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Estimations of Product Quality in China's Food Processing and Manufacturing Industries

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Abstract

Using a product variety model, where higher quality products increase consumer utility and quality products are more costly to produce, this paper shows that optimal product quality depends on a parameter of the consumer utility function and firm cost of production. In addition, a firm's unobserved product quality is structurally linked to its observed sales revenue. The structural relationship allows one to estimate the product quality within an industry. We then utilize firm level data from China over the 2005-2007 period to estimate product quality in China's (i) food processing and (ii) food manufacturing industries. By comparing the distributions of product quality (and product quality growth rates) over time, we argue that product quality in both industries is improving.

Keywords: Food processing; Food manufacturing; Product quality; China

JEL Classifications: L11, L66, D22

1. Introduction

Product quality is important for firms. On the one hand, higher product quality promotes consumers' demand, which in turns increases a firm's revenue and eventually profit, *ceteris paribus*. On the other hand, higher quality products are more costly to produce. For example, for firms, higher quality intermediate inputs are more expensive to purchase, and to implement a stricter quality standard can result in higher defect rate, which translates into a higher cost of production. Hence, firms are faced with a trade-off in deciding their optimal product quality.

Recognizing this trade-off, this study will model a firm's optimal decision on its product quality, which provides a framework for estimating firm product quality that can be used elsewhere. As we will see in Section two, a number of existing studies have explored product quality from different dimensions. Nevertheless, to the best of our knowledge, none of them has tried to directly estimate product quality.

This study focuses on China. The Chinese economy has been growing rapidly in the past four decades, and Chinese production now accounts for a major proportion of the worldwide production of manufactured goods. However, despite of the substantial share of global production, the Chinese-made products are frequently regarded as cheaper and of low quality, compared to the US or EU made products.

In 2007, the *New York Times* reported that one fifth of the food and consumer products surveyed by the Chinese quality regulator were found to be substandard or tainted (Barboza, 2007). A Hong Kong based quality audit company performed about 25,000 one-day factory inspections in China in 2006. *The USA Today* reported that approximately 23 per cent factories received failing grade due to, among other things, poor factory hygiene, inaccurate product manuals and cosmetic blemishes on finished products (Lynch, 2007). In light of these media coverage, it is of practical implications to investigate the distribution of product quality and its evolution across time in China.

We estimate the distributions of product quality in China's food processing and manufacturing industries. These industries are chosen for two reasons. First, consumption of products in these two industries is static [1], consistent with our theoretical modelling in Section three. Second, the Chinese food industry has been rocked by some scalds in recent decades, for example the food safety issue [2] (see Mirosa et al., 2020). Despite the food safety issue is distinct from food quality [3], it motivates us to explore the quality of food products, and in addition, food processing and manufacturing quality are closely related to food safety (Riccioli et al., 2020).

[1] We do not cover the dynamic consumption, for example purchase of cars, and leave this as a direction for future research.
[2] An example is the contaminated infant formula issue in 2008 (see Yang et al., 2020).
[3] We thank an anonymous reviewer for pointing this out.

Specifically, we use a theoretical model, where consumers derive higher utility from higher quality products and higher quality products are more costly to produce, to establish a link between optimal product quality and sales revenue of a firm. We show that optimal product quality and sales revenue of firms are functions of the parameters of consumer utility and production cost, which are structurally related to each other. These parameters can be estimated by making use of the firm revenue. Thus, by estimating the structural parameters of the theoretical model, we are able to estimate the product quality of China's food manufacturing and food processing industries.

The contribution of this paper is two folds. First, we provide a general framework that can be used to estimate product quality in other settings. Second, we estimate the product quality in China's food processing and manufacturing industries and evaluate its evolution over time. In light of the ongoing debate concerning the quality of Chinese products, an assessment of the trend in product quality will be highly valuable to the consumers, exporters as well as the policy makers.

The rest of the paper is organised as follows. Section two discusses the related literature. In Section three, we use a structural model to establish the link between product quality and firm sales revenue. Section four reports the data used in the estimation. In Section five we discuss the estimation results. Section six concludes the paper.

2. Related Literature

While none of the available studies have attempted to directly estimate the product quality, the existing studies have explored some aspects of product quality. For example, product quality has been shown to play an important role in international trade (see for example Fajgelbaum et al., 2011; Hallak, 2006, 2010; and Linder, 1961). Lu, Ng and Tao (2012) show that outsourcing can lead to lower product quality, which in turn can be mitigated by contract enforcement. Dana and Fong (2011) investigate the relationship among product quality, reputation and market structure. Acharyya and Banerjee (2012) show that tariff affects domestic quality innovation. Verhoogen (2008) showed that quality upgrading links trade and wage inequality in developing countries. Yoon *et al.* (2014) report that many consumers are less concerned about product quality and more interested in paying lower prices.

Because product quality cannot be directly observed, a number of empirical studies use price/unit value as a proxy for product quality. Faruq (2011) find that better institutions contribute to higher export quality, where export quality is measured by the export price index. In investigating the impact of legal institutions on product quality, Essaji and Fujiwara (2012) measure product quality as the average unit price of goods and find that a country with better contracting institutions is more capable of producing better quality products. In examining the impact of foreign direct investment (FDI) on export quality, Harding and Javorcik (2012) also use unit value of exports as a proxy for export quality.

For the price/unit value proxy of product quality to be valid, price/unit value and product quality must be positively correlated. Linnemer (2002) shows that price can be a signal of product quality. Kirchler, Fischer and Hölzl (2010) find the correlation between price and quality in the Austrian market is significantly positive but relatively low. Chen and Rizzo (2012) find that higher quality antidepressants were initially sold at a lower price, which then increased over time. Khandelwal (2010) used the price and quantity information to estimate the quality of exports to the U.S. Later, in this paper, we will show that firms producing higher quality products indeed charge a higher price for their products.

Instead of using price/unit value as a proxy of product quality, Crozet *et al.* (2012) measure the quality of French champagne by expert assessments of the quality of champagne producers. While investigating the impact of competition and debt financing on product quality, Matsa (2011a, 2011b) measure quality through product availability in the store. Werner *et al.* (2012) measure quality of nursing home through a public reporting system, whereas Romley and Goldman (2011) infer the hospital quality from patient choices. Coad (2009) captures the product quality by different product attributes. Chen and Rizzo (2012) use a physician survey to measure the quality of antidepressants. Katayama and Miyagiwa (2009) and Linnemer (2012) respectively argue that FDI and advertising can also signal product quality. Using a large sample on diamonds offered for sale, Wolff (2015) shows that price dispersion increases significantly with quality.

Only a handful of existing studies have considered the issue of product quality in China. While identifying the mechanisms underlying the evolutionary process of industrial development in China's Wenzhou region, Sonobe, Hu and Otsuka (2004) find that upon entry into the industry, a large number of firms initially produce relatively poor quality products before engaging into quality upgrading. In order to examine China's export sophistication, Xu (2010) measures product quality by means of a relative price index. Manova and Zhang (2012) find that China's relatively more successful exporting firms (i) use higher quality inputs to produce higher quality products and (ii) export different quality products to different markets.

Yu (2010), in investigating the impact of democratization on trade, argues that democratization in the exporting country can improve product quality. Anwar and Sun (2018) show that FDI can improve the industry export quality. Using data from China's beverage manufacturing industry, Anwar and Sun (2019) show that FDI can affect the quality of goods produced by domestic firms through worker mobility. In contrast to these studies, this paper establishes an analytical framework to directly estimate firms' product quality.

3. Analytical Framework

In principle, if product quality were observable, the first best choice is to measure it directly. Alternatively, one can use the input quality or output price to indirectly measure the quality of the outputs. When all of these measures are not available, in this section, we show that it is possible to uncover the product quality from the firm sales revenue data, which are easily available to researchers.

