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Export price and quality adjustment: The role of financial stress and exchange rate☆

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ABSTRACT

This paper constructs a heterogeneous international trade model to investigate the impact of financial stress and exchange rate on credit-constrained exporting firms' price and quality adjustments. Given that the elasticity of the cut-off cost is higher than the threshold, our model predicts that exporting firms would increase export prices and upgrade quality during times of financial stress or when foreign currency appreciates. Additionally, the incomplete pass-through of exchange rate to prices tends to be greater during times of financial stress. Our predictions on the adjustment effects of export price and quality are broadly confirmed by the trade data of China and its major trading partners from 2001 to 2011.

1. Introduction

Pricing to market (PTM) is a common practice of importing and exporting firms in maintaining or changing their import or export prices to the host or foreign market when exchange rate changes (Krugman, 1986). A large body of literature has focused on how exporting firms adjust their export prices or quantities when exchange rate varies (Martín and Rodríguez, 2004; Gopinath and Rigobon, 2008; Gopinath and Itskhoki, 2010; Gopinath et al., 2010; Berman et al., 2012). Whereas upgrading or downgrading product quality in response to exchange rate fluctuations is also a feasible choice for exporting firms, as Mallick and Marques (2016) find that for exporters in China, an exchange rate depreciation increases their mark-up because of higher product quality. Few works of literature, however, has modeled the product quality adjustment from this perspective. In addition, most exporting firms require external capital to export, which makes well-functioning financial institutions necessary to support the global exchange of goods and services (Manova, 2013). Also, as Choi and Lugovskyy (2019) mentioned, credit and liquidity constraints constitute a formidable obstacle to exporting. Hence, financial stress indeed is a problem faced by credit-constrained exporters. The aforementioned facts raise questions on how credit-constrained firms adjust their exporting strategies, i.e. export price and quality, when exchange rate and financial stress vary, and how the degree of incomplete exchange rate pass-through (ERPT) to prices varies during times of financial stress.

Recent studies on the relationship between the exchange rate with financial stress and export price and quality for credit-constrained firms seem to be relatively underexplored. This paper, therefore, aims to fill this gap by exploring how financial stress would affect the exporting strategies of price and quality adjustments for credit-constrained firms in response to exchange rate movements. We incorporate the exchange rate and the financial stress level, a measure of credit constraints, into a general equilibrium model. In addition, the proxy for the financial stress level is the product of interest rate and the external finance dependence index, so that our financial stress proxy would be time-varying. Therefore, we can theoretically and empirically present that exporters upgrade their product quality when financial stress intensifies. Also, a currency appreciation in exporters' country results in increased export prices and improved product quality.

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Our model theoretically shows how exporters set up their export prices in response to exchange rate movement and changes in financial stress. From the home consumers' point of view, when importing goods become relatively expensive in the domestic market, consumers in the host country might choose domestic goods rather than imported products provided by foreign exporters. If the cut-off cost elasticity with respect to the exchange rate is positive and sufficiently large, foreign exporters can raise the export price to maintain their profit in the host country. Also, we assume that only exporters are credit-constrained. Therefore, when the degree of financial stress increases for those marginal exporters, they would try to increase their prices to earn more profit and to alleviate their financial stress, which helps remain in the exporting markets. Moreover, our model predicts that when the degree of financial stress increases, foreign exporters might increase the magnitude of the adjustment of export prices caused by the exchange rate movement so that they could earn higher revenues to alleviate the cost pressure caused by an increased degree of financial stress.

Regarding the impact of the exchange rate movement and financial stress on their export quality, our model predicts that foreign exporters may upgrade their export product quality in response to the foreign currency appreciation when the elasticity of the cut-off cost with respect to the exchange rate is positive and sufficiently large. The possible channel is that consumers often think that high-priced items reflect high quality, therefore, foreign exporters tend to upgrade the quality of their products to make consumers feel all be worth it. Besides, foreign exporters would raise their export quality in response to an increase in the degree of financial stress. An increase in the degree of financial stress means a higher entry barrier for the marginal exporters, and it also means a higher probability of leaving the exporting market. Therefore, financial stress pushes firms to upgrade the export quality. This model also predicts that when the degree of financial stress grows higher, foreign exporters are more willing to increase the magnitude of the adjustment of export quality led by the exchange rate movement.

The unifying framework in this paper provides some testable predictions: (i) severe financial stress increases export prices and pushes firms to upgrade export quality; (ii) export prices increase and export quality improves as foreign currency appreciates; (iii) financial stress amplifies the effects of exchange rate variation on export price and quality adjustments, and the total effects are dependent on the elasticity of the cut-off cost with respect to the exchange rate and financial stress. Empirically, we test our theoretical predictions by looking at the export unit prices and export quality to China from its three major trading partners, i.e. Germany, Japan, and Korea, from 2001 to 2011. The empirical results from estimating a two-level fixed-effects model are broadly supportive of the theoretical predictions.

This paper contributes to research on the incompleteness of ERPT and provides more insights into ERPT under financial stress. As Strasser (2013) pointed, we have little knowledge of the role of financing constraints for ERPT. Although there is a growing body of literature on the effects of credit constraints on international trade, most of them do not consider the influence of exchange rate fluctuation on product quality (Bellone et al., 2010; Goksel, 2012; Fan et al., 2015). Therefore, they could not say much about the impact of the interaction of exchange rate and credit constraints on the behaviors of exporting firms. For example, Fan et al. (2015) investigate the impacts of credit constraints on export prices by introducing endogenous quality and credit constraints into Arkolakis (2010), however, their model does not consider the effect of the exchange rate on product quality. Egger et al. (2018) use a heterogeneous firm model to study the role of credit constraints for product prices, endogenous mark-up, and welfare in closed and open economies. Their model closely follows Manova's (2013) setting on credit constraints, but the exchange rate plays no role in their paper. Peters and Schnitzer (2015) develop a heterogeneous-firm model with the technology adoption decision. The credit constraint in their model is based on the fact that firms need external funds to finance their technology adoption decision, but the exchange rate is still not a part of their paper. Choi and Lugovskyy (2019) introduce liquidity constraints into a discrete choice model and show that the effects of financial development, proxied by the ratio of private credit to GDP, on export quality and prices are nonlinear and vary greatly across countries. The real exchange rate serves as a control variable in their paper so that they can empirically investigate the impact of real exchange rate on export quality. However, they do not pay much attention to the mechanism of incomplete ERPT to prices under a tightening credit situation. Our model predicts that the incomplete ERPT to prices tends to be greater during financial stress periods.

