications. Thus, our results remain robust to controlling for potential selection biases.[28]

## 6. Conclusion

The search for policies to encourage innovation has been a major challenge for governments around the world. This paper shows that increasing competition by lowering import tariffs is associated with faster quality upgrading – an important component of innovation

[28]The results are also robust to including tariffs and growth in world exports in the first-stage probit, but the sample is smaller because we do not have tariff information for all censored varieties.

– only if the product is close to the world technology frontier. For products distant from the world technology frontier, lower tariffs discourage quality upgrading. These findings are supportive of theories by ABGHP (2009) and consistent with more recent empirical studies that have also found a nonmonotonic relationship between growth and competition.

We build on previous studies by analyzing this relationship for highly disaggregated products for countries that span a wide income distribution. We overcome difficulties faced by other studies, which focus either on within country or aggregate cross-country analysis, by adopting a novel approach to measure quality, based on Khandelwal (forthcoming), which provides quality estimates that are internationally comparable. The advantage of this approach is that it enables us to control for country-year specific effects such as changes in institutions that could be correlated with industry competition measures.

Our results show that support is strongest for countries characterized by good business climates, which is perhaps not surprising given that lower tariffs are unlikely to significantly alter competitive environments in countries that face many other restrictions to competition. Interestingly, the nonmonotonic relationship between competition and quality upgrading holds for both OECD and non-OECD characterized by strong business climates. Thus, our results suggest that a minimum institutional quality, and not simply higher income per capita, is required for the two opposing forces in AGHP to operate.

These findings also suggest that initial heterogeneity in industry characteristics is important for understanding subsequent industry performance following trade liberalizations. In particular, aggregate implications of industry-level trade models, such as Melitz (2003), may differ according to the industry's initial distance to the world frontier. Further research on the implications of this heterogeneity may therefore be important.

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## 7. Tables and Figures

| Variables | OECD | Non-OECD | High DB | Low DB |
|---|---|---|---|---|
| $\Delta Quality_{cht}$ | 0.277 | 0.405 | 0.287 | 0.449 |
| | (1.116) | (1.074) | (1.111) | (1.063) |
| $PF_{cht-5}$ | 0.508 | 0.559 | 0.520 | 0.557 |
| | (0.351) | (0.332) | (0.347) | (0.333) |
| $Tariff_{c,h6,t-5}$ | 0.076 | 0.251 | 0.091 | 0.310 |
| | (0.061) | (0.262) | (0.104) | (0.280) |
| Countries | 20 | 36 | 29 | 27 |
| Observations | 74,053 | 57,204 | 94,274 | 36,983 |

Notes: Table reports summary statistics of changes in quality, lag proximity to frontier and lag tariffs. Mean values are reported with standard deviations in parentheses. DB refers to the World Bank's Doing Business Report and we split countries between those above and below the median values. Countries above the median DB in our sample are: Australia*, Austria*, Belgium/Luxembourg*, Canada*, Chile, Denmark*, Finland*, France*, Germany*, Hong Kong, Ireland*, Italy*, Japan*, Malaysia, Netherlands*, New Zealand*, Nicaragua, Norway*, Poland, Singapore, South Africa, South Korea, Spain*, Sweden*, Taiwan, Thailand, Tunisia, Turkey*, and UK*. Countries below the median DB in our sample are: Argentina, Bangladesh, Brazil, China, Colombia, Costa Rica, Egypt, El Salvador, Greece*, Guatemala, Honduras, India, Indonesia, Kenya, Mexico, Morocco, Nepal, Pakistan, Paraguay, Peru, Philippines, Portugal*, Saudi Arabia, Sri Lanka, Uruguay, Venezuela, and Vietnam. Stars denote OECD countries.