If consumers value product quality and production of quality products is more costly then, intuitively, improvement in product quality results in two effects; a price effect (due to positive correlation with quality) and a quantity effect (which depends on the valuation of price and quality by the consumers). The interaction of consumer utility maximisation and firm profit maximisation leads to a structural relationship between product quality and firm revenue, which can then be used to estimate the product quality. We discuss this structural relationship in the Section 3.1.

3.1 Theoretical model

We consider a monopolistically competitive market, where consumer behaviour is represented by a constant elasticity of the substitution (CES) utility function as follows:[4]

$$U = \left[\int_{\omega\in\Omega} z(\omega)^{1-\rho} q(\omega)^{\rho} d\omega\right]^{1/\rho}$$

where Ω is the set of all available goods, q is the quantity of goods consumed, and z is an index of quality. Note that consuming each variety of goods, consumers derive a level of utility that is the geometric mean of quantity and quality. By choosing an appropriate unit of numeraire, this is without loss of generality.

In the above utility function, consumption of higher quality goods yields higher utility to the consumers, *ceteris paribus*, and all goods are substitutes to each other (i.e., $0 < \rho < 1$). The elasticity of substitution (η), which equals $1/(1-\rho)$, is constant. Consumers maximise utility subject to a budget constraint, $\int_{\omega\in\Omega} p(\omega)q(\omega)d\omega = Y$, where Y is consumer income. Utility maximization yields the demand function as follows:

$$q = \Phi z p^{1/\rho - 1} \qquad (1)$$

where p denotes price, $\Phi \equiv \frac{Y}{\int_{\omega\in\Omega} p(\omega)^{\rho/(\rho-1)} z(\omega) d\omega}$ is a measure of aggregate demand level, which is exogenous to individual producers as they are small in size relative to

[4] Crozet, Head and Mayer (2012), Kugler and Verhoogen (2012) and Hallak (2006, 2010) use a similar quality-augmented CES utility function to investigate the impact of product quality on trade.

the industry. Equation (1) shows that product quality is positively related to product demand.

On the supply side, the industry consists of a continuum of firms. Each firm produces a single variety of a differentiated product. Firms are engaged in a two-stage activity. In stage one, firms decide their product quality. This may involve, for example, by the use of higher quality inputs or better control procedures. In stage two, firms set prices for their products. In this two-stage game, firms compete in both price and quality of their products. It is standard to assume that firms compete in price. Price affects consumers' budget constraints, which in turn influences their quantity of consumption. Similarly, quality affects consumers' optimal choice of consumption by directly entering the utility function. As such, firms have an incentive to use quality to influence consumers' demand, namely, to compete in quality.

The production involves a marginal cost, $C = z^{\alpha}c(x, \zeta)$ where α measures the quality elasticity of marginal cost $\left(0 < \alpha < \frac{1-\rho}{\rho}\right)$ [5] and $c(x, \zeta)$ is a component that depends on observed and unobserved firm characteristics (x and ζ, respectively). Four remarks are warranted here. First, the marginal cost is constant with respect to quantity, namely we consider the situation of constant return to scale. Second, we require the elasticity to be less than $\frac{1-\rho}{\rho}$, which guarantees the second order sufficient condition to be satisfied in the profit maximisation. Our estimations later also support this requirement. Third, the marginal cost is multiplicatively separable in quality. [6] Despite such a multiplicatively separable functional form is frequently used in applied economics, other functional forms are possible. Readers shall be aware of this limitation. Fourth, the quality in the marginal cost function (and fixed cost later) refers to the quality of output, rather than inputs. One can think firms use certain input quality to produce a level of output quality. However, we do not explicitly model such decision.

During the production, firms incur a fixed cost of $F = (1 + z)f$, where f is a component, which does not depend on quality.[7] Note that to produce higher quality products, firms must incur both higher marginal and fixed costs. For example, firms need to use higher quality intermediate inputs, which increases the marginal cost of production. Establishment of appropriate quality control process, which requires one to setup the appropriate facilities, also increases the fixed cost of production. The profit of a firm (π) can be written as follows:

[5] If $\rho < 1/2$, the marginal cost can be a convex function of quality.
[6] We thank an anonymous reviewer for pointing this out.
[7] More generally, one can also assume $F = (1 + g(\tilde{z}))f$, where $\tilde{z}$ is quality and g is an increasing function of $\tilde{z}$. In such a case, the quality index can be re-written as $z = g(\tilde{z})$. Note this supply-side normalization is different from the demand-side normalization in the utility function. The supply-side normalization is done through re-scaling the quality index, while the demand-size normalization is done through choosing an appropriate numeraire.

$$\pi = (p - C)\Phi z p^{1/\rho - 1} - (1 + z)f \tag{2}$$

In stage two, to maximize profit, each firm sets a price as a mark-up over its marginal cost of production, i.e., $p = \frac{C}{\rho}$. Substituting the optimal product price in equation (2) and maximizing the resulting profit with respect to the product quality, the optimal product quality can be derived as follows:

$$z = [1 - (1 + \alpha)\rho]^{\frac{1-\rho}{\alpha\rho}} \rho^{\frac{1}{\alpha}} \Phi^{\frac{1-\rho}{\alpha\rho}} c^{-\frac{1}{\alpha}} f^{-\frac{1-\rho}{\alpha\rho}} \tag{3}$$

Th equilibrium is characterised by the distribution of product quality, $\{z(\omega)\}_{\omega\in\Omega}$, such that consumers maximize utility, firms maximize profit, and the market clears. [8] Accordingly, equation (3) describes the market equilibrium. In the equilibrium, the optimal revenue and profit of a representative firm are as follows:

$$r = [1 - (1 + \alpha)\rho]^{\frac{1-(1+\alpha)\rho}{\alpha\rho}} \rho^{\frac{1}{\alpha}} \Phi^{\frac{1-\rho}{\alpha\rho}} c^{-\frac{1}{\alpha}} f^{-\frac{1-(1+\alpha)\rho}{\alpha\rho}} \tag{4}$$

$$\pi = \alpha[1 - (1 + \alpha)\rho]^{\frac{1-(1+\alpha)\rho}{\alpha\rho}} \rho^{\frac{1+\alpha}{\alpha}} \Phi^{\frac{1-\rho}{\alpha\rho}} c^{-\frac{1}{\alpha}} f^{-\frac{1-(1+\alpha)\rho}{\alpha\rho}} - f \tag{5}$$

where r is the firm revenue.

Comparing equations (3) and (4), it is clear that the unobserved product quality of the firm can be recovered from the observed firm revenue, as follows:

$$lnz = ln[1 - (1 + \alpha)\rho] + lnr - lnf \tag{6}$$

In fact, the product quality can be calculated once we have an estimate of the structural parameters α and ρ. A higher value of lnz implies a higher quality. In addition, any monotone transform of lnz can also be used to measure the quality, for example to rank firms by lnz.

Note in equation (6), we utilize the structural relationship between revenue and quality, implied by firms' profit maximization, to identify the unobserved quality. If a firm is subject to an external shock, for example an increase in consumer income, then its demand and revenue increases, and in addition, it will optimally adjust its product quality such that equation (6) continues to hold.

3.2 Estimation strategy

We now discuss the strategy used in this paper to estimate the structural parameters α and ρ in equation (6). We start by utilizing the relationship between the firm revenue and the total variable cost (TVC) implied by profit maximisation as follows:

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[8] Note here we only consider the short-run equilibrium. In the long run, the low-quality firms may not survive, which in turn can drive an increase in average quality over time. We thank an anonymous reviewer for pointing this out.

$$TVC = \rho r + \epsilon \quad (7)$$

where the error term ϵ is included to capture the measurement error in TVC.