This paper also relates to the literature of PTM. Mallick and Marques (2012) study the link between PTM and trade liberalization in India. They suggest that an upward trend of exchange rates reflects quality-upgrading by Indian exporters, but they do not further investigate the impact of exchange rate on product quality. It seems that an increasing number of related theoretical research work looks at the role of product quality on the determinant of the global pattern of trade (Hallak, 2006; Kugler and Verhoogen, 2012), and how government policies affect product quality adjustment (Shin and Kim, 2010; Meng et al., 2020). Very few of them consider the feature of the credit constraint of exporting firms, which is one of the key factors in our model. For example, based on the product-level data in China and India, Mallick and Marques (2016) provide empirical evidence about the impacts of product quality on product pricing and find that Indian exporters tend to decrease the foreign export prices when exchange rate depreciates, reflecting a decrease in the mark-up due to the absence of quality upgrading. For exporters in China, a similar exchange rate depreciation increases their mark-up because of higher product quality. In this paper, when considering the financial stress and the exchange rate simultaneously, the model predicts that exporting firms would increase export prices and upgrade product quality when facing severe financial stress and an appreciation in the foreign currency. Moreover, our model shows that the interaction of financial stress and the exchange rate leads to a stronger quality adjustment effect when financial stress increases. Auer et al. (2018) show how PTM is formed by both the product quality and consumers' valuation for quality theoretically and empirically. They find that the good's price is positively associated with its quality, and the link is stronger in wealthier market than in poorer market. Besides, the degree to which prices asymmetrically react to the variation of exchange rate is dependent on the interaction of product quality and destination market income. Still, financial stress is not mentioned in their research. Within a symmetric market framework, this paper theoretically shows that the quality adjustment effect, the impact of financial stress on exporting firms choosing quality in response to the exchange rate movement, is stronger when the degree of financial stress increases.

The paper is organized as follows. The next section includes the model setting and comparative analysis, as well as the testable predictions. Section 3 examines theoretical predictions empirically through a fixed-effects model at the industry and the country level. The last section concludes.

2. Model setting

To study exporting firms' decision in pricing and product quality strategy, we extend the model developed by Antoniades (2015) and Kosaka (2014) to construct a two-country heterogeneous trade model with the features of financial stress, endogenous product quality choices and exchange rate fluctuations.

2.1. Consumers

We start from a symmetric case that labor is immobile between two countries, host (h) and foreign (f), and assume that consumers in the two countries have identical preferences as the setting in

Antoniades (2015). The consumer preference is

$$U = q_0 + \alpha \int_{i\in\Omega} (q_i + z_i)di - \frac{1}{2}\gamma \int_{i\in\Omega} (q_i - z_i)^2 di$$
$$-\frac{1}{2}\eta(\int_{i\in\Omega} (q_i - \frac{1}{2}z_i)di)^2, \tag{1}$$

where preference is defined over a homogeneous good chosen as numeraire, and a continuum of horizontally-differentiated varieties indexed by $i \in \Omega$. q_0 and q_i denote the individual consumption levels of the numeraire good and variety i, respectively. z_i is the quality level of variety i. γ is used to measure the level of product differentiation among varieties. α and η are used to describe the degree of substitution between each variety and the numeraire. We assume that all parameters are positive.

The linear inverse demand function for each variety i in country l, $l = \{h,f\}$, is

$$p_i = \alpha - \gamma q_i^c + \gamma z_i - \eta Q, \tag{2}$$

where $Q = \int_{i\in\Omega} (q_i - \frac{1}{2}z_i)di$.

Then, the linear market demand function for variety i in country l is given as

$$q_i^l \equiv \frac{\alpha}{\eta N^l + \gamma} - \frac{1}{\gamma}p_i^l + \frac{\eta N^l}{(\eta N^l + \gamma)\gamma}\overline{p}^l + z_i^l - \frac{1}{2}\frac{\eta N^l}{\eta N^l + \gamma}\overline{z}^l, \tag{3}$$

where q_i^l is the quantity demanded of good i in country l; p_i^l and $\overline{p}^l = \frac{1}{N}\int_{i\in\Omega} p_i^l di$ stand for the price and the average price of good i in country l; z_i^l and $\overline{z}^l = \frac{1}{N}\int_{i\in\Omega} z_i^l di$ denote the quality and the average quality of variety i in country l. There are N^l firms selling in country l, and a firm can sell its products to home and foreign markets.

2.2. Cost function and credit constraint

Assume firms can serve domestic and foreign markets at the same time, and markets are segmented. Therefore, firms can choose separate levels of quality of products for two different markets. Firms have to pay $\tau^l c_i$ to ship good i to country l, where τ^l is the per unit shipping cost to country l and the shipping cost for serving domestic market firms only is one; c_i is the marginal cost of production. Taking domestic exporting firms as an example, the cost function of domestic exporting firms in foreign markets is

$$TC_{iX}^l = \tau^l c_i q_{iX}^l + \theta(z_{iX}^l)^2, \tag{4}$$

where $\theta(z_{iX}^l)^2$ is a fixed amount that firms spend on upgrading product quality which is unrelated to production level, and θ captures the cost of innovation.

In this paper, we assume that labor is the only production factor which is inelastically supplied in a competitive market, and one unit of labor input could produce one unit of q. Let p_D^l and q_D^l be the price and quantity level of the profit maximizing problem in the domestic market, respectively. Firms can serve domestic and foreign markets at the same time, and we assume that firms are not bothered by financial constraints when they serve the domestic market. Hence, firms serving their domestic market face the following profit maximization problem:

$$\pi_D^l(c,z) = [\alpha - \frac{\gamma}{1}q(c,z) + \gamma z_D^l - \eta Q]q_D^l(c,z) - (cq(c,z) + \theta(z_D^l)^2), \tag{5}$$

where the superscript $l = \{h,f\}$ refers firms in the host or foreign country. We use a subscript to describe whether firms serve domestic (D) market or export (X) their products to other countries. We assume that there is no financial constraint for firms when they serve their domestic market, therefore firms' performance measures are identical to the closed economy situation in Antoniades (2015), which can be expressed as below:

$$\pi_D^h = \frac{1}{4\gamma}\left(1 + \lambda_D^h\right)(c_D^h - c)^2, \tag{6}$$

$$p_D^h(c_D^h, z_D^h) = \frac{1}{2}(c_D^h + c) + \frac{\gamma}{2}z_D^h, \tag{7}$$

$$q_D^h(c_D^h, z_D^h) = \frac{1}{2\gamma}(c_D^h - c) + \frac{1}{2}z_D^h, \tag{8}$$

$$\left(z_D^h\right)^* = \frac{1}{4\theta - \gamma}(c_D^h - c). \tag{9}$$

Similarly, performance measures for foreign firms serving foreign market are

$$\pi_D^f = \frac{1}{4\gamma}\left(1 + \lambda_D^f\right)(c_D^f - c)^2, \tag{10}$$

$$p_D^f(c_D^f, z_D^f) = \frac{1}{2}(c_D^f + c) + \frac{\gamma}{2}z_D^f, \tag{11}$$

$$q_D^h(c_D^f, z_D^f) = \frac{1}{2\gamma}(c_D^h - c) + \frac{1}{2}z_D^f, \tag{12}$$

$$\left(z_D^f\right)^* = \frac{1}{4\theta - \gamma}(c_D^f - c). \tag{13}$$

For credit constrained exporting firms, we follow the setting in Kosaka (2014) and assume that firms need to raise external funds to finance partition, $0 < \sigma < 1$, of their total cost (TC). Firms rely more on external finance when σ increases. Therefore, firms' external financial need is σTC_X. Let p_X^l and q_X^l be the foreign market price and quantity level of the profit maximizing, respectively. Export price of a firm in host country in terms of host currency is $p = \frac{p_X^l}{e}$, where e is the exchange rate that refers to the price of host currency per unit of foreign currency, thus an increase in e means a depreciation of the host currency.

