Export Quality and Trade: A Theoretical and an Empirical Analysis

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Abstract

I explore the impact of export quality on the levels of exports and domestic trade. First, I developed a theoretical framework, using the two-country oligopolistic model with quality differentials in product. I find that a consumer-preference driven increase in export quality improves export performance of a country but it reduces domestic trade, in the absence of any constraint on production capacity. I then test the theoretical findings empirically, using annual bilateral inter-country and intra-country trade data for 142 countries from 1963 – 2014 and by applying the gravity model of trade. I use the IMF's Export-Quality Index to estimate a two-stage gravity model and to examine the effects of exports quality on both exports and domestic trade. The empirical findings are consistent with our theoretical predictions. The empirical findings suggest that an one percent increase in quality leads to an increase in total exports by 1.08%and a fall in intra-national trade by 2.69%. I also find that the effect of export quality is more pronounced for OECD member countries than the non-OECD member countries.

JEL Classifications: F10, F14, H20
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1 Introduction

The importance of quality as a non-price dimension of exports for fostering growth in developing countries is gaining significant attention (Acharyya and Ganguly, 2023). Improving export quality not only enhances a country's export performance but is also pivotal for economic growth, particularly in developing nations. Henn et al. (2017) provide compelling evidence of a positive correlation between high-quality exports and economic development. They argue that higher quality varieties of existing goods contribute to improving comparative advantages, increasing productivity, and boosting revenues. Sutton and Trefler (2011), find that between 1980 and 2005 low-income countries (LICs) have moved into more "sophisticated" products that were predominantly produced by rich countries. However, within in these industries LICs are producing low-quality products due to which the diversification has not led to a big boost in GDP per capita (Henn et al., 2017).

Many studies have pointed out the importance of economic growth not just depends on the type of a product that they export but also on the quality (Hausmann et al., 2007, Hallak and Schott 2011, Henn et al. 2017) and that rich countries export and consume high quality products (Linder, 1961, Hallak, 2006). Schott (2004), Hallak (2006) and Hummels and Klenow (2005) used unit values as a proxy for product quality. Unit values may not be an accurate predictor of export quality as they can be driven by production costs differences hence, Khandelwal (2010) used price and market share as a measure of quality to account for both horizontal and vertical product differentiation in the United States using the data for HS10 level products. Using bilateral trade data for 166 countries over 1962 – 2014 and modifying Hallak's (2006) approach of measuring quality, Henn et al. (2017) found that quality upgrading is more rapid during the early stages of development. They focused on how liberal trade policies, FDI, institutional quality and human capital promote quality upgrading across various sectors of the economy though their impact varies by sector. However, these studies did not look at the impact of improvement in export product quality on international and intranational trade both empirically and theoretically. This is the gap in the literature that my paper tries to fill. The theoretical framework developed in this study shows that an increase in quality of the high-quality good will increase the exports of both the high-quality and the low-quality good, and will reduce domestic sales. I then test the theoretical findings empirically, using a bilateral trade dataset for 142 countries from 1963 – 2014 and by applying the gravity model of trade. The empirical findings of this study also confirm that improving export quality increases international trade but reduces intranational trade.

The concept of export quality encompasses both demand and supply aspects. As incomes in developed countries have increased over the decades, consumers have become more sensitive to quality rather than price variations. They tend to prefer higher quality goods, even at a higher price, over cheaper low-quality goods (Acharyya and Ganguly, 2023). Linder's (1961) hypothesis suggests that wealthier countries allocate a higher proportion of their income to high-quality goods compared to poorer countries, making them significant producers of high-quality products. Hallak

(2006) also finds that wealthier nations tend to have a stronger demand for high-unit-value imports, which is considered an indirect measure of export quality, and they tend to import more from countries that produce high-quality goods. Schott (2004) uses cross-sectional data across countries and industries, using price as a proxy for higher quality, to conclude that wealthier and more human- and capital-abundant economies tend to export higher-quality varieties.

Many studies indicate that exporters who sell higher quality goods at premium prices tend to be more successful and productive than those selling lower-quality goods. Tian et al. (2016) conducted a study on China's agri-food exports to 213 countries and found that exporters with higher product quality can capture more demand in the international market. In the presence of heterogeneous consumers, firms often differentiate their products by offering different quality levels and adjusting prices accordingly (Acharyya and Ganguly, 2023).

There is a need to explore more about the impact of quality on exports and its contribution in economic growth of a country. Previous studies have pointed out that export quality matters to capture international market (Papageorgiou et.al., 2019). This study also reinforces this by using aggregate bilateral trade data and complimenting the dataset with intranational trade and applying a gravity model. However, this study further investigates the impact of improving export quality on domestic trade. The contribution to the literature are the unique theoretical and empirical findings of this research that show that quality only matters for international trade but not for intranational trade.

The main research question that this study addresses is how improving export quality impacts international and domestic trade (of both high-quality and low-quality goods) of a developed and a developing country? The study aims to add to the literature on export quality and trade by using a relatively newer dataset on export quality by IMF which includes the export quality of most low-income countries. Second, I propose a quantitative framework to estimate the impact of improving export quality on the export performance of developing countries.

The rest of the paper is structured as follows. In Section 2, I present a theoretical framework. In Section 3, I describe the estimation strategy and the dataset that I have used for the empirical analysis. Section 4 presents the results, and Section 5 concludes.