The fixed cost of production can be measured by $f = iK$, where i denotes the real interest rate, K is the capital stock. The capital stock is defined as $K = I + (1-\delta)K_{-1}$, where I denotes investment, δ is the depreciation rate and the subscript -1 represents the previous period. The aggregate demand is measured as $ln\Phi = \beta_0 + \beta_1 lnY$. The marginal cost of production is measured as $ln[c(x,\zeta)] = \sum_{k=3}^{K-1} \beta_k x_k - \zeta$. Using theses specifications, firm revenue (i.e., equation 4) can then be written as follows:

$$lnr = \theta_0 + \theta_1 lnY + \theta_2 lnf + \sum_{k=3}^{K-1} \theta_k x_k + \varepsilon$$

where $\varepsilon = \zeta/\alpha$, $\theta_0 = ln\left\{[1-(1+\alpha)\rho]^{\frac{1-(1+\alpha)\rho}{\alpha\rho}} \rho^{\frac{1}{\alpha}}\right\} + \frac{1-\rho}{\alpha\rho}\beta_0$, $\theta_1 = \frac{1-\rho}{\alpha\rho}\beta_1$, $\theta_2 = -\frac{1-(1+\alpha)\rho}{\alpha\rho}$, and $\theta_k = -\frac{\beta_k}{\alpha}$, $k = 3, \cdots, K-1$.

Firms enter the market only if they earn non-negative profit, which using equation (5), implies

$$\varepsilon \geq \underline{\varepsilon} \equiv ln\left\{\alpha^{-1}[1-(1+\alpha)\rho]^{-\frac{1-(1+\alpha)\rho}{\alpha\rho}} \rho^{-\frac{1+\alpha}{\alpha}}\right\} - \frac{1-\rho}{\alpha\rho} ln\Phi + \left[1 + \frac{1-(1+\alpha)\rho}{\alpha\rho}\right] lnf + \sum_{k=3}^{K-1} \frac{\beta_k}{\alpha} x_k$$

Therefore, the population moment conditions can be written as follows:

$$E\left[\left(lnr_j - x_j'\theta - E\left[\varepsilon_j \middle| \varepsilon_j \geq \underline{\varepsilon}_j\right]\right)x_j \middle| \varepsilon_j \geq \underline{\varepsilon}_j\right] = 0$$

where the subscript j represents the firm-year observation; θ is a $K \times 1$ vector of parameters and $\theta = (\theta_0 \quad \cdots \quad \theta_K)'$; x_j is a $K \times 1$ vector of explanatory variables and $x_j = (1 \quad lnY_j \quad lnf_j \quad x_3 \quad \cdots \quad x_{K-1})'$.

Accordingly, the sample moment conditions are as follows:

$$\frac{1}{J}\sum_{j=1}^{J}\left(lnr_j - x_j'\theta - E\left[\varepsilon_j \middle| \varepsilon_j \geq \underline{\varepsilon}_j\right]\right)x_j = 0$$

where J is the total number of firm-year observations.

The method of moments estimator of θ is then:

$$\hat{\theta} = (X'X)^{-1}X'\left(R - E\left[\varepsilon \middle| \varepsilon \geq \underline{\varepsilon}\right]\right) \quad (8)$$

where $\hat{\theta}$ is the estimated value of θ; R is a $J \times 1$ vector of firm revenue and $R = (lnr_1 \quad \cdots \quad lnr_J)'$; X is a $J \times K$ matrix of explanatory variables and $X = (x_1' \quad \cdots \quad x_J')'$; and $E[\varepsilon|\varepsilon \geq \underline{\varepsilon}]$ is a $J \times 1$ vector of the expected ε.

The Monte Carlo methodology can be used to compute the standard errors of $\hat{\theta}$. Note the estimator in equation (8) contains an integral $E[\varepsilon|\varepsilon \geq \underline{\varepsilon}]$, which in turn depends on θ and the data. We simulate the value of this integral in the estimation process. We utilize a three-step algorithm for estimation as follows.

Step 1: We draw 10,000 random numbers for ε_j, which are normally distributed.

Step 2: Given θ^{r-1}, where the superscript indexes the iteration loops and $\theta^0 = 0$, for each j, we then simulate $E[\varepsilon_J \widehat{|\varepsilon_J \geq \underline{\varepsilon}_J}]$, where the caret over ε_j represents the simulated version of the integral. We then compute $\theta^r = (X'X)^{-1}X'\left(R - E[\varepsilon_J \widehat{|\varepsilon_J \geq \underline{\varepsilon}_J}]\right)$.

Step 3: If $|\theta^r - \theta^{r-1}| < ltor$, where ltor represents the level of a pre-defined tolerance, the algorithm stops. Otherwise, go to Step 2.

Finally, with the estimated parameter and the data on firm revenue and fixed cost of production, we use equation (6) to compute the product quality index.

4. Data

To estimate product quality in China's (i) food processing and (ii) food manufacturing industries (two-digit), we use firm level data from 2005 to 2007. This is the most recent firm level dataset available to researchers. The two industries can be considered as close to monopolistic competition as their average Herfindahl indexes are low (0.0112 for food processing and 0.0264 for food manufacturing) and their products are differentiated. Both industries are small relative to the aggregate industrial economy, with food processing and manufacturing accounting for around 4.24 and 1.48 per cent of the aggregate industry sales in the period of 2005-2007 respectively.

The data are obtained from the China National Bureau of Statistics (NBS). NBS surveyed firms annually to compile the 'Industry' section of the *China Statistical Yearbook*. This survey accounts for over 85 per cent of China's total industrial output. A number of previous studies have utilised similar data from NBS to investigate different aspects of the Chinese economy. For example Hu *et al.* (2005) used the same dataset to evaluate the impact of research and development (R&D), Jefferson *et al.* (2008) examined the issue of productivity growth, Fu and Wu (2010) considered the export growth and Sun (2009, 2010; 2012) focused on some aspects of foreign direct investment and export behaviour.

Before using the dataset, we excluded the firms with less than eight employees, as these firms may not have reliable accounting system (Jefferson et al., 2008). In addition, firms that reported negative values of fixed assets, non-positive outputs, value added, and wages were also excluded, which occurs possibly due to entry errors. We also excluded firms that are located in the upper and lower tails of the productivity distribution (namely more than four standard deviations from the mean) to avoid the possible undesirable impact of outliers. Using the producer price index for manufactured goods, which we obtain from the *China Statistical Yearbook* 2008, except for the capital stock, all nominal variables (e.g., the domestic sales revenue) were deflated by the year 2005 prices.

For the capital stock, the dataset reports the original cost of fixed assets. We deflated this cost by the fixed asset investment price index (1990 = 100). We treated the deflated original cost of fixed assets in 2005 as the capital stock in 2005, and then calculated the investment in 2006 and 2007 as the differences in the deflated original cost of fixed assets with its value in the previous period. The capital stock for 2006 and 2007 are the investment plus the depreciated capital stock in the previous period, where the depreciation rate is assumed to be 5 per cent. With data on the capital stock, we calculated the fixed cost of production as the real interest rate times the capital stock. The real interest rate is calculated as the difference between the lending rate and the CPI inflation rate, both of which are obtained from the World Development Indicators, 2020.

The total variable cost is the sum of total salary and intermediate inputs cost, both of which are reported in the dataset. The domestic sales and export revenues are also reported in the dataset. The aggregate income is calculated from *China Statistical Yearbook* 2008. The vector X, in equation (8), includes the firm size, productivity, capital intensity, average wage, firm age, whether a firm exports, whether a firm conducts R&D, and the level of foreign presence in a four-digit industry.