Table 1: Summary Statics

| Regressors | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $PF_{cht-5}$ | | | -0.823 *** | |
| | | | 0.014 | |
| $Tariff_{c,h6,t-5}$ | 0.207 *** | -0.070 ** | 0.214 *** | |
| | 0.014 | 0.033 | 0.048 | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | | | -0.438 *** | |
| | | | 0.048 | |
| OECD Indicator interacted with | | | | |
| $PF_{cht-5}$ | | | | -0.737 *** |
| | | | | 0.021 |
| $Tariff_{c,h6,t-5}$ | | | | 0.416 ** |
| | | | | 0.165 |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | | | | -0.973 *** |
| | | | | 0.220 |
| Non-OECD Indicator interacted with | | | | |
| $PF_{cht-5}$ | | | | -0.943 *** |
| | | | | 0.020 |
| $Tariff_{c,h6,t-5}$ | | | | 0.113 ** |
| | | | | 0.050 |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | | | | -0.241 *** |
| | | | | 0.051 |
| Product-Year FEs | yes | yes | yes | yes |
| Country-Year FEs | no | yes | yes | yes |
| R-squared | 0.54 | 0.54 | 0.58 | 0.58 |
| Observations | 131,257 | 131,257 | 131,257 | 131,257 |

Notes: Table reports regression results of change in (log) quality of a variety on the lag HS6 level tariff faced in the origin country, the varieties lag proximity to frontier and the interaction. Columns 1 reports quality growth on tariffs. Columns 2 introduces country-year fixed effects. Column 2 reports the baseline specification with the interaction between proximity to frontier and tariffs. Columns 4 estimates separate coefficients for the OECD and non-OECD countries (the OECD dummy is not reported). All regressions include product-year fixed effects. Standard errors clustered by exporting country (with EU countries treated as one country because of its common trade policy). Significance * .10 **.05 *** .01.

Table 2: Quality Upgrading, Competition, and Distance to Frontier

| Regressors | All Countries (1) | | OECD Indicator interactions (2a) | | Non-OECD Indicator interactions (2b) | | HDB Countries Only (3) | |
|---|---|---|---|---|---|---|---|---|
| Countries Above Median DB | | | | | | | | |
| $PF_{cht-5}$ | -0.769 | *** | -0.739 | *** | -0.836 | *** | -0.810 | *** |
| | 0.017 | | 0.021 | | 0.027 | | 0.019 | |
| $Tariff_{c,h6,t-5}$ | 0.438 | *** | 0.420 | ** | 0.413 | *** | 0.524 | *** |
| | 0.089 | | 0.167 | | 0.104 | | 0.094 | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | -0.790 | *** | -0.991 | *** | -0.622 | *** | -0.907 | *** |
| | 0.111 | | 0.221 | | 0.130 | | 0.119 | |
| Countries Below Median DB | | | | | | | | |
| $PF_{cht-5}$ | -0.992 | *** | -0.652 | *** | -1.037 | *** | | |
| | 0.026 | | 0.114 | | 0.027 | | | |
| $Tariff_{c,h6,t-5}$ | 0.033 | | 0.590 | | -0.017 | | | |
| | 0.058 | | 0.702 | | 0.059 | | | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | -0.121 | ** | -0.740 | | -0.051 | | | |
| | 0.057 | | 0.985 | | 0.058 | | | |
| Product-Year FEs | yes | | yes | | | | yes | |
| Country-Year FEs | yes | | yes | | | | yes | |
| R-squared | 0.58 | | 0.58 | | | | 0.58 | |
| Observations | 131,257 | | 131,257 | | | | 94,274 | |

Notes: Column 1 reports regression results of change in (log) quality of a variety on the lag HS6 level tariff faced in the origin country, the varieties lag proximity to frontier and the interaction, with each coefficient interacted with a dummy variable if the country is above (HDB) or below (LDB) the median Doing Business value. Panel two introduces an additional interaction if the country is an OECD country. Column 2a reports the OECD interactions and column 2b reports the non-OECD interactions; note that these coefficients are estimated in a single regression. Column 3 reports the baseline specification for just countries above the median Doing Business values. See footnote of Table 1 for a list of the country classificatoins. All regressions include product-year and country-year fixed effects. Standard errors clustered by exporting country (with EU countries treated as one country because of the common trade policy). Significance * .10 **.05 *** .01.

Table 3: Quality Upgrading, Competition, and Institutions

| Regressors | (1) | |
|---|---|---|
| $PF_{cht-5}$ | -0.660 | *** |
| | 0.033 | |
| $PF_{cht-5}$ X $Ladder_h$ | -0.059 | *** |
| | 0.015 | |
| $Tariff_{c,h6,t-5}$ | 0.311 | ** |
| | 0.157 | |
| $Tariff_{c,h6,t-5}$ X $Ladder_h$ | 0.135 | * |
| | 0.071 | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | -0.533 | *** |
| | 0.188 | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ X $Ladder_h$ | -0.229 | ** |
| | 0.106 | |
| Product-Year FEs | yes | |
| Country-Year FEs | yes | |
| R-squared | 0.58 | |
| Observations | 74,729 | |

Notes: Table reports the results where baseline coefficients are interacted with a product's quality ladder ($Ladder_h$), defined as the difference between the best and worst quality within a product in the baseline year, 1990. The regression includes product-year and country-year fixed effects and is run on the set of HDB countries only. The number of observations fall because we use the ladder variable defined in 1990. Standard errors clustered by exporting country (with EU countries treated as one country because of the common trade policy). Significance * .10 **.05 *** .01.