2 Quantitative Model

In this section, I will talk about the theoretical model we developed. Brander (1981) initially presented the concept of segmented markets within a model in which domestic and foreign firms independently determining their outputs in each country separately under a Cournot competition. This resulted in two-way trade in identical products. Based on the traditional assumption of integrated markets, Markusen (1981) shows that trade by a Cournot oligopoly increases world welfare, but that it is possible for a large country to lose. Krugman (1984) examined whether targeted import protection promotes exports in increasing returns industries by using a trade and oligopoly model. Spencer and Brander (1983) were the pioneers in examining the incentives for research and development (R&D) and export policy in a model of oligopolistic competition (Head and Spencer, 2017). Das and Donnenfeld (1989) examined trade restrictions such as quantity and quality limitations on imports in an oligopolistic industry consisting of foreign and domestic firms. Their findings indicate that the effects of trade policy are determined by the location of the quality produced by the firms in the quality spectrum. They state that a quota results in a positive protection while minimum quality standards lead to negative protection. Although the literature discussed above is very important and path-breaking in many ways, these studies did distinguish between the effect of product quality on international and domestic or intra-national trade. It is possible that the effect on the two types of trade could be qualitatively different even in the absence of production capacity constraints, because of the ways the production and the demand sides of the markets interact. This is the gap in the literature that our paper tries to fill. I do so both theoretically and empirically.

Changing the quality of products have implications not only for international trade, but also for domestic trade. If improving export quality reduces domestic trade, then the effect on economic growth can be compromised. The theoretical framework developed in this study shows that an increase in quality of the high-quality good will increase the exports of both the high-quality and the low-quality good, and will reduce domestic sales. I propose a quantitative framework to estimate the impact of improving export quality on the export performance of developing countries. The demand side of the model is based on the theoretical framework proposed by Khun et al. (2020) to analyze the demand behavior of adoptive parents in the U.S.A. The model is constructed based on a product differentiation framework like the one proposed by Shaked and Sutton (1982).

I have developed a partial equilibrium two-country oligopolistic model in which the home (developing) country produces a high quality and a low quality good but consumes only the low quality good. The developing country exports both the high quality and the low quality good to the foreign (developed) country that also produces the highest quality good. Each country produces a homogeneous high quality good. I assume that the consumers get a higher marginal utility (MU) from the consumption of a high quality good i.e. $u_2 > u_1 > u_0$. Where u_2 is the utility a consumer gets from consuming one unit of high quality good, u_1 is the utility a consumer gets from consuming one unit of low quality good and u_0 is the utility a consumer gets from no consumption. There is a larger demand for high quality goods in the developed country than the developing country hence, I assume that the home (developing) country consumers only consume the low-quality good. The results suggest that an increase in quality of the high-quality good will increase the exports of both the high-quality and the low-quality good, and will reduce domestic sales.

2.1 Set-up

There are different ways that researchers have modelled product quality in oligopolistic models. Helpmand and Grossman (1991) develop a quality ladder model. Shaked and Sutton (1982) focus on the demand side demands for low-quality and high-quality products by incorporating quality in consumer utilities. Khun et al. (2020) use the second approach to analyze the demand behavior of adoptive parents in the U.S.A. In this paper, I also adopt this approach.

P_l represents the price of low quality good and P_h is the price of high quality good in the international market ($P_l < P_h$). Quantity of low quality and high quality good being produced in home country (developing) is q_l^H and q_h^H respectively. q_h^F represents the quantity of high quality good produced in the foreign country (developed country). Let y be the household income. As for the foreign country, there is a continuum identical consumption preferences but differing in incomes. Incomes are uniformly distributed over the interval [0, 1]. Each consumer has three choices: consumes one unit of the low-quality good, or consumes one unit of the high-quality good, or does not consumer either of the two. I denote the three scenarios by q, where q = 0, 1, 2, representing no consumption, consumption of the low-quality good, and consumption of the high-quality good, respectively.

I follow Pliskin, Shepard, and Weinstein (1980) and Shaked and Sutton (1982) to specify the utility function of a consumer as U(c, q) = cu_q, where c is the consumption of other goods and services, u_q is the sub-utility received from consuming one unit of the good with attribute q.

$$U(y_0, q_0) = U(y_0 - P_l, q_1), \tag{1}$$

Using (1) and then solving for y_0, we get:

$$y_0 = \frac{P_l u_1}{u_1 - u_0} \tag{2}$$

Let y^* be the income level such that a consumer is indifferent between high-quality and low-quality goods. Hence, at income level y^*, we have:

$$U(y^* - P_h, q_2) = U(y^* - P_l, q_1) \tag{3}$$

Using Equation (1) and then solving for y^*, we get:

$$y^* = \frac{P_h u_2 - P_l u_1}{u_2 - u_1} \tag{4}$$

The denominators of Equations (2) and (4) represent utility premia of low-quality and high-quality goods, respectively, while the numerators reflect additional costs associated with them. Given product prices and associated utilities, consumers with income $y_0 < y < y^*$ get higher utility from consuming low-quality good than consuming no good at all, that is, $(u_1 - u_0)y > P_l u_1$; hence, they prefer consuming low-quality good over no consumption at all. Consumers with income $y > y^*$ achieve higher utility from consuming one unit of high-quality good than one unit of low-quality good, that is, $[u_2(1 - u_1)]y > P_h u_2 - P_l u_1$; thus, they prefer high-quality good over low-quality good. Therefore, consumers with income $y_0 < y < y^*$ make up the demand for low-quality good (D_l), and consumers with income $y > y^*$ make up the demand for high-quality good (D_h^F), while the remaining consumers do not consume either of the two goods (D_0). The demand for low quality good in the foreign and home country is D_l^F and D_l^H, respectively. The world demand for low quality good is D_l.

$$D_l = D_l^H + D_l^F \tag{5}$$

$$D_0 + D_l^F + D_h^F = 1 \tag{6}$$

$$D_l^F = 1 - D_h^F - D_0 \tag{7}$$

Demand of low-quality good in-home country is:

$$D_l^H = a - bP_l + cP_h \tag{8}$$

Let c = 0 since the home country only consumes the low quality good.