The firm size is measured by the number of employees. Capital intensity is measured by the capital stock per employee. The average wage equals the total salary divided by the number of employees. Firm age is the number of years the firm has been in business. Whether a firm exports and whether a firm conducts R&D is captured by two dummy variables. These variables take a value of one if the phenomenon exists (for example if the firm conducts R&D), 0 otherwise. The level of foreign presence is measured by the share of the employment of the foreign firm in a four-digit industry. The productivity is total the factor productivity, which is estimated using Levinsohn and Petrin (2003) method.

Conceptually, firms of different sizes will have different marginal cost of production due to economies of scale. The capital intensity and average wage, respectively, capture the impact of physical and human capital on the marginal cost of production. Firm productivity is an important determinant of the cost of production, which has been found to play an important role in the production (see for example Aw et al., 2011). Due to learning by exporting, the cost of production of firms varies across their export status. The empirical evidence provided by (see for example Yang and Mallick, 2010) shows that exporting improves the productivity of firms, which supports the presence of a learning by exporting effect. Not surprisingly, R&D activities also affect the marginal cost of production of firms. The level of foreign presence is also included among the control variables to account for possible spillovers from foreign firms to domestic firms. Several studies, e.g. Sun (2011), find that foreign direct investment generates significant productivity spillovers to domestic firms in China's manufacturing sector.

As shown in Section 3, firm sales revenue (in the domestic market) contains information on product quality. Thus, we first examine the estimated distribution of firm revenue and its evolution over time. The distribution of firm revenue (in natural logarithm) and its growth rate over time in the food processing industry is shown in Figures 1 and 2, whereas Figures 3 and 4 show the same information for China's food manufacturing industry. Figure 1 appears to suggest that the distribution of firm revenue has shifted to the right over the 2005 to 2007 period. The mean of the distribution has increased from 9.9991 in 2005 and 10.0726 in 2006 to 10.2537 in 2007. The associated standard deviations have decreased slightly from 1.4380 in 2005 and 1.4278 in 2006 to 1.4234 in 2007. Not only there is evidence of some growth but the distribution has also become slightly tighter over time. This trend is also confirmed by the graph of the growth rate of firm revenue distribution. In Figure 2, the distribution of the growth rate of firm revenue has shifted to the right. It has a mean of 18.9 per cent in 2006 and 28 per cent in 2007, with the associated standard deviations of 0.7579 and 0.7235, respectively.

<insert Figure 1 here>

<insert Figure 2 here>

Figures 3 and 4, respectively, are the distributions of firm domestic sales revenue and its growth rate in China's food manufacturing industry. Like the food processing industry, the distribution of firm revenue in the food manufacturing industry also exhibits a growth trend. The mean (standard deviation) of the revenue distribution is 9.8161 (1.5028) in 2005, 9.9692 (1.4538) in 2006, and 10.1224 (1.4204) in 2007, where figures in the brackets are corresponding standard deviations. On average food manufacturing firms are slightly smaller in size than food processing firms. The growth rate of the firm revenue has a tent shape distribution, with the mean and standard deviation, respectively, of 0.2009 and 0.7052 in 2006 and 0.2282 and 0.6802 in 2007.

<insert Figure 3 here>

<insert Figure 4 here>

Table 1 presents the summary statistics of the variables. Several features emerge from Table 1. First, the sample includes a large number of firms from both industries. For example, the food manufacturing industry has 5285 firms in 2005, 5788 firm in 2006, and 6442 firm in 2007. Second, sufficient variation exists in both industries. For example, firms in food processing industry are on average 7.6 years old, with a standard deviation of 8.7 and minimum and maximum age of 1and 96, respectively. We utilise the variation in the variable cost to identify the preference parameter (ρ) and the variation in the domestic sales revenue to identify the unobserved product quality. Third, whether a firm exports, and whether a firm conducts R&D are two dummy variables. We only report their means (i.e., the proportion of firms who export and conduct R&D). In the case of both industries, around 20 per cent of the firms have exporting experience, and the proportion of firms that conduct R&D is much smaller.

<insert Table 1 here>

5. Distributions of Product Quality in Food Industries

As described in Section 3, we first regress the total variable cost against domestic sales revenue using the ordinary least square estimator, where the constant is not included, and the sample is restricted to the non-exporting firms. In stage two, we use the algorithm described in Section 3 to perform the method of simulated moments estimation. In the following, we report the estimates of the structural parameters and discuss the estimated product quality.

5.1 Estimation of structural parameters

Table 2 presents the estimated structural parameters. The point estimates of ρ in food processing and food manufacturing industries, respectively, are 0.783 and 0.7970. This implies that the price elasticities of demand in the two industries, respectively, are 4.61 and 4.93. The point estimates are lower than, but approximately in line with, the previous studies. For example, Aw *et al.* (2011) estimate a price elasticity of 6.3776 for the electronics manufacturing industry in Taiwan. Das *et al.* (2007) estimate price elasticity of export demand in the range of 8.02 (quintile 1) to 37.189 (quintile 4) in Colombia's leather product industry.

The point estimates of α, which measures the quality elasticity of marginal cost in the food processing and food manufacturing industries, respectively, are 0.1003 and 0.0767. Both of these estimated values are statistically significant at the 5% cent level. Accordingly, a 1% increase in product quality results in around 0.1% increase in the marginal cost of production in both food processing and manufacturing industries.

<insert Table 2 here>

Equation (6) can also be used to examine the marginal impact of each of the firm characteristics on product quality. This follows from the fact that $\partial lnz/\partial x = \partial lnr/\partial x$, where x is one of the firm characteristics (i.e., firm size, total factor productivity, and average wage). The effect of each of the firm characteristics on firm revenue and product quality is positive and statistically significant at the 5% level. These positive impacts highlight the importance of size (possibly due to economies of scale), productivity, and human capital (which is proxied by the average wage) in quality production.

The marginal influences of capital intensity, firm age, FDI presence, and whether a firm conducts R&D are mixed in the sense that they generate significant impacts in one industry, but insignificant impacts in the other, reflecting the industry heterogeneity. For example, a firm with higher capital intensity is found to have significantly higher revenue and product quality in the food manufacturing industry, but not in the food processing industry. In both industries, whether a firm exports negatively affects sales revenue and product quality in the domestic market. It is likely that exporting firms focus more on international market, which in turn leaves fewer resources for domestic market quality improvement.

5.2 Estimated quality distributions

Using equation (6), together with the estimates of α and ρ, we can obtain the estimate of product quality. Figures 5 and 7, respectively, present the probability distributions of the estimated product quality (in natural logarithm) in food processing and food manufacturing industries. Figures 6 and 8 show the distributions of the growth rates of expected product quality in the two industries.

In the food processing industry, despite a leftward shift in 2006, in overall terms, the distribution of the estimated product quality shows a rightward shift from 2005 to 2007. In 2005, the mean and standard deviation of the distribution are 3.6323 and 1.5062, respectively. In contrast, the mean decreases slightly to 3.4978 in 2006, which then increases to 4.1299 in 2007. The standard deviation slightly decreases over the three years (1.4777 in 2006 and 1.4560 in 2007). This trend is also observable in the distribution of the growth rates of the estimated product quality. In Figure 6, the probability distribution of the growth rates exhibits a typical tent shape pattern. The average growth rates are negative in 2006 and positive in 2007 (-0.0854 in 2006 and 0.6608 in 2007).

<insert Figure 5 here>

<insert Figure 6 here>

In order to further investigate the extent of the shift in the relevant probability distributions over time, we make use of the Kolmogorov-Smirnov test. This test allows one to investigate whether probability distributions of the estimated product quality are equal over the three years. Comparing the quality distribution in 2005 with that of 2006, the Kolmogorov-Smirnov test statistic is 0.0450 with a *p*-value < 0.001, rejecting the null hypothesis that the two distributions are equal. Similarly, the quality distribution in 2007 is different from that of 2006 with a test statistic of 0.2036 and *p*-value < 0.001. In addition, the distribution in 2007 is also different from that of 2005 with a test statistic of 0.1613 with *p*-value < 0.001. The distributions of the growth rates of the expected product quality also exhibit significant differences over time. The estimated test statistic of the Kolmogorov-Smirnov test is 0.5254 with a *p*-value < 0.001, rejecting the null hypothesis of equality between the two distributions.