The profit maximization problem for foreign exporting firms is

$$\pi_X^f = \frac{1}{e}p_X^f q_X^f - \widetilde{\sigma}^* \left[\tau^f c q_X^f + \theta\left(z_X^f\right)^2\right], \tag{14}$$

where π_X^f and p_X^f are denominated in two different currencies, p_X^f is the price which is set in terms of the currency of the destination, and π_X^f shows in the currency of origin country. For example, when a Japanese firm exports goods to China, the currency in this case used in π_X^f is the JPY and p_X^f is denominated in CNY.

Firms' financial stress is denoted as $\widetilde{\sigma}^* = 1 + \sigma^* r$. In Kosaka (2014), $\widetilde{\sigma}^*$ is influenced by the share of external fund σ^* and the interest rate r. Both the share of external fund and the interest rate are exogenous, which denote the unit rate of return of external fund. σ^* and r are used as measures of financial constraints. $\tau^f > 1$ is the iceberg transportation cost.

Solving the profit maximization problem for foreign exporting firms, we can have price, quantity, revenue and profit function for foreign exporting firms in terms of c, c_X^l and e.

$$\pi_X^f = \frac{e\left(\widetilde{\sigma}^*\tau^f\right)^2}{4\gamma}\left(1 + \frac{\gamma}{e}\lambda_X^f\right)(c_X^f - c)^2, \tag{15}$$

$$p_X^f = \frac{e\widetilde{\sigma}^*\tau^f}{2}(c_X^f + c) + \frac{\gamma}{2}z_X^f, \tag{16}$$

$$q_X^f = \frac{e\widetilde{\sigma}^*\tau^f}{2\gamma}(c_X^f - c) + \frac{1}{2}z_X^f, \tag{17}$$

$$\left(z_X^f\right)^* = \frac{e\widetilde{\sigma}^*\tau^f}{4\theta\widetilde{\sigma}^* e - \gamma}(c_X^f - c) = \widetilde{\sigma}^*\tau^f\lambda_X^f(c_X^f - c), \tag{18}$$

where $\lambda_X^f = \frac{e}{4\theta\widetilde{\sigma}^* e - \gamma}$.

Similarly, for host exporting firms,

$$\pi_X^h = (c_X^h - c)^2\left(\widetilde{\sigma}\tau^h\right)^2[\frac{\widetilde{\sigma}\theta}{e\gamma(4\widetilde{\sigma}\theta - e\gamma)}], \tag{19}$$

$$p_X^h = \frac{1}{2}\frac{\widetilde{\sigma}}{e}\tau^h(c_X^h + c) + \frac{\gamma}{2}z_X^h, \tag{20}$$

$$q_X^h = \frac{1}{2\gamma}\frac{\widetilde{\sigma}}{e}\tau^h(c_X^h - c) + \frac{1}{2}z_X^h, \tag{21}$$

$$\left(z_X^h\right)^* = \frac{\widetilde{\sigma}\tau^h}{4\widetilde{\sigma}\theta - e\gamma}(c_X^h - c) = \widetilde{\sigma}\tau^h\lambda_X^h(c_X^h - c); \tag{22}$$

where $\lambda_X^h = \frac{1}{4\widetilde{\sigma}\theta - e\gamma}$, and $\widetilde{\sigma} = 1 + \sigma r$.

To obtain positive product quality, we assume that $4\theta - \gamma > 0$, $4\theta\widetilde{\sigma}^* e - \gamma > 0$, and $4\theta\widetilde{\sigma}e - \gamma > 0$.

2.3. Free-entry equilibrium

We then turn to determine the threshold level of cost, c_X^l by setting the format of cost function. Assume that the cost function is $G(c) = (\frac{c}{c_M})^k, c \in [0, c_M]$, in equilibrium, firms earn zero expected profit. Hence, a firm's total expected profits from domestic and foreign markets should be equal to the fixed entry cost, f_E. Thus,

$$f_E = \int_0^{c_D^l} \pi_D^l(c)dG(c) + \int_0^{c_X^l} \pi_X^l(c)dG(c). \tag{23}$$

Given the free-entry equation, we can have it for host country and foreign firms, therefore, we obtain two free-entry equations to have the closed-form solution for two unknown variables, c_D^h and c_D^f. The system of free-entry condition is:

$$\int_0^{c_D^h} \pi_D^h(c)dG(c) + \int_0^{c_X^h} \pi_X^h(c)dG(c) = f_E^h, \tag{24}$$

$$\int_0^{c_D^f} \pi_D^f(c)dG(c) + \int_0^{c_X^f} \pi_X^f(c)dG(c) = f_E^f. \tag{25}$$

In host domestic market, the marginal foreign exporting firm has $p_X^f = e\widetilde{\sigma}^*\tau^f c_X^f$, while the marginal host firm in domestic market has $p_D^h = c_D^h$. As $p_D^h = p_X^f$, the relationships between cut-off threshold in domestic and foreign market are therefore $e\widetilde{\sigma}^*\tau^f c_X^f = c_D^h$ and $\frac{1}{e}\widetilde{\sigma}\tau^h c_X^h = c_D^f$, where c_D^h and c_X^h are cut-off thresholds for home firms in domestic and foreign markets, respectively.

Then, the cut-off threshold in home market is

$$c_D^h = \left[\frac{2\gamma(k+1)(k+2)\left[f_E^h c_m^k\left(1+\lambda_D^f\right) - f_E^f\left(c_m^*\right)^k\left(\widetilde{\sigma}\tau^h\right)^{-k}e^{k+1}\left(1+e\gamma\lambda_X^h\right)\right]}{\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) - \left[\left(\widetilde{\sigma}\tau^h\right)^{-k}\left(\widetilde{\sigma}^*\tau^f\right)^{-k}\left(1+e\gamma\lambda_X^h\right)\left(1+\frac{\gamma}{e}\lambda_X^f\right)\right]}\right]^{\frac{1}{k+2}} \tag{26}$$

To ensure positive c_D^h we assume that the denominator and numerator are both negative, which means that

$$f_E^h c_m^k\left(1+\lambda_D^f\right) < f_E^f\left(c_m^*\right)^k\left(\widetilde{\sigma}\tau^h\right)^{-k}e^{k+1}\left(1+e\gamma\lambda_X^h\right); \tag{27}$$

$$\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) < \left[\frac{1+e\gamma\lambda_X^h}{\left(\widetilde{\sigma}\tau^h\right)^k}\frac{1+\frac{\gamma}{e}\lambda_X^f}{\left(\widetilde{\sigma}^*\tau^f\right)^k}\right]. \tag{28}$$

2.4. Exchange rate, price and quality

Exchange rate movement always brings about questions for exporting and importing firms, unless they export to or import from countries that are located in the same currency zone. For example, there would be no issues about the exchange rate pass-through when a German firm exports its product to Spain, France, or Greece, since they are all in the euro zone. However, there might be an incomplete exchange rate pass-through when China imports consumption goods from Korea or Japan. In these circumstances, the variation of the exchange rate plays a role in exporters' pricing decisions.