The low quality good is produced only in the home country by only one firm, but the high-quality good is produced by two firms: one in the home country and one in the foreign country. The inverse demand functions for low-quality and high-quality goods are presented in equations (17) and (20), respectively.

$$\int_{y_0}^{y^*} 1\, dy = y^* - y_0 \tag{9}$$

$$D_l^F = \frac{P_h u_2 - P_l u_1}{u_2 - u_1} - \frac{P_l u_1}{u_1 - u_0} \tag{10}$$

$$D_l = \frac{P_h u_2 - P_l u_1}{u_2 - u_1} - \frac{P_l u_1}{u_1 - u_0} + a - bP_l \tag{11}$$

$$\int_{y^*}^{1} y\, dy = 1 - y^* \tag{12}$$

$$D_h^F = 1 - \frac{P_h u_2 - P_l u_1}{u_2 - u_1} \tag{13}$$

$$1 - D_h^F = \frac{P_h u_2 - P_l u_1}{u_2 - u_1} \tag{14}$$

Substituting (14) in (11) we get:

$$D_l = 1 - D_h^F - \frac{P_l u_1}{u_1 - u_0} + a - bP_l \tag{15}$$

$$\frac{P_l u_1}{u_1 - u_0} + bP_l = 1 - D_h^F - D_l + a \tag{16}$$

$$P_l = \frac{(1 - D_h^F - D_l + a)(u_1 - u_0)}{(u_1 + b(u_1 - u_0))} \tag{17}$$

$$P_l = e - fD_h^F - gD_l \tag{18}$$

$$f = \frac{u_1 - u_0}{u_1 + b(u_1 - u_0)} > 0, g = \frac{u_1 - u_0}{u_1 + b(u_1 - u_0)} > 0, e = \frac{(u_1 - u_0)(1 + a)}{u_1 + b(u_1 - u_0)} \tag{19}$$

Substitute (17) in (14) to get P_h

$$\begin{aligned} P_h =& \frac{u_0u_1 - u_1u_2 - u_1u_2b + u_0u_2b + u_1^2b - u_0u_1b}{u_2(u_1 + b(u_1 - u_0))} D_h^F \\ &+ \frac{-u_1(u_1 - u_0)}{u_2(u_1 + b(u_1 - u_0))} D_l \\ &+ \frac{au_1^2 - au_0u_1 - u_0u_1 + u_1u_2 + u_1u_2b - u_0u_2b - u_1^2b + u_0u_1b}{u_2(u_1 + b(u_1 - u_0))} \end{aligned} \tag{20}$$

$$P_h = h - kD_h^F - mD_l \tag{21}$$

$$P_h = h - k(q_h^F + q_h^H) - mq_l^H \tag{22}$$

$$k = -[\frac{u_0u_1 - u_1u_2 - u_1u_2b + u_0u_2b + u_1^2b - u_0u_1b}{u_2(u_1 + b(u_1 - u_0))}] > 0 \tag{23}$$

$$m = \frac{u_1(u_1 - u_0)}{u_2(u_1 + b(u_1 - u_0))} > 0 \tag{24}$$

$$h = \frac{au_1^2 - u_0u_1 - au_0u_1 + u_1u_2 + u_1u_2b - u_0u_2b - u_1^2b + u_0u_1b}{u_2(u_1 + b(u_1 - u_0))} \tag{25}$$

$$h = \frac{au_1(u_1 - u_0) + u_1(u_2 - u_0) + u_2b(u_1 - u_0) - u_1b(u_1 - u_0)}{u_2(u_1 + b(u_1 - u_0)))} > 0 \tag{26}$$

The profit function of the firm producing high quality good in the home country is given in equation (27) where C_h^H is the cost of producing high quality good in the home country.

$$\pi_h^H = P_h q_h^H - q_h^H C_h^H, \tag{27}$$

The profit function of the firm producing low quality good in the home country is given in equation (28) where C_l^H is the cost of producing low quality good in the home country.

$$\pi_l^H = P_l q_l^H - q_l^H C_l^H, \tag{28}$$

Equation (29) presents the profit function of the foreign firm producing high quality good. C_h^F represents the cost incurred by the foreign firm when producing the high quality good.

$$\pi_h^F = P_h q_h^F - q_h^F C_h^F, \tag{29}$$

The First-Order Conditions (FOCs) of the three profit functions in equlibrium are:

$$\frac{\partial \pi_h^H}{\partial q_h^H} = P_h - C_h^H + \frac{\partial P_h}{\partial q_h^H} q_h^H = 0 \tag{30}$$

$$\frac{\partial \pi_l^H}{\partial q_l^H} = P_l - C_l^H + \frac{\partial P_l}{\partial q_l^H} q_l^H = 0 \tag{31}$$

$$\frac{\partial \pi_h^F}{\partial q_h^F} = P_h - C_h^F + \frac{\partial P_h}{\partial q_h^F} q_h^F = 0 \tag{32}$$

Where:

$$-k = \frac{\partial P_h}{\partial q_h^H} = \frac{\partial P_h}{\partial q_h^F} \tag{33}$$

$$-m = \frac{\partial P_h}{\partial q_l^H} \tag{34}$$

$$-f = \frac{\partial P_l}{\partial q_h^H} = \frac{\partial P_l}{\partial q_h^F} \tag{35}$$

$$-g = \frac{\partial P_l}{\partial q_l^H} \tag{36}$$

k > m and g > f as the direct effect is greater than the indirect effect.

Substituting the inverse demand function in equations (30), (31) and (32), we can solve for the three output levels, and then substituting these equilibrium output levels in the two inverse demand functions, I solve for the prices.