Comparing the distributions of the estimated product quality (Figure 5) with that of the domestic sales (Figure 1), three interesting observations emerge. First, the growth trend of product quality is weaker than that of domestic sales revenue in the sense that the 2006 quality distribution shifts left relative to that of 2005. Nevertheless, with a correlation of 0.4885, the quality improvement appears to positively contribute to the sales revenue growth. Second, the average domestic sales are higher than that of average estimated quality, which is not surprising as product quality is not the sole driving force of sales growth. Third, the distributions of sales revenue appear to be tighter than those of product quality, suggesting that firms are more likely to have higher or lower product quality relative to their sales in food processing industry.

Figures 7 and 8, respectively, show the probability distribution of the product quality and its growth rate in China's food manufacturing industry. Like the trend observed in the food processing industry, we observe a rightward shift in the quality distributions from 2005 to 2007. In 2005, the estimated mean and standard deviation of the product quality, respectively, are 2.8651 and 1.4696. In 2006 and 2007, respectively, the mean slightly decreases to 2.8068 and then increases to 3.4397. The corresponding standard deviations are 1.4432 and 1.4119. Furthermore, the probability distribution appears to become tighter from 2005 to 2007.

<insert Figure 7 here>

<insert Figure 8 here>

The probability distributions of the growth rates exhibit a similar pattern (see Figure 8), which shows a typical tent shape. In 2006, the mean and standard deviation of the growth rate, respectively, are -0.077 and 0.8861 and the corresponding figures in 2007 are 0.6475 and 0 .8408. The Kolmogorov-Smirnov tests reject the null hypothesis of equality in distributions of the estimated product quality over the three-year period. For example, in comparing the distributions of 2005 and 2006, the test statistic is 0.0329 with a *p*-value of 0.006. The distribution of growth rate of product quality in 2007 is also different from that of 2006, with a Kolmogorov-Smirnov test statistic of 0.5667 (*p*-value < 0.001).

Comparing the distribution of the expected product quality with that of domestic sales, we observe a pattern that is similar to the food processing industry.

Both distributions exhibit a similar growth pattern and the product quality distributions have smaller variance than those of sales revenue distributions. Comparing the probability distributions of the food processing industry with food manufacturing industry, we find very similar growth pattern. Specifically, there is a leftward shift from 2005 to 2006 and then there is a rightward shift from 2006 to 2007. This pattern is also confirmed by the distribution of growth rates. The distribution of the growth rate in 2006 has a negative mean while the 2007 distribution has a positive mean.

Based on the results presented in this section, it can be argued that product quality in China's food processing and food manufacturing industries has improved over time. However, the average growth of the improvement is modest, with room for further improvement. Given the importance of product quality, policy makers may adopt measures to incentivize firms to improve their product quality, for example through implementing stricter quality standards or providing tax benefits to firms that set up quality control facilities. Such kind of measures are likely to result in a Pareto improvement to the society.

5.3 Simple validity tests

We have presented the estimated quality index in Section 5.2. However, how reasonable are our estimates? Since product quality is unobserved, it is difficult to directly test our quality index. Nevertheless, we have three observations regarding product quality. First, the quality of inputs is important for the output quality. As such, they shall be positively correlated. Second, more productive firms are more capable of producing high quality products, *ceteris paribus*. Hence, productivity and product quality are positively correlated. Third, since consumers value quality products, a higher quality firm shall have a higher market share, *ceteris paribus*. Therefore, the quality index is positively correlated with market share.

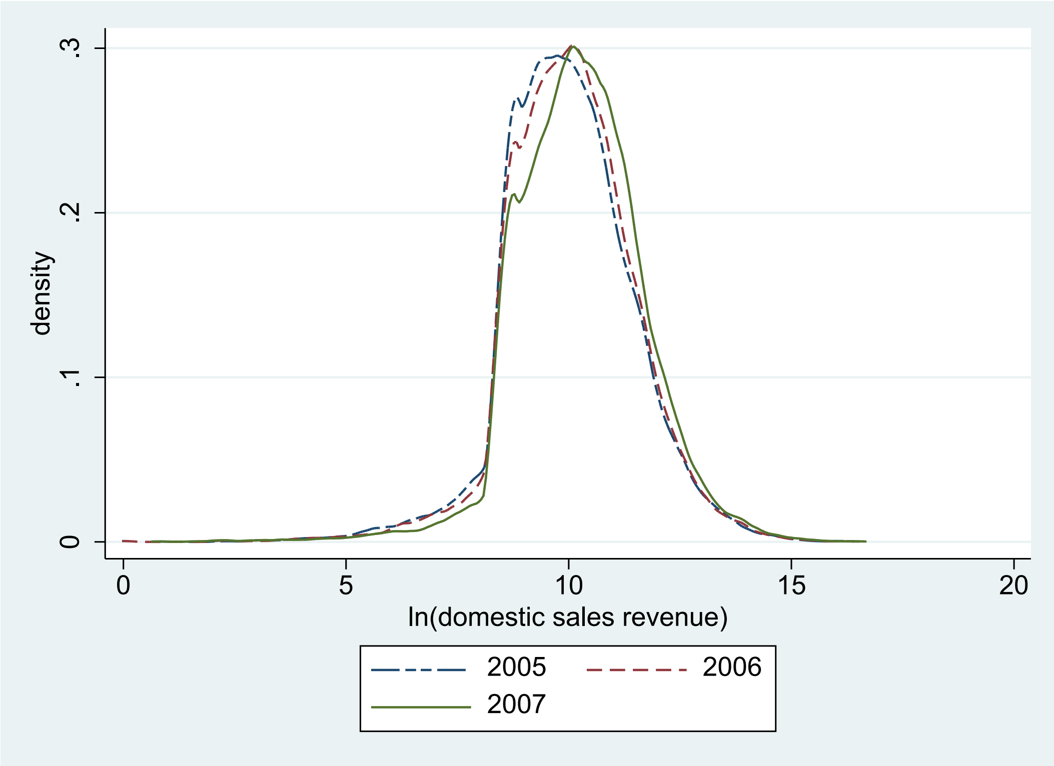
Based on these three observations, we perform some simple tests, by examining the correlations, to check the validity of our estimates. We use average wage to proxy for the input quality (namely labour quality). In a perfectly competitive labour market, workers earn a salary equal to their value of marginal product. So, a higher average wage implies higher labour quality (or human capital). The correlation between quality estimate and average wage is 0.047 and 0.001 for the food processing and manufacturing industries respectively, which is also consistent with the estimates in Table 2. Similarly, the correlation between quality estimate and total factor productivity is 0.5857 and 0.3623 for the food processing and manufacturing industries respectively. Regarding the correlation between quality estimate and market share, the food processing industry has a correlation of 0.0266, while it is 0.0719 for the food manufacturing industry. The positive correlations, to some extent, confirm the validity of our quality estimates.

6. Concluding Remarks

Using a theoretical model, where consumers derive higher utility from consuming higher quality products and quality products are more costly to produce, we show that product quality depends on, among other things, the parameters of consumer utility function and marginal cost of production. We then argue that these unobserved parameters can be estimated using the information on firm revenue and hence it is possible to provide an estimate of the product quality.