Table 4: Quality Ladders

| Regressors | Exclude PF=1 (1) | | Frontier Defined After Dropping Top 2 Qualities (2) | | Frontier Defined on HDB Countries (3) | | Exclude China from Quality Estimation (4) | | Unit Values (5) | |
|---|---|---|---|---|---|---|---|---|---|---|
| $PF_{cht-5}$ | -1.025 | *** | -0.784 | *** | -0.778 | *** | -0.868 | *** | -1.106 | *** |
| | 0.024 | | 0.022 | | 0.017 | | 0.019 | | 0.018 | |
| $Tariff_{c,h6,t-5}$ | 0.423 | *** | 0.529 | *** | 0.511 | *** | 0.424 | *** | 0.285 | *** |
| | 0.099 | | 0.123 | | 0.094 | | 0.095 | | 0.059 | |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | -0.726 | *** | -0.774 | *** | -0.841 | *** | -0.883 | *** | -0.496 | *** |
| | 0.127 | | 0.146 | | 0.115 | | 0.117 | | 0.115 | |
| Product-Year FEs | yes | | yes | | yes | | yes | | yes | |
| Country-Year FEs | yes | | yes | | yes | | yes | | yes | |
| R-squared | 0.58 | | 0.586 | | 0.584 | | 0.57 | | 0.214 | |
| Observations | 83,552 | | 73,326 | | 94,274 | | 90,276 | | 91,754 | |

Notes: Table reports regression results of change in (log) quality of a variety on the lag HS6 level tariff faced in the origin country, the varieties lag proximity to frontier and the interaction along with additional controls. Column 1 excludes observations with a proximity to frontier equal to one. Column 2 removes the top two qualities from each product and re-defines the proximity to frontier measure (that is, the third highest quality becomes the frontier). Column 3 re-defines the frontier measure using just the sample of HDB countries. Column 4 uses quality measures from estimating equation (7) excluding China and then re-running the baseline regression (10). Column 5 uses unit values as the proxy for quality, and so it regresses the change in unit values on tariffs, a unit value proximity to frontier measure, and the interaction. All regressions include country-year and product-year fixed effects, and run on the set of high DB countries. Standard errors clustered by exporting country (with EU countries treated as one country because of the common tariff). Significance * .10 **.05 *** .01.

Table 5: Alternative Proxy to Frontier Measures

| Regressors | Input Tariffs (1) | World Export Growth (2) | MFA (final period) (3) | MFA (all periods) (4) | IV Regression (5) | 1st Stage Probit (Heckman) (6) | Heckman Selection Correction (7) |
|---|---|---|---|---|---|---|---|
| $PF_{cht-5}$ | -0.815 *** | -0.806 *** | -1.180 *** | -1.156 *** | -0.436 *** | | -0.818 *** |
| | 0.019 | 0.019 | 0.057 | 0.044 | 0.036 | | 0.019 |
| $Tariff_{c,h6,t-5}$ | 0.511 *** | 0.487 *** | | | 0.431 ** | | 0.538 *** |
| | 0.100 | 0.095 | | | 0.195 | | 0.094 |
| $PF_{cht-5}$ X $Tariff_{c,h6,t-5}$ | -0.907 *** | -0.870 *** | | | -0.769 *** | | -0.913 *** |
| | 0.121 | 0.121 | | | 0.252 | | 0.119 |
| World Export $Growth_{c,h6,t}$ | | 0.047 *** | | | | | |
| | | 0.007 | | | | | |
| Input $Tariff_{c,h6,t-5}$ | 0.055 | | | | | | |
| | 0.169 | | | | | | |
| $PF_{cht-5}$ X $B_h$ | | | 0.267 *** | 0.048 | | | |
| | | | 0.092 | 0.078 | | | |
| $PF_{cht-5}$ X $B_h$ X $PostWTO_t$ | | | | 0.219 * | | | |
| | | | | 0.114 | | | |
| Log Potential $Freight_{c,h6,t-5}$ | | | | | | -0.097 *** | |
| | | | | | | 0.002 | |
| Inverse Mills $Ratio_{c,h6,t}$ | | | | | | | -2.844 *** |
| | | | | | | | 0.239 |
| Product-Year FEs | yes | yes | yes | yes | yes | no | yes |
| HS2-Year FEs | no | no | no | no | no | yes | no |
| Country-Year FEs | yes | yes | yes | yes | yes | yes | yes |
| R-squared | 0.58 | 0.59 | 0.623 | 0.65 | 0.07 | 0.17 | 0.58 |
| Observations | 92,612 | 90,868 | 8655 | 25097 | 35,156 | 922,606 | 94,274 |