2.2 Effects of Quality

I now examine the effect of a change in u_2 on the equilibrium values. An increase in u_2 increases the value consumers attach to quality and therefore raises the demand for the high-quality good in the foreign country. Thus, I see this exercise as an investigation into the effect of a consumer-preference-driven increase in the quality on the levels of exports and on domestic trade. I should note that there is some evidence to suggest that efforts by the developing countries to increase the quality of exports can, to a large extent, be attributed to their response to an increase in demand for high-quality products in the developed countries (Linder, 1961 and Hallak, 2006)). It should also be noted that even though the theoretical model posits a binary division: a low-quality and a high-quality product, an increase in u_2 represents an increase in the level of quality of the high-quality product. Thus, quality is also a continuous variable in our framework.

Proposition 1. Enhancing export quality improves export performance of a country but it will reduce domestic trade.

2.3 Possible Extensions

The below mentioned extensions of the basic model are possible, which will keep all the qualitative results:
i) Production of the low-quality good in the foreign country
ii) No production of the high-quality good in the foreign country or in the domestic country
iii) No domestic demand of the low-quality good in the domestic market, but the presence of demand for the high-quality good there.

Considering demand for both goods in both countries will complicate matter. Depending on which extension you consider, either country can be called a developed or developing country.

3 Empirical Evidence

3.1 Estimation Strategy

This study uses the gravity model like the one suggested by Anderson and van Wincoop (2003) and Bergstrand et al. (2015). The gravity equation derived by Anderson and van Wincoop (2003) is:

$$X_{ij} = \left(\frac{E_j Y_i}{Y_w}\right)\left(\frac{t_{ij}}{P_j \Pi_i}\right)^{1-\sigma}, \quad s > 1 \tag{37}$$

Where X_{ij} represents the value of exports from country i to country j. E_j is the total expenditure in country j. Y_i is the sales of goods by country i at destination prices. Y_w is the world output. t_{ij} is the trade cost factors on exports from country i to country j. P_j and Π_i are inward and outward multilateral resistances, respectively. s represents the elasticity of substitution between the goods.

To estimate the impact of quality on exports, I have followed Paudel and Lahiri's (2023) 2-stage regression approach to separate out the relative and absolute effects. In the first stage, the gravity equation (38) is estimated using the Poisson pseudo-maximum likelihood (PPML) method suggested by Silva and Teneyro (2006) as it caters for potential endogeneity and bias produced by heteroscedasticity, multicollinearity and serial correlation (Álvarez et al. 2018). It can also include zero export values that would've been otherwise excluded if ordinary least square (OLS) was used (Francois and Manchin 2013).

$$\begin{aligned} X_{ijt} = \exp\Bigg[&\beta_0 + \beta_1 \text{RTA}_{ijt} + \beta_2 \text{Linder}_{ijt} + \beta_3 \ln(\text{Quality}_{it}) * \text{INTD}_{ij} \\ &+ \beta_4 \ln(\text{Price}_{it}) * \text{INTD}_{ij} + \beta_5 \ln(\text{Price}_{it}) * \ln(\text{Quality}_{it}) * \text{INTD}_{ij} \\ &+ \mu_{it} + \theta_{jt} + \delta_{ij}\Bigg] + \epsilon_{ijt} \end{aligned} \tag{38}$$

X_{ijt} is the bilateral trade flows from country i to country j at time t. RTA is a binary dummy variable representing regional trade agreements between country i and country j at time t. It takes the value 1 when a regional trade agreement exists between the two countries; otherwise, it takes the value 0. $Linder_{ijt}$ is estimated by taking the absolute value of the difference between the log of GDP per capita of country i and j.[1] $\ln Quality_{it}$ represents the natural logarithm of a quality index, while $\ln Price$ is the natural logarithm of unit value of export and is used to control for the unit price in the quality index. $INTD_{ij}$ is a binary dummy variable that takes the value 1 in the presence of international trade and 0 otherwise.

The variables μ_{it}, θ_{jt}, and δ_{ij} represent exporter-time, importer-time, and pair-wise fixed effects, respectively. The inclusion of exporter-time and importer-time fixed effects is essential to account for changes in macroeconomic conditions or trade policies affecting trade flows that cannot solely be explained by GDP growth or cost differentials, as highlighted by Larson et al. (2018). Pair-wise fixed effects are employed to address endogeneity issues between the dependent variable and time-varying regressors such as RTA and $Linder$ (Kitenge and Lahiri, 2021). Finally, ϵ_{ijt} is the error term in the equation.

[1] $|Linder_{ijt}| = |\ln GDPPC_{it} - \ln GDPPC_{jt}|$

$$\hat{\mu}_{it} = \beta_0 + \beta_1 \ln \text{GDP}_{it} + \beta_2 \ln \text{Quality}_{it} + \beta_3 \ln \text{Price}_{it} + \beta_4 \ln \text{Quality}_{it} * \ln \text{Price}_{it} + \sigma_i + \eta_t + \varepsilon_{it} \quad (39)$$

Equation (39) is used to perform the 2nd stage OLS regression. $\hat{\mu}_{it}$ is the exporter-time fixed effects that we generated from our first regression analysis using the PPML and represent exports of country i at time t. $\ln \text{GDP}_{it}$ is the log of real GDP of country i at time t. $\ln \text{Quality}_{it}$ and $\ln \text{Price}_{it}$ are the log of export quality and log of unit price of exports of country i at time t, respectively. $\ln \text{Quality}_{it} * \ln \text{Price}_{it}$ is the interaction term between the log of quality and log of unit price of exports. σ_i are the country fixed effects, and η_t represents time fixed effects. ε_{it} is the error term.

3.2 Data

I use annual bilateral trade data of 142 countries over the period of 52 years starting from 1963 – 2014 which was constructed by Fouquin and Hugot (2016). This dataset was complemented with observations for intra-national trade following Baier et al. (2016) approach by taking the difference between total domestic production and total export. Data for regional trade agreements (RTA) was constructed by Head et al. (2010) and retrieved from the Centre d'tudes Prospectives et d'Informations Internationales (CEPII). The GDP data from the World Development Indicators (WDI) has been used to calculate the Linder variable. IMF's Export Quality Index and Unit Value of exports are used as a measure of quality and export prices respectively. Data for both the variables is taken from the IMF's Export Quality and Diversification dataset, constructed by Henn et al. (2018) and covers over 800 export products, 166 countries from 1963 - 2014.[2] The quality index has values between 0 -1.2 where higher values of the quality index represent higher quality levels.