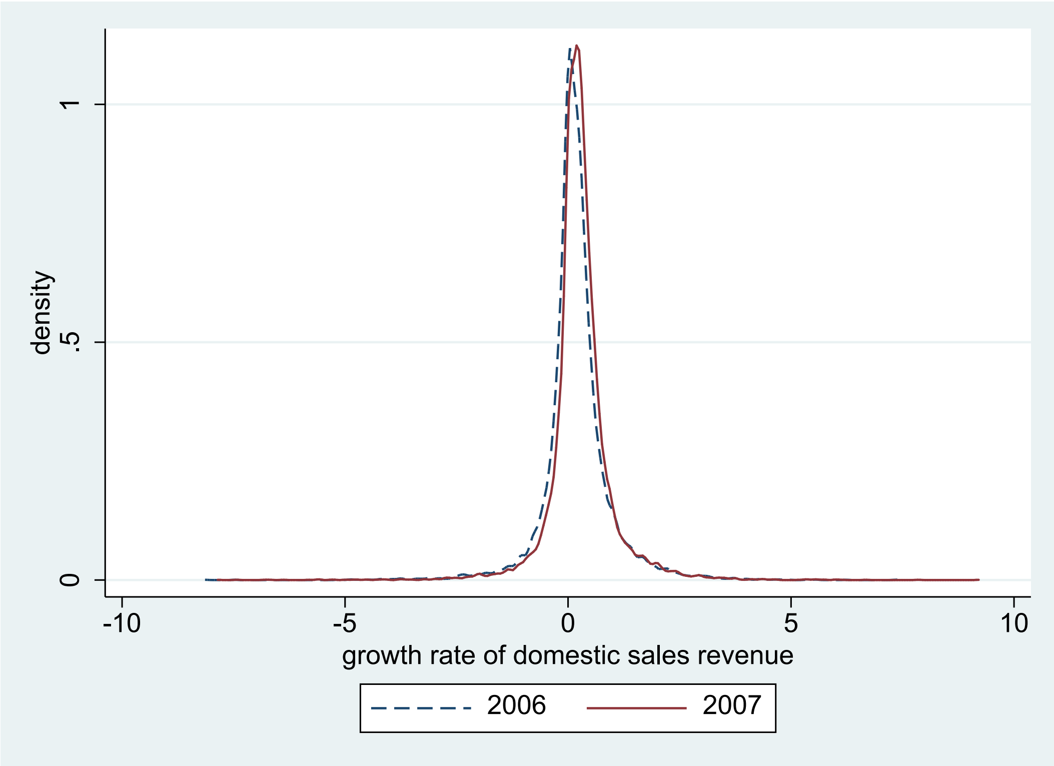
In the second part of the paper, using firm level data from China's food processing and food manufacturing industries from 2005 to 2007 (which is the most recent available dataset), we estimate the product quality and its growth rates. Our empirical analysis shows that product quality in both industries is improving over time in the sense that the probability distributions of product quality have shifted to the right from 2005 to 2007. The probability distributions of product quality growth rates in both industries have positive means in 2007, which confirms that product quality in both industries is indeed improving over time. However, based on the media reports and the general perception regarding the quality of a number of Chinese made products (particularly food items), it is clear that there is lots of room for further improvement in the area of product quality.

Figure 1. Distributions of Firm Domestic Sales Revenue in the Food Processing Industry, 2005 – 2007



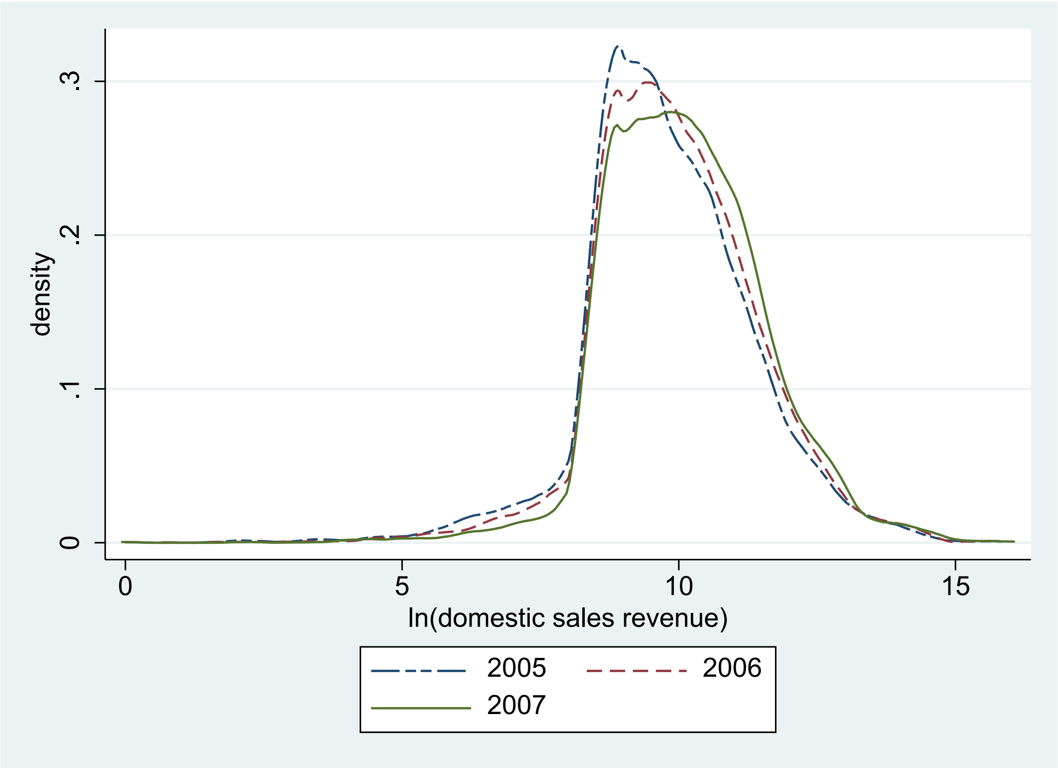
Source: NBS, China.

Figure 2. Distributions of Growth Rate of Firm Domestic Sales Revenue in the Food Processing Industry, 2006 – 2007



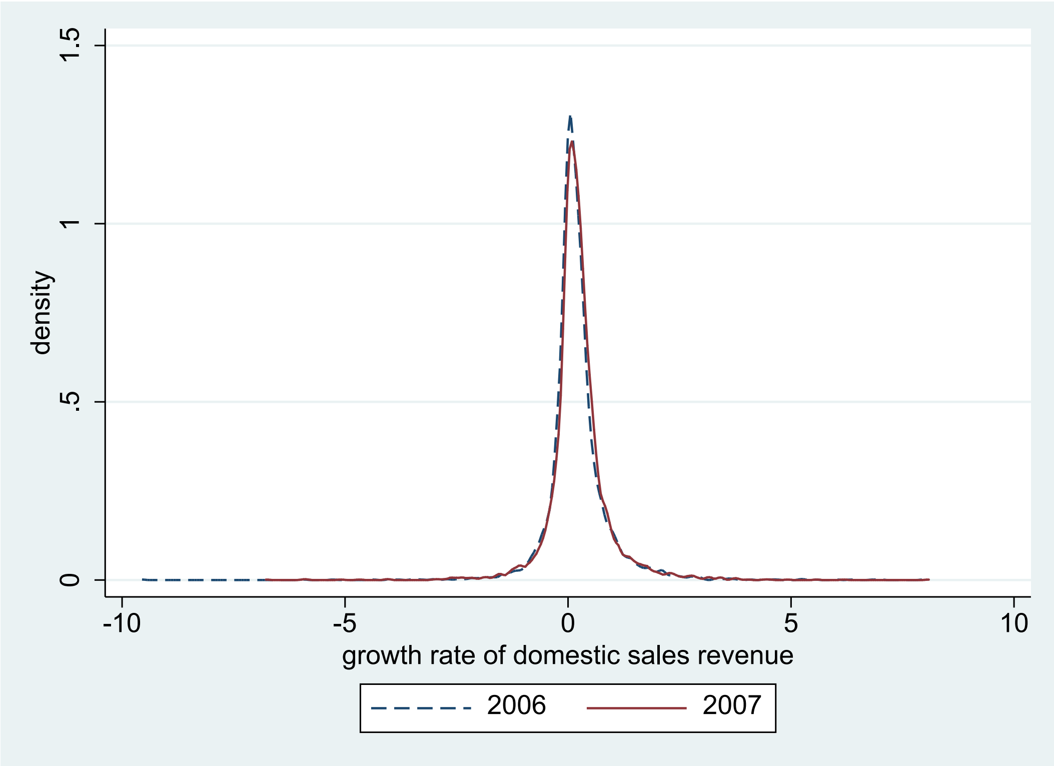
Source: NBS, China.