$$p_X^f = \left[\frac{2\theta e\widetilde{\sigma}^*}{(4\theta e\widetilde{\sigma}^* - \gamma)}\right]c_D^h + \left[\frac{2\theta e\widetilde{\sigma}^* e\widetilde{\sigma}^* - \gamma e\widetilde{\sigma}^*}{(4\theta e\widetilde{\sigma}^* - \gamma)}\right]c\tau^f. \tag{29}$$

Having the cut-off threshold in the host market in hand, we can explore the cost-adjustment effect induced by different factors. The cut-off cost for host firms in domestic market c_D^h decreases when foreign currency appreciates, i.e. $\frac{\partial c_D^h}{\partial e} < 0$. Severe financial stress increases the domestic market cut-off cost, $\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} > 0$. In addition, the tightening of the financial environment means that exporters have to pay higher interest to finance their funds needed. The cost-adjustment effect caused by financial stress is stronger when foreign currency appreciates, i.e., $\frac{\partial^2 c_D^h}{\partial e\partial\widetilde{\sigma}^*} > 0$. With the understanding of the cost-adjustment effect, we, therefore, can investigate the price-adjustment effect and quality-adjustment effect caused by the exchange rate movement and the variation of the degree of financial stress.

Proposition 1. *(Pricing)*

All else constant, foreign export price increases in foreign currency appreciation, $\frac{\partial p_X^f}{\partial e} > 0$, *if the elasticity of the cut-off cost with respect to exchange rate is positive and sufficiently large, i.e.* $\frac{\partial c_D^h}{\partial e}\frac{e}{c_D^h} > \frac{\gamma}{(4\theta e\widetilde{\sigma}^* - \gamma)}$, *and* $\theta\widetilde{\sigma}^* > \frac{\gamma}{e}$.

All else constant, the effect of the financial stress on foreign firms' export price is positive, $\frac{\partial p_X^f}{\partial\widetilde{\sigma}^*} > 0$, *if the elasticity of the cut-off cost with respect to financial stress is positive and sufficiently large, i.e.* $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} > \frac{\gamma}{4\theta e\widetilde{\sigma}^* - \gamma}$, *and* $\theta\widetilde{\sigma}^* > \frac{\gamma}{2e}$.

All else constant, the price adjustment effect is stronger when the degree of financial stress increases, $\frac{\partial^2 p_X^f}{\partial e\partial\widetilde{\sigma}^*} > 0$, *if* $(\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} + \frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e}) < (1 + \frac{2\gamma}{4\theta e\widetilde{\sigma}^* - \gamma})$, *and* $\theta\widetilde{\sigma}^* > \frac{3\gamma}{4e}$.

Proof. *See Appendix.*

In Proposition 1, we conclude the price adjustment effect for exporters to be associated with the impact of the exchange rate movement and financial stress on their export prices. An appreciation of foreign country A's currency for a certain period would, on average, hurt its exports because the exporting goods from country A become relatively expensive. On the other hand, from the domestic consumers' point of view, importing goods become relatively expensive in domestic market. Therefore, consumers in the host country might choose goods provided by domestic firms rather than selecting imported products provided by foreign exporters. The theoretical model predicts that if the elasticity of the cut-off cost with respect to the exchange rate is positive and sufficiently large, foreign exporters can raise the export price to maintain their profit in the host country. Besides, the condition, $\theta\widetilde{\sigma}^* > \frac{\gamma}{e}$ implies that the external share of financial costs of innovation, $\theta\widetilde{\sigma}^* = \theta(1 + \sigma^* r)$, is required to be sufficiently large.

The model also shows that credit-constrained exporters would increase their export prices in response to an increase in financial stress when the elasticity of the cut-off cost with respect to the financial stress is positive and sufficiently substantial. In this paper, we assume that only exporters are credit-constrained. Therefore, they face financial stress and seek external funds to sell their products abroad. For those marginal exporters, when financial institutions tighten credit or raise the interest rate, it means that there is an increasing degree of financial stress for them. They would try to increase their prices to earn more profit to alleviate their financial stress and keep to stay in the exporting markets.

Moreover, our model predicts that the price adjustment effect is stronger when the degree of financial stress increases. During the period with high degree of financial stress, foreign exporters might increase the magnitude of the adjustment of export prices caused by the exchange rate movement. One possible explanation is that exporters could earn higher revenue by raising export prices to alleviate the cost pressure caused by increased degree of financial stress.

One of the main contributions of this paper is that we provide a prediction on the impact of financial stress on firms' export quality when the exchange rate moves. According to the optimal export quality of a foreign exporter shown in Equation (18), we can obtain the following proposition.

Proposition 2. *(Quality)*
All else constant, foreign export quality increases in foreign currency appreciation, $\frac{\partial z_x^f}{\partial e} > 0$, *if the elasticity of the cut-off cost with respect to exchange rate is positive and sufficiently large, i.e.* $\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} > \frac{4e\theta\widetilde{\sigma}^*}{(4\theta e\widetilde{\sigma}^* - \gamma)}$.

All else constant, The effect of the financial stress on foreign credit constrained exporting firms' export quality is positive, $\frac{\partial z_x^f}{\partial \widetilde{\sigma}^*} > 0$, *if the elasticity of the cut-off cost with respect to financial stress is positive and sufficiently large, i.e.* $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} > \frac{\gamma}{4\theta e\widetilde{\sigma}^* - \gamma}$, *and* $\theta\widetilde{\sigma}^* > \frac{\gamma}{2e}$.

All else constant, the quality adjustment effect is stronger when the degree of financial stress increases, $\frac{\partial^2 z_x^f}{\partial e \partial \widetilde{\sigma}^*} > 0$, *if* $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} < \frac{4\theta e\widetilde{\sigma}^* + \gamma}{4\theta e\widetilde{\sigma}^* - \gamma}$, *and the cost-adjustment effect caused by financial stress is sufficiently large when foreign currency appreciates.*

Proof. *See Appendix.*

In Proposition 2, we conclude the quality adjustment effect for exporters associated with the impact of the exchange rate movement and financial stress on their export quality. The model predicts that foreign exporters may upgrade their export product quality in response to the impact of the foreign currency appreciation when the elasticity of the cut-off cost with respect to the exchange rate is positive and sufficiently large. When the foreign export price is fixed, the consequence of foreign currency appreciation indicates that home currency depreciates. Therefore, domestic customers have to pay more domestic currency to get the same goods as before. Consumers often think that high-priced items reflect higher quality, so that foreign exporters tend to upgrade the quality of their products to make consumers feel all be worth it. The model also predicts that foreign exporters would raise their export quality in response to an increase in the degree of financial stress when the elasticity of the cut-off cost with respect to financial stress is positive and sufficiently large. An increase in financial stress means a higher entry barrier for the marginal exporters; it also means a higher probability of leaving the exporting market. Therefore, financial stress pushes firms to upgrade the export quality. Because people usually wish to get a relatively good quality product given the same amount of payment. The marginal foreign exporter may raise export product quality to attract more clients. Moreover, this model predicts that the effect of the quality adjustment is stronger in the presence of financial stress. Foreign exporters are more willing to increase the magnitude of the adjustment of export quality led by the exchange rate movement when the degree of financial stress is higher.