Table 1: Descriptive Statistics: Summary Statistics of Variables

	Obs	Mean	SD	Min	Max
X_{ijt}	1,523,462	6.12e+08	3.35e+10	0	9.65e+12
RTA	2,579,198	0.629	0.243	0	1
Linder	1,537,265	1.709	1.254	0	7.361
lnGDP	1,690,501	22.345	2.55	15.169	29.997
lnQuality	1,250,204	-0.250	0.253	-1.999	0.111
lnPrice	2,188,072	4.245	0.521	2.51	6.419
INTD	3,367,647	0.996	0.065	0	1

[2]Henn et al. (2018) used unit values at the SITC 4-digit level and then normalized them into a price index for each 2-digit "sector".

3.2.1 Export Quality Index

Henn et al. (2018) estimate a gravity equation for 851 sectors separately to adjust the unit values for factors other than quality such as production costs, market shares and selection bias (higher priced items make it to far away destinations. The coefficients derived from the gravity equation are then used to derive quality estimates. Once the quality estimates are obtained, they are normalized and aggregated across sectors. For each sector the world frontier (=90th percentile) is set equal to 1. The quality index has values between 0 - 1.2 where higher values of the quality index represent higher quality levels. Henn et al. (2018) used unit values at the SITC 4-digit level and then normalized them into a price index for each 2-digit "sector".

They define trade price (unit value) as a function of unobservable quality θ_{mxt}, exporter income per capita y_{xt}, and distance between importer and exporter, Dist_{mx} as shown in the equation below:

$$\ln p_{mxt} = \zeta_0 + \zeta_1 \ln \theta_{mxt} + \zeta_2 \ln y_{xt} + \zeta_3 \ln \text{Dist}_{mx} + \xi_{mxt} \tag{40}$$

Then they estimate a quality augmented gravity equation, specified separately for each product as trade costs and quality may vary across products.

$$\ln(Imports)_{mxt} = FE_m + FE_x + \alpha \ln(Dist_{mx}) + \beta I_{mxt} + \delta \ln(\theta_{mxt}) \ln(y_{mt}) + \epsilon_{mxt} \tag{41}$$

Where FE_m and FE_x represent importer and exporter fixed effects respectively. The matrix I_{mxt} is a set of standard trade determinants from the gravity literature. $ln(\theta_{mxt})ln(y_{mt})$ is the interaction term between the exporter-specific quality parameter and the importer's income per capita.[3]

4 Results

In this section, I will present our results for the empirical analysis and the robustness checks. Table 2 presents the results of the PPML regression analysis for all four specifications. The first column is presented for reference purpose only; it has two of the key variables of gravity analysis, viz., RTA (regional trade agreement) and Linder, but does not include lnQuality*INTD. The coefficients of RTA and Linder are positive and negative and statistically significant, as one would expect. The second column gives our main regression and it includes lnQuality*INTD. The coefficient of this variable is highly significant and positive. This implies that an increase in export quality significantly increases exports relative to intra-country trade (domestic trade). The coefficients of RTA and Linder continues to as before qualitatively, the magnitude of their effects go down significant. That is, the absence of lnQuality*INTD possibly introduces an upward

[3]Detailed methodology about how Export Quality Index was calculated can be found here: https://www.imf.org/external/np/seminars/eng/2014/trade/pdf/henn.pdf

omitted-variable bias in the magnitudes of these two variables. I find that a 1% increase in Quality increases exports (relative to domestic trade) by 4.45%.

The next two columns introduces variables involving lnPrice in order to see if our results that quality increases exports, is robust under the new specifications. I find that it is robust. Price has a positive effect on exports (relative to domestic sales). This is possibly a supply-side effect. This effect gets amplified as the the quality of exports increases.

Table 3 presents the results of the second-stage OLS regression analysis, i.e., OLS results for equation (39). AS mentioned before, the coefficients of this table give us the value of coefficients for intra-country trade. The sum of the coefficients here plus the corresponding coefficients give the values for the effect on international trade. Column 1 presents the reference regression with only one important variable, viz., GDP which has the country-time dimension. The next equation is the key equation and it includes the variable lnQuality. The next two columns introduces the variable lnPrice and its interaction with lnQuality to examine the robustness of the result on the effect of product quality on trade. The coefficient of GDP is positive and significant throughout, as one would expect. However, interestingly, the coefficient of lnQuality is negative and significant throughout, implying that an incrase in export quality has a negative effect on domestic trade. An one percent increase in quality reduces domestic trade by 3.3%. The total effects of lnQuality and other variables on International and Intra-national trade are presented in Table 6.