Figure 3. Distributions of Firm Domestic Sales Revenue in the Food Manufacturing Industry, 2005 – 2007



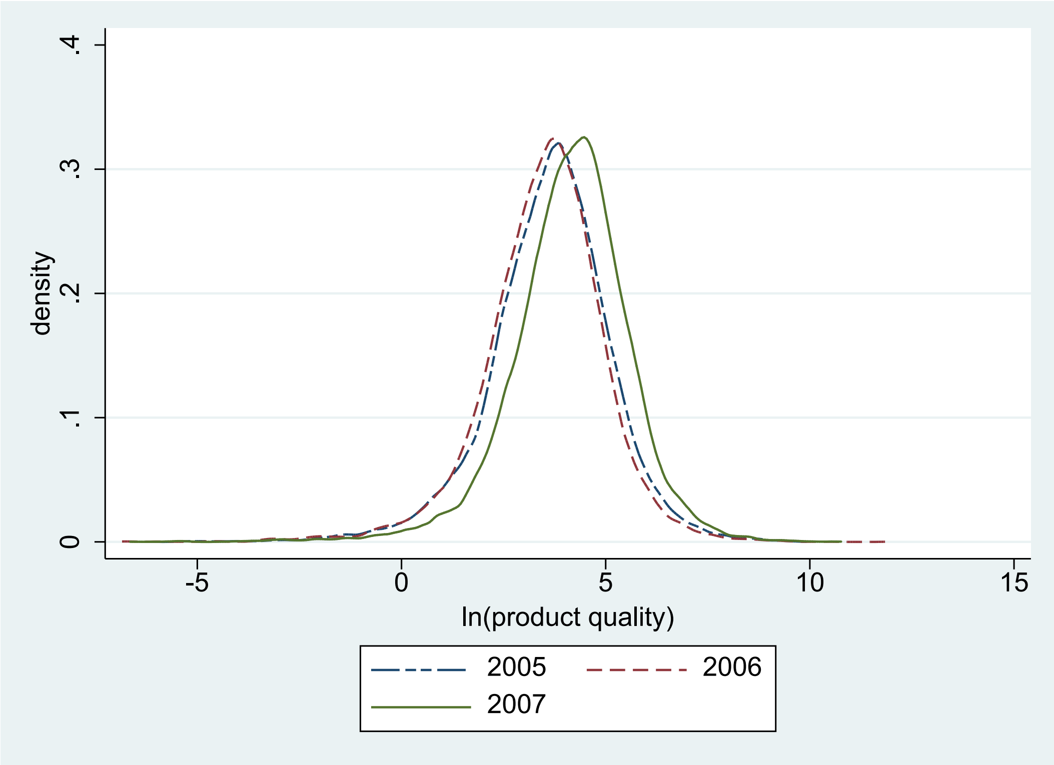
Source: NBS, China.

Figure 4. Distributions of Growth Rate of Firm Domestic Sales Revenue in the Food Manufacturing Industry, 2006 – 2007



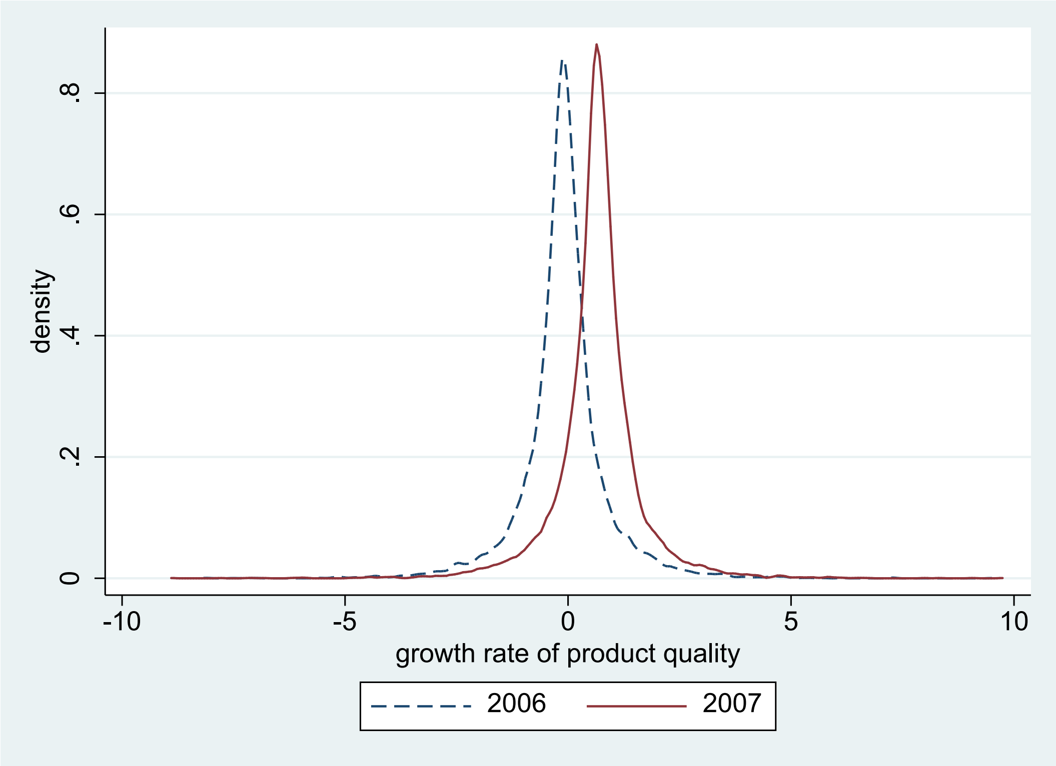
Source: NBS, China.

Figure 5. Distributions of Firm Product Quality in the Food Processing Industry, 2005 – 2007