Notes: Table reports regression results of change in (log) quality of a variety on the lag HS6 level tariff faced in the origin country, the varieties lag proximity to frontier and the interaction along with additional controls. Column 1 includes lag input tariffs as a control. Column 2 includes a measure of a country's HS6-level world export growth. Column 3 restricts the analysis to 2000-2005 and to products that were subject to quotas under the MFA. These products are taken from Brambilla et al. (2008). The "B" dummy that takes a value of one if China's fill rate exceeded 90 percent in 1991 for that product; fill rate information is also taken from Brambilla et al. (2008). Column 4 includes all periods and interacts PF X B with a dummy "PostWTO" that takes a value of one in the period 2000-2005. We suppress the coeffient on PF * PostWTO for readibility purposes (the coefficient is not statistically significant). Column 5 instruments the lag proximity to frontier with the previous period lag PF measure (i.e., the lag-lag proximity to frontier). Using the lag-lag PF measure is why the number of observations falls. Column 6 reports the first-stage probit regression of the probability of being observed in the sample on the (log) potential freight measure, country-year fixed effects and HS2-year fixed effects. Column 7 includes the inverse mills ratio obtained from column 6 to correct for selection. All regressions (excluding column 6) include country-year and product-year fixed effects and are run on the set of high DB countries. Standard errors clustered by exporting country (with EU countries treated as one country because of the common tariff). Significance * .10 **.05 *** .01.