Table 2: First Stage PPML Estimates

Dependent Variable: Total Exports	(1)	(2)	(3)	(4)
RTA	0.426***	0.271***	0.176***	0.173***
	(0.0586)	(0.0542)	(0.0516)	(0.0517)
Linder	-0.292***	-0.190***	-0.0867***	-0.0861***
	(0.0254)	(0.0250)	(0.0276)	(0.0279)
lnQuality*INTD		4.455***	3.633***	2.114***
		(0.424)	(0.419)	(0.782)
lnPrices*INTD			0.457***	0.489***
			(0.0363)	(0.0444)
lnPrices*lnQuality*INTD				0.390**
				(0.168)
Observations	1,113,248	851,574	845,830	845,830
R-square	0.9979	0.9978	0.9979	0.9979
Exporter*Time FE	Yes	Yes	Yes	Yes
Importer*Time FE	Yes	Yes	Yes	Yes
Pair FE	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: Second-Stage OLS regression Estimates

Dependent Variable: ETFE	(1)	(2)	(3)	(4)
lnGDP	0.607***	0.626***	0.564***	0.578***
	(0.0077)	(0.0109)	(0.0113)	(0.0115)
lnQuality		-3.289***	-2.620***	-2.3122***
		(0.0324)	(0.0315)	(0.1532)
lnPrice			-0.178***	-0.133***
			(0.0163)	(0.021)
lnPrice*lnQuality				-0.090***
				(0.0353)
Observations	8,549	6,258	6,189	6,189
R-square	0.9886	0.9837	0.9866	0.9866
Exporter FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

4.0.1 Effects of Quality on OECD and Non-OECD countries

In the preceding analysis, we have seen that export quality increases exports, but reduces domestic or intra-national trade. In this section, I want to see if there are heterogeneities in these relationships. In particular, I want to examine if these relationships vary between Organization of Economic Cooperation and Development (OECD) member countries and the non-OECD countries. For this, I define a dummy variable OECD which takes the value 1 if the exporting country belongs to OECD, and 0 otherwise. I then modify equations (38) and (39) to include a terms that interacts with the quality variable. That is, I estimate:

$$X_{ijt} = \exp\Big[\beta_0 + \beta_1 \text{RTA}_{ijt} + \beta_2 \text{Linder}_{ijt} + \beta_3 \ln(\text{Quality}_{it}) * \text{INTD}_{ij} + \beta_4 \ln(\text{Price}_{it}) * \text{INTD}_{ij} + \beta_5 * \ln(\text{Quality}_{it}) * \text{INTD}_{ij} * \text{OECD}_i + \mu_{it} + \theta_{jt} + \delta_{ij}\Big] + \epsilon_{ijt} \quad (42)$$

$$\hat{\mu}_{it} = \beta_0 + \beta_1 \ln \text{GDP}_{it} + \beta_2 \ln \text{Quality}_{it} + \beta_3 \ln \text{Price}_{it} + \beta_4 \ln \text{Quality}_{it} * \text{OECD}_i + \sigma_i + \eta_t + \varepsilon_{it} \quad (43)$$

The results of the first-stage and second stage regression are shown in Tables 4 and 5 respectively. The effect of improving export quality both on exports and on intra-national trade are more pronounced for OECD countries than for the non-OECD countries. That is the estimated value of β_5 in Table 4 is positive and significant, and that of α_4 is negative and significant. As for the magnitude of the effects, based on the last columns of tables 4 and 5, I find that an one percent increase in export quality increase exports of OECD countries by 3.18 (=3.023+4.778-2.236 -2.383)% and that of non-OECD countries by 0.79 (=3.023-2.236)%. Quality has a negative impact on the domestic trade of both OECD and non-OECD countries. An one percent increase in export quality reduces domestic trade of OECD countries by 4.61 (=2.236+2.283)% and of non-OECD countries by 2.24%. The total effects of export quality on exports for both OECD and non-OECD countries are shown in Table 6. The column numbers in Table 6 correspond to the column numbers in Tables 2, 3, 4 and 5.

Table 4: First Stage PPML Estimates

Dependent Variable: Total Exports	(5)
RTA	0.167***
	(0.5045)
Linder	-0.102***
	(0.0263)
lnQuality*INTD	3.023***
	(0.4595)
lnPrices*INTD	0.446***
	(0.3432)
lnQuality*INTD*OECD	4.778***
	(0.9147)
Observations	845,830
R-square	0.9979
Exporter*Time FE	Yes
Importer*Time FE	Yes
Pair FE	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Second Stage OLS Estimates

Dependent Variable: ETFE	(5)
lnGDP	0.564***
	(0.011)
lnQuality	-2.236***
	(0.0308)
lnPrices	-0.168***
	(0.0159)
lnQuality*OECD	-2.383***
	(0.2239)
Observations	6,189
R-square	0.9979
Exporter FE	Yes
Time FE	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.0.2 Total effects of Quality and Price

Table 6: Total Effects

	Intranational Trade				International Trade			
	(2)	(3)	(4)	(5)	(2)	(3)	(4)	(5)
Ln_Quality	-3.288754***	-2.620068***	-2.69309**		1.165931***	1.013028***	1.076782**	
Ln_Price		-0.1778905***	-0.514209**			0.2791984**	1.02841**	
Ln_Quality (OECD)				- 4.618456***				3.182612***
Ln_Quality (Non-OECD)				-2.235771***				0.787644***

4.1 Results with 3-year interval data

Finally, Chang and Wall (2005) suggest that the adjustment of trade in response to changes in other covariates can takes time, and recommend using intervals data instead of continuous panel data. In this section, I ran the same regressions as in Table 2 and 3 with 3-year interval data and the results are reported in Tables 7 and 8. The results remain qualitative the same.

Table 7: First Stage PPML estimates with 3-year intervals

Dependent Variable: Total Exports	(1)	(2)	(3)	(4)
RTA	0.342***	0.289***	0.170***	0.167***
	(0.0544)	(0.0558)	(0.0526)	(0.0526)
Linder	-0.220***	-0.1852***	-0.0668***	-0.0657***
	(0.0245)	(0.0250)	(0.0276)	(0.0280)
lnQuality*INTD		4.667***	3.757***	2.042***
		(0.4547)	(0.4554)	(0.7841)
lnPrices*INTD			0.509***	0.544***
			(0.0342)	(0.0416)
lnPrices*lnQuality*INTD				0.453***
				(0.1699)
Observations	679,678	283,372	281,650	281,650
R-square	0.9983	0.9977	0.9979	0.9979
Exporter*Time FE	Yes	Yes	Yes	Yes
Importer*Time FE	Yes	Yes	Yes	Yes
Pair FE	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Second-Stage OLS regression with 3-year intervals