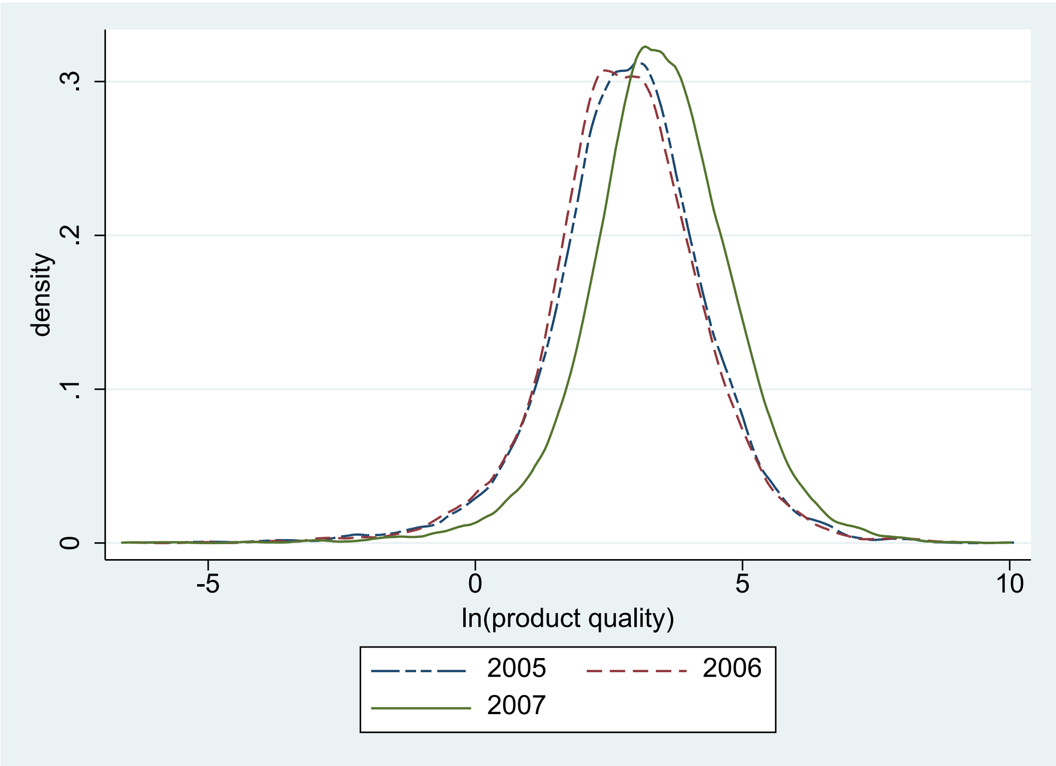
Source: Authors' estimation with data from NBS, China.

Figure 6. Distributions of Growth Rate of Firm Product Quality in the Food Processing Industry, 2006 – 2007



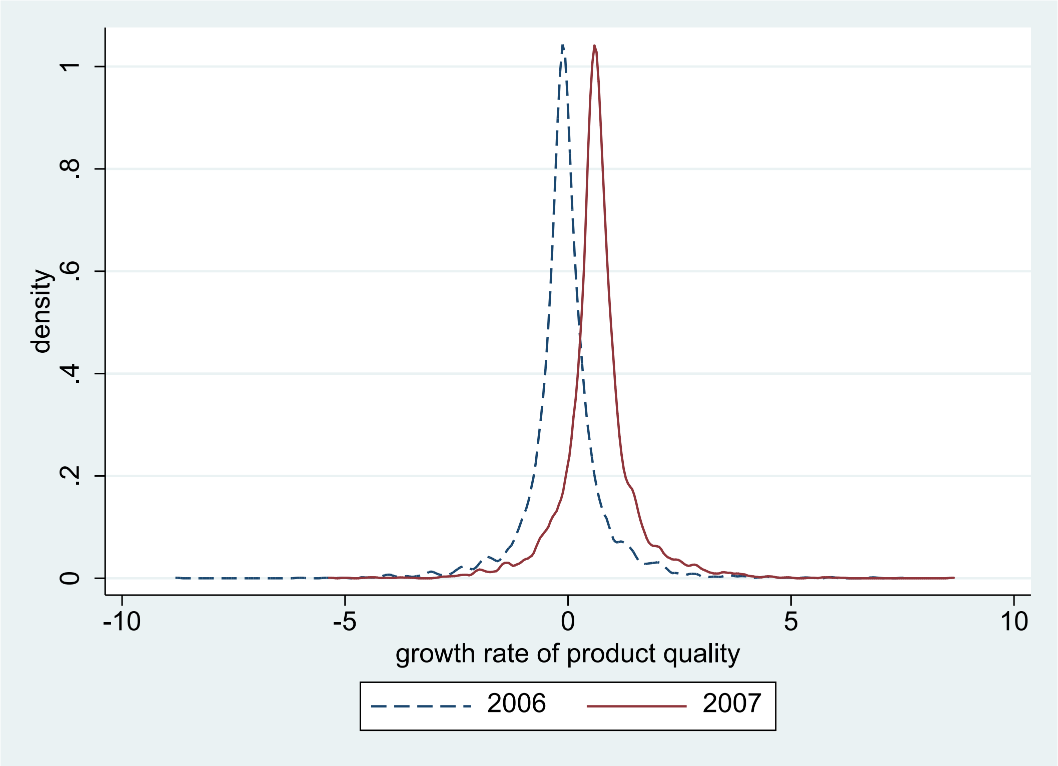
Source: Authors' estimation with data from NBS, China.

Figure 7. Distributions of Firm Product Quality in the Food Manufacturing Industry, 2005 – 2007



Source: Authors' estimation with data from NBS, China.

Figure 8. Distributions of Growth Rate of Firm Product Quality in the Food Manufacturing Industry, 2006 – 2007



Source: Authors' estimation with data from NBS, China.

Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Food processing industry					
ln(domestic sales)	45447	10.1185	1.4333	-0.0296	16.6667
variable cost	47135	63807.2	248027	56.5078	1.4E+07
ln(aggregate income)	47135	9.0290	0.0791	8.9281	9.1214
ln(firm size)	47135	-2.5902	1.0347	-4.8283	3.3612
ln(total factor productivity)	47122	3.9744	0.5733	0.8456	9.5625
ln(capital intensity)	47135	3.5132	1.1724	-5.2777	8.0473
ln(average wage)	47135	2.3972	0.5805	-5.3279	5.8096
FDI	47135	0.2071	0.1383	0	0.6277
Firm age	43938	7.6398	8.7276	1	96
ln(fixed production cost)	47135	4.4896	1.4904	-5.3342	12.1033
whether export	47135	0.1879			
whether R&D	47135	0.0702			
Food manufacturing industry					
ln(domestic sales)	16903	9.9797	1.4619	-0.06	16.0577
variable cost	17515	61045.4	224525	84	8740680
ln(aggregate income)	17515	9.0280	0.0792	8.9281	9.1214
ln(firm size)	17515	-2.2502	1.0616	-4.8283	3.1036
ln(total factor productivity)	17512	3.1281	0.4299	0.9585	9.1780
capital intensity	17515	3.4974	1.2018	-3.9342	7.8453
average wage	17515	2.4925	0.6045	-1.6422	5.3534
Firm age	17515	0.2941	0.1214	0	0.5964
FDI	16519	8.6106	9.8047	1	142
ln(fixed production cost)	17515	4.8150	1.5873	-1.8084	11.8304
whether export	17515	0.2251			
whether R&D	17515	0.1348			

Source: NBS, 2005-2007.

Table 2: Parameter Estimates

	Food processing industry		**Food manufacturing industry**	
	Coef.	S. E.	Coef.	S. E.
ρ	0.7830*	0.0007	0.7970*	0.0008
α	0.1003*	0.0041	0.0767*	0.0026
θ_0(constant)	-95.5340*	5.3045	-76.9971*	3.1766
θ_1(Aggregate demand)	1.0609*	0.5362	-0.9254*	0.3095
θ_2(Fixed production cost)	-1.5386*	0.1097	-2.6119*	0.1223
θ_3(firm size)	1.1766*	0.1419	2.0656*	0.1353
θ_4(total factor productivity)	5.5517*	0.2721	5.3704*	0.0947
θ_5(capital intensity)	0.2466	0.1596	1.3842*	0.1431
θ_6(average wage)	0.4071*	0.0665	0.1838*	0.0369
θ_7(age)	-0.0058*	0.0027	-0.0035	0.0019
θ_8(whether export)	-2.2728*	0.1073	-3.3556*	0.0867
θ_9(whether R&D)	0.3968*	0.1025	0.1365	0.0718
θ_{10}(FDI)	-0.3702	0.2444	-2.0410*	0.1556

Note: * denotes significance at the 5 per cent level.
Source: Authors' estimation.

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