Table 6: Robustness Checks

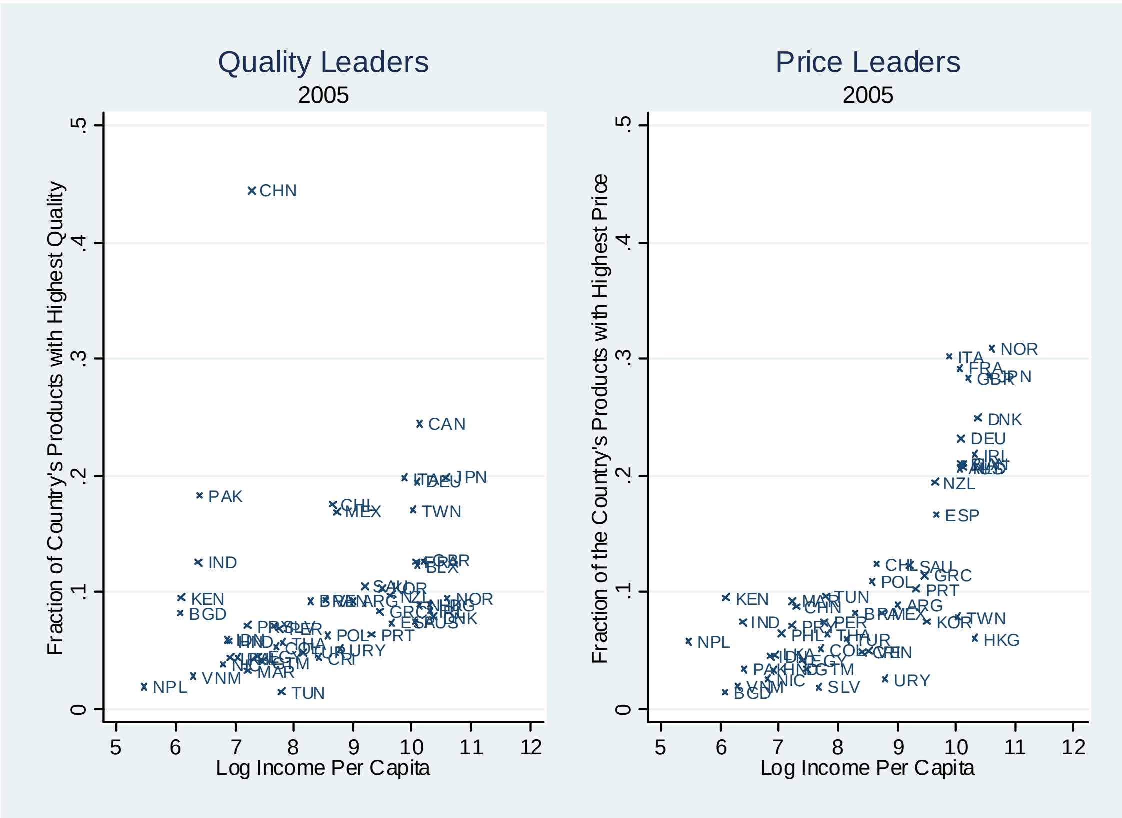


Figure 1: Quality and Price Leaders

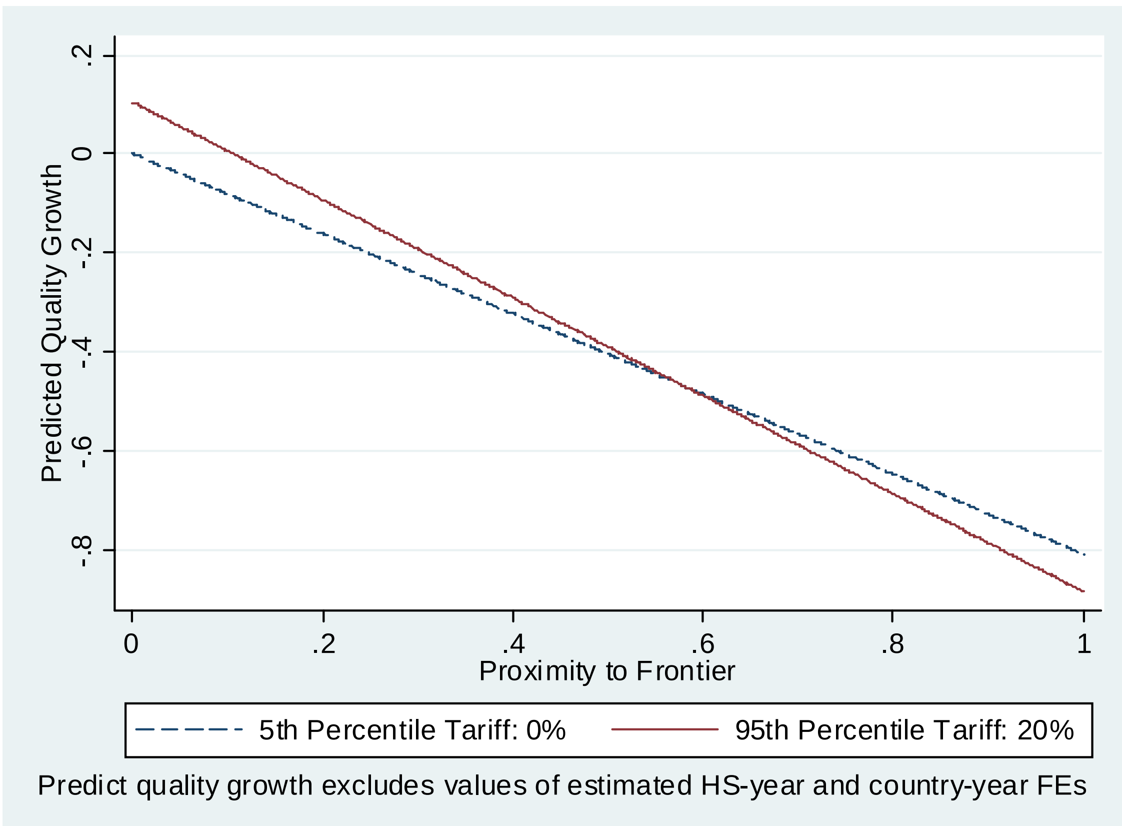


Figure 2: Predict Quality Growth and Proximity to Frontier