Dependent Variable: ETFE	(1)	(2)	(3)	(4)
lnGDP	0.628***	0.638***	0.576***	0 .590***
	(0.0098)	(0.0181)	(0.0185)	(0.0190)
lnQuality		-3.502***	-2.762***	-2.344***
		(0.0544)	(0.0519)	(0 .2575)
lnPrice			-0.229***	-0.185***
			(0.0271)	(0.0341)
lnPrice*lnQuality				-0.128**
				(0.0589)
Observations	4,977	2,152	2,129	2,129
R-square	0.9906	0.9851	0.9883	0.9881
Exporter FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5 Conclusion

This paper provides a comprehensive analysis of the impact of improving the export quality on international and domestic trade. The theoretical framework developed in this study shows that an increase in quality of the high-quality good will increase the exports of both the high-quality and the low-quality good, and will reduce domestic sales in the absence of any overall capacity constraint.

The empirical findings from the gravity analysis support my theoretical predictions. That is, product quality matters for international trade only, impacting exports positively. However, product quality and domestic trade have a negative relationship. Higher quality and high prices reduce domestic trade. The positive effect of improving export quality on the exports is more pronounced for OECD countries than the non-OECD countries. On the other hand, the negative effect of product quality on domestic trade is also more pronounced for the OECD member countries.

Thus, as a policy prescription, countries need to be careful when adopting policies to enhance international trade via quality improvement. They also to adopt policies to stimulate domestic trade and otherwise export promotion policy might compromise domestic trade.

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Appendix

Additional details of the estimation strategy

The three First-Order Conditions (FOCs) of the profit function are:

$$\frac{\partial \pi_h^H}{\partial q_h^H} = P_h - C_h^H - kq_h^H = 0 \tag{44}$$

$$\frac{\partial \pi_l^H}{\partial q_l^H} = P_l - C_l^H - gq_l^H = 0 \tag{45}$$

$$\frac{\partial \pi_h^F}{\partial q_h^F} = P_h - C_h^F - kq_h^F = 0 \tag{46}$$

$$P_h - kq_h^H = C_h^H \tag{47}$$

$$P_l - gq_l^H = C_l^H \tag{48}$$

Applying Cramer's Rule:

$$\begin{bmatrix} G_{h1}^H & G_{h2}^H & G_{h3}^H \\ G_{h1}^F & G_{h2}^F & G_{h3}^F \\ G_{l1}^H & G_{l2}^H & G_{l3}^H \end{bmatrix} \begin{bmatrix} dq_h^H \\ dq_h^F \\ dq_l^H \end{bmatrix} = - \begin{bmatrix} G_{h4}^H \\ G_{h4}^F \\ G_{l4}^H \end{bmatrix} du_2$$

$$\frac{\partial \pi_h^H}{\partial q_h^H} = P_h - C_h^H + kq_h^H = 0 \tag{49}$$

$$G_{h1}^H = -2k \tag{50}$$

$$G_{h2}^H = -k \tag{51}$$

$$G_{h3}^H = -m \tag{52}$$

$$G_{h4}^H = \frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^H \tag{53}$$

$$\frac{\partial \pi_h^F}{\partial q_h^F} = P_h - C_h^F - kq_h^F = 0 \tag{54}$$

$$G_{h1}^F = -k \tag{55}$$

$$G_{h2}^F = -2k \tag{56}$$

$$G_{h3}^F = -m \tag{57}$$

$$G_{h4}^F = \frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^F \tag{58}$$

$$\frac{\partial \pi_l^H}{\partial q_l^H} = P_l - C_l^H - g q_l^H = 0 \tag{59}$$

$$G_{l1}^H = -f \tag{60}$$

$$G_{l2}^H = -f \tag{61}$$

$$G_{l3}^H = -2g \tag{62}$$

$$G_{l4}^H = \frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \tag{63}$$

$$|P| = -G_{h4}^H (G_{h2}^F G_{l3}^H - G_{h3}^F G_{l2}^H) - G_{h2}^H (-G_{h4}^F G_{l3}^H + G_{h3}^F G_{l4}^H) + G_{h3}^H (-G_{h4}^F G_{l2}^H + G_{h2}^F G_{l4}^H) \tag{64}$$

$$\begin{aligned} |P| = &- \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^H \right) [4kg - mf] + k \left[2g \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^F \right) - m \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \right) \right] \\ &- m \left[f \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^F \right) - 2k \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \right) \right] \end{aligned} \tag{65}$$

$$\begin{aligned} |P| = &- \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^H \right) [4kg - mf] + [2kg \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^F \right) - mk \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \right)] \\ &- [mf \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^F \right) - 2mk \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \right)] \end{aligned} \tag{66}$$

$$
\begin{aligned}
|P| = &-4kg\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) + mf\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) \\
&+ 2kg\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^F\right) - mk\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) - mf\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^F\right) \\
&+ 2mk\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right)
\end{aligned} \tag{67}
$$

$$
|P| = -2kg\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) + mk\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) \tag{68}
$$

$$
\frac{dq_h^H}{du_2} = \frac{|P|}{|A|} = \frac{-2kg\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) + mk\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right)}{(-k)[6kg - 2mf]} \tag{69}
$$

$$
\frac{dq_h^H}{du_2} = \frac{|P|}{|A|} = \frac{2g\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) - m\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right)}{[6kg - 2mf]} \tag{70}
$$

$$
g = \frac{u_1 - u_0}{u_1 + b(u_1 - u_0)} > 0 \tag{71}
$$

$$
m = \frac{u_1(u_1 - u_0)}{u_2(u_1 + b(u_1 - u_0))} > 0 \tag{72}
$$

So $g > m$

$$
\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H > \frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H \tag{73}
$$