3. Empirical analysis

3.1. Model and data selection

To examine the effects of exchange rate and financial stress on export prices and quality, this study looks at the exports from China's main trading partners since 2001, when China became a member of the World Trade Organization (WTO). In the following empirical analysis, we treat China as the host country and its trading partners as foreign countries. The model to be tested regarding export prices and quality is

Table 3
Empirical results from price and quality equations.

Variables	Price ($\log p_{ijt}$)	Quality ($\log z_{ijt}$)
$stress_{ijt}$	0.046**	0.020*
	(2.87)	(2.29)
$\log ex_{jt}$	0.641***	0.235***
	(7.94)	(5.45)
$stress_{ijt} \times \log ex_{jt}$	−0.009***	0.003
	(-4.34)	(1.75)
$\log pgdp_{jt}$	1.930***	0.338***
	(22.49)	(8.14)
N	15857	15594

Note: t statistics are reported in parentheses. *** indicates $p < 0.01$, ** indicates $p < 0.05$ and * indicates $p < 0.1$.

Table 1
Data sources.

Variable	Description	Data Sources
p_{ijt}	FOB unit prices for industry i from country j at time t	UNComtrade; SITC Rev2 4-digit level
z_{ijt}	export quality for industry i from country j at time t	Feenstra and Romalis (2014); SITC Rev2 4-digit level
fd_i	external financial dependence for industry i	Rajan and Zingales (1998); ISIC Rev2 3-digit level
$interest_{jt}$	long-term interest rate on bank loans in country j at time t	International Financial Statistics; Bundesbank.
ex_{jt}	bilateral exchange rates of country j at time t	International Financial Statistics
$pgdp_{jt}$	PPP-adjusted GDP per capita of country j at time t	World Development Indicators

Table 2
Summary statistics.

Variable	No. Obs	Mean	SD	Min	Max
$\log p_{ijt}$	15,857	2.391	2.015	−4.729	17.670
$\log z_{ijt}$	15,594	0.252	0.724	−4.824	6.006
$stress_{ijt}$	15,857	1.460	1.372	0.015	8.788
$\log ex_{jt}$	15,857	0.796	3.003	−2.558	4.991
$\log pgdp_{jt}$	15,857	10.310	0.181	9.861	10.660

a two-level fixed-effects model shown as follows:

$$\boldsymbol{y}_{ijt} = \beta_1 stress_{ijt} + \beta_2 \log ex_{jt} + \beta_3 stress_{ijt} \times \log ex_{jt} + \beta_4 \log pgdp_{jt} + u_i + v_j + \varepsilon_{ijt} \quad (30)$$

where $\boldsymbol{y}_{ijt} = \left[\log p_{ijt}, \quad \log z_{ijt}\right]'$ is the logarithm of export prices p_{ijt} and export quality z_{ijt} of industry i from country j to China at time t, respectively; $stress_{ijt}$ represents the degree of financial stress in industry i of country j at time t; $\log ex_{jt}$ is the logarithm of the exchange rate of country j at time t, interpreted as the price of domestic currency per unit of foreign currency; $\log pgdp_{jt}$ is the logarithm of the PPP-adjusted GDP per capita for country j at time t, which is used to describe the market size. u_i and v_j are the industry and country fixed effects, respectively. The homoscedastic error term ε_{ijt} with mean zero includes all unobserved factors that may affect $\boldsymbol{y}_{ijt}$. All the β's are expected to be positive according to the theoretical predictions.

The study selects three China's major import trading partners, i.e. Germany, Japan and Korea, during 2001 and 2011. Our annual data come from several databases. The data for export prices are the unit prices for each industry and are collected from the UNComtrade database at the SITC 4-digit level. For the export quality data, we use the export quality index calculated by Feenstra and Romalis (2014) at the SITC 4-digit level. Consistent with our theoretical model setting, the degree of financial stress, $stress_{ijt}$, in Equation (30) is measured by $stress_{ijt} = fd_i \times interest_{jt}$, where fd_i is the dependence on external finance for industry i, and $interest_{jt}$ is the long-term interest rate on bank loans in country j at time t. To measure the degree of external dependence, we follow the results calculated by Rajan and Zingales (1998), reported based on an ISIC category, where the external dependence is defined as the percentage of capital expenditures that are not financed with cash flow from operations. The long-term bank lending rates and the bilateral exchange rates of the three countries are drawn from the International Financial Statistics. The interest rates before 2003 in Germany are obtained from Bundesbank's interest rate statistics. The data for PPP-adjusted GDP per capita is obtained from the World Development Indicators. Tables 1 and 2 summarize the source and the descriptive statistics of the data. Finally, the ISIC 3-digit codes used in the degree of external dependence are converted to be consistent with the SITC 4-digit codes using the concordance table provided by the World Integrated Trade Solution (WITS).

3.2. Empirical results

The model is estimated following the method proposed by Schmieder (2009) using the Guimarães and Portugal (2010) algorithm, and the estimated results for export price and quality equations are presented in Table 3.

The effects of price adjustment based on the whole sample are reported in the second column of Table 3. The degree of financial stress advocates an increase of export price from foreign firms due to a significantly positive $\beta_1 = 0.046$. $\beta_2 = 0.641 > 0$ indicates that a foreign currency appreciation induces foreign firms to raise export prices to China, which is consistent with our theoretical prediction. The coefficient of the intersection term, $\beta_3 = -0.009$, is surprisingly negative and significant, indicating a negative effect from the financial stress on the responses of export prices to the fluctuations of the exchange rate. One possible reason why financial stress fails to increase the effect of exchange rates on export price adjustments as suggested in the theoretical model, is that the sum of the elasticity of the cut-off cost with respect to exchange rate and financial stress is not that small to meet the condition outlined in Proposition 1.

Export quality adjustment of foreign firms is presented in the third column of Table 3, and the result is in supportive of Proposition 2. The average effect of the degree of financial stress on export quality is positive and significant, with $\beta_1 = 0.02$, which is supported by our theoretical model. A significantly positive coefficient of $\beta_2 = 0.235$ suggests that foreign firms' export quality improves in response of a foreign currency appreciation. The intersection term shows a positive sign, though not significant.

4. Conclusion

This paper builds a heterogeneous international trade model to investigate the adjustments of firms' export price and quality in response to the variation of the exchange rate and the degree of financial stress. By incorporating both financial stress and ERPT, the model provides predictions on how firms under financial stress could adjust their export product prices and quality in order to absorb the variation of the exchange rate. Moreover, firms need external funds to operate their production and support their expense on quality upgrading, which makes them financially vulnerable. The model in this paper could help to analyze how financial vulnerable firms decide the magnitude of quality adjustment when exchange rate fluctuates.