$$
\frac{dq_h^H}{du_2} = \frac{2g\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) - m\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right)}{[6kg - 2mf]} > 0 \tag{74}
$$

$$
\frac{dq_l^H}{du_2} = \frac{|Q|}{|A|} \tag{75}
$$

$$
|Q| = G_{h1}^H(-G_{h2}^F G_{l4}^H + G_{h4}^F G_{l2}^H) - G_{h2}^H(-G_{h1}^F G_{l4}^H + G_{h4}^F G_{l1}^H) - G_{h4}^H(G_{h1}^F G_{l2}^H - G_{h2}^F G_{l1}^H) \tag{76}
$$

$$|Q| = -2k\left[2k\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) - f\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^F\right)\right]$$
$$+ k\left[k\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) - f\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^F\right) - \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right)(kf - 2kf)\right] \tag{77}$$

$$|Q| = -3k^2\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) + 2kf\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) \tag{78}$$

$$\frac{dq_l^H}{du_2} = \frac{|Q|}{|A|} = \frac{3k\left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) - 2f\left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right)}{[6kg - 2mf]} \tag{79}$$

$$k > f, \frac{\partial k}{\partial u_2} < 0; \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) > 0 \text{ and } \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2}q_l^H\right) < \left(\frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2}q_h^H\right) \text{ so } \frac{dq_l^H}{du_2} < 0 \tag{80}$$

$$k = -\frac{(u_0u_1 - u_1u_2 - u_1u_2b + u_0u_2b + u_1^2b - u_0u_1b)}{u_2(u_1 + b(u_1 - u_0))} > 0 \tag{81}$$

$$\frac{\partial k}{\partial u_2} = -\frac{(u_1 + u_1b - u_0b)(u_1 + b(u_1 - u_0))}{[u_2(u_1 + b(u_1 - u_0))]^2} \tag{82}$$

$$\frac{\partial k}{\partial u_2} = -\frac{(u_1 - b(u_1 - u_0))(u_1 + b(u_1 - u_0))}{[u_2(u_1 + b(u_1 - u_0))]^2} < 0 \tag{83}$$

$$P_h = \frac{1}{u_2(u_1 + b(u_1 - u_0))}\left[D_h^F\left(u_1(u_0 - u_2) - u_2b(u_1 - u_0) + u_1b(u_1 - u_0)\right)\right.$$
$$\left. + D_l\left(-u_1(u_1 - u_0)\right) + au_1^2 - au_0u_1 - u_0u_1 + u_1u_2 + u_1u_2b - u_0u_2b - u_1^2b + u_0u_1b\right] \tag{84}$$

$$\frac{\partial P_h}{\partial u_2} = \frac{(u_1 + b(u_1 - u_0))\left[(u_1 + b(u_1 - u_0))D_h^F + u_1(u_1 - u_0)D_l - (u_1 + u_1b - u_0b)(u_1 + b(u_1 - u_0))\right]}{[u_2(u_1 + b(u_1 - u_0))]^2} \tag{85}$$

$$\frac{\partial P_h}{\partial u_2} = \frac{(u_1 + b(u_1 - u_0))}{[u_2(u_1 + b(u_1 - u_0))]^2}\left[(u_1 + b(u_1 - u_0))D_h^F + u_1(u_1 - u_0)D_l - (u_1 + b(u_1 - u_0))\right] > 0 \tag{86}$$

Total Derivative of prices:

$$dP_h = dkq_h^H + dq_h^H k \tag{87}$$

$$dP_l = dgq_l^H + dq_l^H g \tag{88}$$

$$\frac{dP_h}{du_2} = \frac{\partial P_h}{\partial u_2} - \frac{\partial k}{\partial u_2} q_h^H \tag{89}$$

$$\frac{dP_l}{du_2} = \frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \tag{90}$$

$$\frac{dD_l^H}{du_2} = -b \frac{dP_l}{du_2} \tag{91}$$

$$\frac{dD_l^H}{du_2} = -b \left(\frac{\partial P_l}{\partial u_2} - \frac{\partial g}{\partial u_2} q_l^H \right) \tag{92}$$

Since $\frac{\partial P_l}{\partial u_2} > 0$ and $\frac{\partial P_l}{\partial u_2} > \frac{\partial g}{\partial u_2} q_l^H$, so $\frac{dD_l^H}{du_2} < 0$.

$$D_l = \frac{P_h u_2 - P_l u_1}{u_2 - u_1} - \frac{P_l u_1}{u_1 - u_0} + a - bP_l \tag{93}$$

$$P_l = \frac{(u_1 - u_0)(D_l - a)(u_1 + u_1 b - u_0 b) - P_h u_2 (u_1 - u_0)}{(u_0 u_1 - u_1 u_2 - b u_1 u_2 + b u_1^2 + b u_0 u_2 - b u_0 u_1)} \tag{94}$$

$$\begin{aligned} \frac{\partial P_l}{\partial u_2} = & \frac{(u_1 - u_0)(D_l - a)(u_1 + b(u_1 - u_0))}{(u_0 u_1 - u_1 u_2 - b u_1 u_2 + b u_1^2 + b u_0 u_2 - b u_0 u_1)^2} \\ & + \frac{P_h (u_1 - u_0)(u_1 + b(u_1 - u_0))}{(u_0 u_1 - u_1 u_2 - b u_1 u_2 + b u_1^2 + b u_0 u_2 - b u_0 u_1)^2} \\ & + \frac{u_2 (u_1 - u_0)(u_1 + b(u_1 - u_0)) \frac{\partial P_h}{\partial u_2}}{(u_0 u_1 - u_1 u_2 - b u_1 u_2 + b u_1^2 + b u_0 u_2 - b u_0 u_1)^2} \end{aligned} \tag{95}$$

$$\frac{\partial P_l}{\partial u_2} > 0 \tag{96}$$