In addition, our model suggests that foreign export firms would increase their export prices and improve the product quality when foreign currency appreciates and when their financial stress intensifies. Policymakers may consider adjusting the interest rate level in response to exchange rate fluctuations so as to lower the degree of financial stress for firms. For example, domestic banks could offer preferential loan rates to domestic exporters in specific industries when they are confronted with exchange rate fluctuations. The degree of financial stress, to some extent, helps boost the effects of exchange rate fluctuations on increasing export prices or improving product quality, but it is subject to the elasticity of the cut-off costs in specific industries.

This model could be extended to look into the case of heterogeneity in financial development and the case that firms need external funds to adopt advanced technology, both of which are expected to influence the exporting decisions of credit constrained firms as well.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

The profit functions for domestic-market-only firms in home and foreign countries are

$$\pi_D^h = \frac{1}{4\gamma}\left(1 + \lambda_D^h\right)(c_D^h - c)^2, \quad (.1)$$

$$\pi_D^f = \frac{1}{4\gamma}\left(1 + \lambda_D^f\right)(c_D^f - c)^2. \quad (.2)$$

The profit functions for exporting firms in home and foreign countries are

$$\pi_X^h = \frac{\left(\widetilde{\sigma}\tau^h\right)^2}{4e\gamma}\left(1 + e\gamma\lambda_X^h\right)(c_X^h - c)^2, \quad (.3)$$

$$\pi_X^f = \frac{e\left(\widetilde{\sigma}^*\tau^f\right)^2}{4\gamma}\left(1+\frac{\gamma}{e}\lambda_X^f\right)(c_X^f - c)^2. \tag{.4}$$

Free-Entry conditions for home market and foreign market are

$$\int_0^{c_D^h} \pi_D^h(c)dG(c) + \int_0^{c_X^h} \pi_X^h(c)dG(c) = f_E^h, \tag{.5}$$

$$\int_0^{c_D^f} \pi_D^f(c)dG(c) + \int_0^{c_X^f} \pi_X^f(c)dG(c) = f_E^f. \tag{.6}$$

The system of free-entry condition is, therefore,

$$\left[\frac{\left(1+\lambda_D^h\right)c_m^{-k}}{2\gamma\,(k+1)\,(k+2)}\right]\left(c_D^h\right)^{k+2} + \left[\frac{\left(\widetilde{\sigma}\tau^h\right)^2\left(1+e\gamma\lambda_X^h\right)c_m^{-k}}{2e\gamma\,(k+1)\,(k+2)}\right]\left(c_X^h\right)^{k+2} = f_E^h, \tag{.7}$$

$$\left[\frac{\left(1+\lambda_D^f\right)\left(c_m^*\right)^{-k}}{2\gamma\,(k+1)\,(k+2)}\right]\left(c_D^f\right)^{k+2} + \left[\frac{e\left(\widetilde{\sigma}^*\tau^f\right)^2\left(1+\frac{\gamma}{e}\lambda_X^f\right)\left(c_m^*\right)^{-k}}{2\gamma\,(k+1)\,(k+2)}\right]\left(c_X^f\right)^{k+2} = f_E^f. \tag{.8}$$

Let $2\gamma c_m^k\,(k+1)\,(k+2)f_E^h = \varphi_E^h$, and $2\gamma\left(c_m^*\right)^k(k+1)\,(k+2)f_E^f = \varphi_E^f$. Therefore,

$$\left(1+\lambda_D^h\right)\left(c_D^h\right)^{k+2} + \frac{\left(\widetilde{\sigma}\tau^h\right)^2\left(1+e\gamma\lambda_X^h\right)}{e}\left(c_X^h\right)^{k+2} = \varphi_E^h, \tag{.9}$$

$$\left(1+\lambda_D^f\right)\left(c_D^f\right)^{k+2} + e\left(\widetilde{\sigma}^*\tau^f\right)^2\left(1+\frac{\gamma}{e}\lambda_X^f\right)\left(c_X^f\right)^{k+2} = \varphi_E^f. \tag{.10}$$

Rewrite above as the functions of c_D^h and c_D^f,

$$\left(1+\lambda_D^h\right)\left(c_D^h\right)^{k+2} + e^{k+1}\left(\widetilde{\sigma}\tau^h\right)^{-k}\left(1+e\gamma\lambda_X^h\right)\left(c_D^f\right)^{k+2} = \varphi_E^h, \tag{.11}$$

$$\left(1+\lambda_D^f\right)\left(c_D^f\right)^{k+2} + \left(\frac{1}{e}\right)^{k+1}\left(\widetilde{\sigma}^*\tau^f\right)^{-k}\left(1+\frac{\gamma}{e}\lambda_X^f\right)\left(c_D^h\right)^{k+2} = \varphi_E^f. \tag{.12}$$

We have therefore got the cut-off consumption for a marginal home firm in domestic market as follows:

$$\left(c_D^h\right)^{k+2} = \frac{\left[\varphi_E^h\left(1+\lambda_D^f\right) - \varphi_E^f\left(\widetilde{\sigma}\tau^h\right)^{-k}e^{k+1}\left(1+e\gamma\lambda_X^h\right)\right]}{\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) - \left[\left(\widetilde{\sigma}\tau^h\right)^{-k}\left(\widetilde{\sigma}^*\tau^f\right)^{-k}\left(1+e\gamma\lambda_X^h\right)\left(1+\frac{\gamma}{e}\lambda_X^f\right)\right]}, \tag{.13}$$

$$\left(c_D^f\right)^{k+2} = \frac{\left[\varphi_E^f\left(1+\lambda_D^h\right) - \varphi_E^h\left(\widetilde{\sigma}^*\tau^f\right)^{-k}\left(\frac{1}{e}\right)^{k+1}\left(1+\frac{\gamma}{e}\lambda_X^f\right)\right]}{\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) - \left[\left(\widetilde{\sigma}\tau^h\right)^{-k}\left(\widetilde{\sigma}^*\tau^f\right)^{-k}\left(1+e\gamma\lambda_X^h\right)\left(1+\frac{\gamma}{e}\lambda_X^f\right)\right]}. \tag{.14}$$

By solving profit maximization problem, we have the optimal export price of foreign exporting firms as

$$p_X^f = \left[\frac{2\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right]c_D^h + \left[\frac{2\theta e\widetilde{\sigma}^* e\widetilde{\sigma}^* - \gamma e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right]c\tau^f. \tag{.15}$$

Also,

$$\left(z_X^h\right)^* = \frac{\widetilde{\sigma}\tau^h}{4\widetilde{\sigma}\theta - e\gamma}(c_X^h - c), \tag{.16}$$

$$p_X^h = \frac{1}{2}\frac{\widetilde{\sigma}}{e}\tau^h(c_X^h + c) + \frac{\gamma}{2}z_X^h. \tag{.17}$$

The cut-off cost function for home firms in domestic country is

$$c_D^h = \left[\frac{\varphi_E^h\left(1+\lambda_D^f\right) - \varphi_E^f\left(\widetilde{\sigma}\tau^h\right)^{-k}e^{k+1}\left(1+e\gamma\lambda_X^h\right)}{\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) - \frac{\left(1+e\gamma\lambda_X^h\right)}{\left(\widetilde{\sigma}\tau^h\right)^k}\frac{\left(1+\frac{\gamma}{e}\lambda_X^f\right)}{\left(\widetilde{\sigma}^*\tau^f\right)^k}}\right]^{\frac{1}{k+2}}. \tag{.18}$$

$\frac{\partial c_D^h}{\partial e} < 0$ if $\widetilde{\sigma} < e^2\widetilde{\sigma}^*$, and $\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) < \left[\frac{\left(1+\frac{e\gamma}{4\widetilde{\sigma}\theta-e\gamma}\right)}{\left(\widetilde{\sigma}\tau^h\right)^k}\frac{\left(1+\frac{\frac{\gamma}{e}}{4\theta\widetilde{\sigma}^*-\frac{\gamma}{e}}\right)}{\left(\widetilde{\sigma}^*\tau^f\right)^k}\right]$, with $\varphi_E^h\left(1+\lambda_D^f\right) - \frac{\varphi_E^f}{\left(\widetilde{\sigma}\tau^h\right)^k}e^{k+1}\left(1+e\gamma\lambda_X^h\right) < 0$,and $\left(1+\lambda_D^h\right)\left(1+\lambda_D^f\right) - \frac{\left(\frac{4\theta\widetilde{\sigma}}{4\theta\widetilde{\sigma}-e\gamma}\right)}{\left(\widetilde{\sigma}\tau^h\right)^k}\frac{\left(\frac{4\theta\widetilde{\sigma}^*}{4\theta\widetilde{\sigma}^*-\frac{\gamma}{e}}\right)}{\left(\widetilde{\sigma}^*\tau^f\right)^k} < 0$.

Proof for Proposition 1. The impact of exchange rate variation on the home import price (foreign export price) is

$$\begin{aligned}\frac{\partial p_x^f}{\partial e} &= \left(\frac{2\theta e\widetilde{\sigma}^*}{4\theta e\widetilde{\sigma}^*-\gamma}\right)\frac{\partial c_D^h}{\partial e} + \left[\frac{2\theta\widetilde{\sigma}^*\left(4\theta e\widetilde{\sigma}^*-\gamma\right)-2\theta e\widetilde{\sigma}^*\left(4\theta\widetilde{\sigma}^*\right)}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]c_D^h + c\tau^f\left[\frac{\left(4\theta e\left(\widetilde{\sigma}^*\right)^2-\gamma\widetilde{\sigma}^*\right)\left(4\theta e\widetilde{\sigma}^*-\gamma\right)-\left(2\theta e^2\left(\widetilde{\sigma}^*\right)^2-e\widetilde{\sigma}^*\gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right],\\
&= \left(\frac{2\theta e\widetilde{\sigma}^*}{4\theta e\widetilde{\sigma}^*-\gamma}\right)\frac{\partial c_D^h}{\partial e} + \left[\frac{-2\theta\widetilde{\sigma}^*\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]c_D^h + c\left[\frac{8\theta e\widetilde{\sigma}^*(\theta e\widetilde{\sigma}^*-\gamma)+\gamma^2+4\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\\
&= \left(\frac{2\theta\widetilde{\sigma}^*}{4\theta e\widetilde{\sigma}^*-\gamma}\right)c_D^h\left[\left(\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e}-\frac{\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right)\right] + c\left[\frac{8\theta e\widetilde{\sigma}^*(\theta e\widetilde{\sigma}^*-\gamma)+\gamma^2+4\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\end{aligned} \tag{.19}$$

If $\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} > \frac{\gamma}{(4\theta e\widetilde{\sigma}^*-\gamma)}$ and $(\theta e\widetilde{\sigma}^*-\gamma) > 0$, then $\frac{\partial p_x^f}{\partial e} > 0$.

Moreover, the impact of financial stress $\widetilde{\sigma}^*$ on home import price (p_x^f) is

$$\begin{aligned}\frac{\partial p_x^f}{\partial\widetilde{\sigma}^*} &= \left[\frac{2\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right]\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} + \left[\frac{2\theta e\left(4\theta e\widetilde{\sigma}^*-\gamma\right)-2\theta e\widetilde{\sigma}^*(4\theta e)}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]c_D^h + c\tau^f\left[\frac{\left(4\theta e^2\left(\widetilde{\sigma}^*\right)-\gamma e\right)\left(4\theta e\widetilde{\sigma}^*-\gamma\right)-\left(2\theta e^2\left(\widetilde{\sigma}^*\right)^2-\gamma e\widetilde{\sigma}^*\right)4\theta e}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\\
&= \left[\frac{2\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right]\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} + \left[\frac{-2\theta e\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]c_D^h + c\tau^f\left[\frac{8\theta^2e^3\left(\widetilde{\sigma}^*\right)^2-4\theta e^2(\widetilde{\sigma}^*)\gamma+\gamma^2e}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\\
&= \left[\frac{2\theta e}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right]c_D^h\left[\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*}-\frac{\gamma}{4\theta e\widetilde{\sigma}^*-\gamma}\right] + c\tau^f\left[\frac{4\theta e^2\widetilde{\sigma}^*(2\theta e\widetilde{\sigma}^*-\gamma)+\gamma^2e}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right].\end{aligned} \tag{.20}$$

$\frac{\partial p_x^f}{\partial\widetilde{\sigma}^*} > 0$ if $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} > \frac{\gamma}{4\theta e\widetilde{\sigma}^*-\gamma}$ and $2\theta e\widetilde{\sigma}^*-\gamma > 0$.

The interaction effect of financial stress and exchange rate on the export price is

$$\begin{aligned}\frac{\partial^2 p_x^f}{\partial e\partial\widetilde{\sigma}^*} &= \left[\frac{2\theta\widetilde{\sigma}^*\left(4\theta e\widetilde{\sigma}^*-\gamma\right)-2\theta e\widetilde{\sigma}^*4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} + \left[\frac{2\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right]\frac{\partial^2 c_D^h}{\partial e\partial\widetilde{\sigma}^*} + \left[\frac{-2\theta e\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\frac{\partial c_D^h}{\partial e}\\
&\quad + \left[\frac{-2\theta\gamma\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2+2\theta e\gamma 2\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^4}\right]c_D^h\\
&\quad + c\tau^f\left[\frac{\left[-8\theta e\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2+24\theta^2e^2\left(\widetilde{\sigma}^*\right)^2\right]\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2-\left(-4\theta e^2\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2e+8\theta^2e^3\left(\widetilde{\sigma}^*\right)^2\right)2\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^4}\right]\\
&= \left[\frac{-2\theta\widetilde{\sigma}^*\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*} + \left[\frac{-2\theta e\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}\right]\frac{\partial c_D^h}{\partial e} + \left[\frac{2\theta\gamma\left(4\theta e\widetilde{\sigma}^*-\gamma\right)\left(4\theta e\widetilde{\sigma}^*+\gamma\right)}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^4}\right]c_D^h\\
&\quad + c\tau^f\left[\frac{\left[-8\theta e\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2+24\theta^2e^2\left(\widetilde{\sigma}^*\right)^2\right]\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2-\left(-4\theta e^2\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2e+8\theta^2e^3\left(\widetilde{\sigma}^*\right)^2\right)2\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4}\right]\\
&= \left[-\frac{2\theta\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}c_D^h\right]\left(\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*}+\frac{\theta}{c_D^h}\frac{\partial c_D^h}{\partial e}-\frac{4\theta e\widetilde{\sigma}^*+\gamma}{4\theta e\widetilde{\sigma}^*-\gamma}\right)\\
&\quad + c\tau^f\left[\frac{\left[-8\theta e\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2+24\theta^2e^2\left(\widetilde{\sigma}^*\right)^2\right]\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2-\left(-4\theta e^2\left(\widetilde{\sigma}^*\right)\gamma+\gamma^2e+8\theta^2e^3\left(\widetilde{\sigma}^*\right)^2\right)2\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)4}\right]\end{aligned} \tag{.21}$$

hence,

$$\frac{\partial^2 p_x^f}{\partial e\partial\widetilde{\sigma}^*} = \left[-\frac{2\theta\gamma}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^2}c_D^h\right]\left[\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial\widetilde{\sigma}^*}+\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e}-\left(1+\frac{2\gamma}{4\theta e\widetilde{\sigma}^*-\gamma}\right)\right] + c\tau^f\left[\frac{8(\theta e\widetilde{\sigma}^*)^3(4\theta e\widetilde{\sigma}^*-3\gamma)+\gamma^2(8\theta e\widetilde{\sigma}^*-\gamma)}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)^3}\right] + \left[\frac{2\theta e\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^*-\gamma\right)}\right]\frac{\partial^2 c_D^h}{\partial e\partial\widetilde{\sigma}^*} \tag{.22}$$

$\frac{\partial^2 p_x^f}{\partial e \partial \widetilde{\sigma}^*} > 0$ if $\left(\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e}\right) < \left(1 + \frac{2\gamma}{4\theta e\widetilde{\sigma}^* - \gamma}\right)$, $4\theta e\widetilde{\sigma}^* > 3\gamma$, and $\frac{\partial^2 c_D^h}{\partial e \partial \widetilde{\sigma}^*} > 0$.

Proof for Proposition 2. The impact of exchange rate changes on product quality is

$$\begin{aligned}\frac{\partial z_x^f}{\partial e} &= \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial c_D^h}{\partial e} + \left[\frac{-4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]c_D^h - c\left[\frac{\widetilde{\sigma}^*\tau^f\left(4\theta e\widetilde{\sigma}^* - \gamma\right) - \left(e\widetilde{\sigma}^*\tau^f\right)\left(4\theta\widetilde{\sigma}^*\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right] \\ &= \left(\frac{1}{e}\frac{c_D^h}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\left[\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} - \frac{4e\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right] + c\left[\frac{\widetilde{\sigma}^*\tau^f\gamma}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\end{aligned} \tag{.23}$$

$\frac{\partial z_x^f}{\partial e} > 0$ if $\frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} > \frac{4e\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}$.

Moreover, the impact of financial stress $\widetilde{\sigma}^*$ on product quality is

$$\begin{aligned}\frac{\partial z_x^f}{\partial \widetilde{\sigma}^*} &= \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \left[\frac{-4\theta e}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]c_D^h - c\left[\frac{e\tau^f\left(4\theta e\widetilde{\sigma}^* - \gamma\right) - \left(e\widetilde{\sigma}^*\tau^f\right)\left(4\theta e\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right] \\ &= \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \left[\frac{-4\theta e}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]c_D^h - \frac{ce\tau^f\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2} + \frac{ce\widetilde{\sigma}^*\tau^f\left(4\theta e\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2} \\ &= \left(\frac{1}{\widetilde{\sigma}^*}\frac{c_D^h}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\left[\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} - \frac{4e\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right] - c\left[\frac{-\gamma e\tau^f}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right] \\ &= \left(\frac{1}{\widetilde{\sigma}^*}\frac{c_D^h}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\left[\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} - \frac{4e\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right] + c\left[\frac{\gamma e\tau^f}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\end{aligned} \tag{.24}$$

$\frac{\partial z_x^f}{\partial \widetilde{\sigma}^*} > 0$ if $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} > \frac{4e\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}$.

The interaction effect of financial stress and exchange rate on the export quality is

$$\begin{aligned}\frac{\partial^2 z_x^f}{\partial e \partial \widetilde{\sigma}^*} &= \left[\frac{-4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial^2 c_D^h}{\partial \widetilde{\sigma}^* \partial e} + \left[\frac{-4\theta\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2 + 4\theta e 2\left(4\theta e\widetilde{\sigma}^* - \gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^4}\right]c_D^h + \left[\frac{-4\theta e}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\frac{\partial c_D^h}{\partial e} \\ &\quad + c\left[\frac{\tau^f\gamma\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2 - e\tau^f\gamma 2\left(4\theta e\widetilde{\sigma}^* - \gamma\right)4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^4}\right] \\ &= \left[\frac{-4\theta\widetilde{\sigma}^*}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \left[\frac{-4\theta e}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\frac{\partial c_D^h}{\partial e} + \left[\frac{4\theta\left(4\theta e\widetilde{\sigma}^* - \gamma\right)\left(4\theta e\widetilde{\sigma}^* + \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^4}\right]c_D^h + \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial^2 c_D^h}{\partial \widetilde{\sigma}^* \partial e} \\ &\quad + c\left[\frac{\tau^f\gamma\left(4\theta e\widetilde{\sigma}^* - \gamma\right)\left(4\theta e\widetilde{\sigma}^* - \gamma - 8e\theta\widetilde{\sigma}^*\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^4}\right] \\ &= \left[\frac{-4\theta}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]\left[\widetilde{\sigma}^*\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + e\frac{\partial c_D^h}{\partial e} - \frac{\left(4\theta e\widetilde{\sigma}^* + \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}c_D^h\right] + \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial^2 c_D^h}{\partial \widetilde{\sigma}^* \partial e} - c\left[\frac{\tau^f\gamma(4e\theta\widetilde{\sigma}^* + \gamma)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^3}\right] \\ &= \left[\frac{-4\theta}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}\right]c_D^h\left[\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} - \frac{\left(4\theta e\widetilde{\sigma}^* + \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}\right] + \left(\frac{1}{4\theta e\widetilde{\sigma}^* - \gamma}\right)\frac{\partial^2 c_D^h}{\partial \widetilde{\sigma}^* \partial e} + c\left[\frac{\tau^f\gamma(-4e\theta\widetilde{\sigma}^* - \gamma)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^3}\right]\end{aligned} \tag{.25}$$

when $\frac{\widetilde{\sigma}^*}{c_D^h}\frac{\partial c_D^h}{\partial \widetilde{\sigma}^*} + \frac{e}{c_D^h}\frac{\partial c_D^h}{\partial e} < \frac{\left(4\theta e\widetilde{\sigma}^* + \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)}$, and $\frac{\partial^2\left(c_D^h\right)}{\partial \widetilde{\sigma}^* \partial e} > \tau^f\gamma c\frac{\left(4e\theta\widetilde{\sigma}^* + \gamma\right)}{\left(4\theta e\widetilde{\sigma}^* - \gamma\right)^2}$,we have $\frac{\partial^2 z_x^f}{\partial e \partial \widetilde{\sigma}^*} > 0$.

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