Are Family Firms More Efficient? Revisiting the U-Shaped Curve of Scale and Efficiency

Ku-Hsieh Chen

Department of Applied Economics and Management,

National Ilan University

Pei-Hwa Chen

Department of Economics

National Taipei University

Julie Ann Elston

Oregon State University

1500 SW Chandler Way

Bend, OR 97702-5998 USA

Yingchao Zhang

Durham University,

Millhill Ln, Durham

DH1 3LB, Durham, UK

Tel +44 0191 45533

Email: yingchao.zhang@durham.ac.uk

Abstract

This study applies a stochastic frontier model to examine the relationship between firm size and efficiency using a novel approach. The first novelty is that this study examines large and small firms separately to allow for heterogeneity between firm group sizes in terms of measuring the size-efficiency relationship. The second is that we use a modified model which explicitly includes a family firm variable when measuring firm efficiency. Empirical results reveal that firms are in fact heterogeneous, with small-and-medium-sized enterprises (SMEs) exhibiting a U-shaped scale efficiency curve, while large enterprises (LE) exhibit an efficiency curve which is linear, positive, and monotonically increasing. In addition, while controlling for family firms does not appear to change the firm's size-efficiency dynamics, the study demonstrates that failure to control for family firms leads to a bias in characterizing the nature of the firm's production returns to scale.

Plain English Summary

This study reveals that with scale expansion, firm efficiency dynamics vary depending on firm size. Empirical results show that SMEs go through an initial stage of efficiency loss and then rebound, exhibiting a U-shaped efficiency curve. While for LEs, the effect is linear with a slightly positive slope as firm efficiency increases slowly and steadily. Findings suggests that there are implications for entrepreneurship policy, as the important role of family firms in increasing production efficiency are revealed. There are also important implications for small business research, as results show that failure to control for family effects in the efficiency model can cause misjudgement in characterizing production as increasing in returns to scale rather than decreasing returns to scale.

Keywords: Small firms • efficiency • family firms

JEL Classifications: C51 • C63 • D24

1. Introduction

The relationship between firm size and performance is an enduring puzzle in small business economics with no consistent conclusion on the underlying dynamics. Many studies have found a positive relationship between size and performance (Abbas & Siddiqui, 2020; Alvarez & Crespi, 2003; Assaf et al., 2011; Coto-Millán et al., 2014; Taymaz, 2005; Taymaz & Saatci, 1997; Toma, 2020; Xu & Chi, 2017). These studies have emphasized that firms driven by the competition mechanism, invest in a series of learning activities (Jovanovich, 1982) where the better performers evolve toward the optimal scale while continuing to compete and grow. In addition, larger enterprises (LEs) also have advantages in terms of economies of scale, specialized inputs, bargaining power, financing conditions, and human capital acquisition (Giancotti et al., 2017; Taymaz, 2005; Toma, 2020; Yang & Chen, 2009).

Conversely, some studies have found a negative impact of firm size on performance (Diaz & Sánchez, 2008; Hart & Oulton, 1996; Kagin et al., 2016; Le & Harvie, 2010). Reasons include the fact that due to the flat organizational structures, small and medium-sized enterprises (hereafter SMEs) have reduced agency costs due to size and as well as fewer issues relating to moral hazard. Moreover, SMEs have a low adjustment cost and are relatively agile and flexible in responding to industry competition and internal/external shocks. In addition, due to the consistency of ownership and management authority, the agency problem of conflicting goals is alleviated. Some studies have also argued that the impact of size on performance varies across industries (Yang & Chen, 2009) or depends on different scale phases (Chen & Ghosh, 2013).

To the best of our knowledge, Schiersch (2013) was the first to conclude that the relationship between firm scale and performance is not monotonic, but rather that positive and negative coexist in a "U-shape" using data on German manufacturing firms. It is also likely that although SMEs often exhibit a negative between size and performance, when large scales dominate the sample, this may lead to positive empirical results for the entire sample.

In a parallel literature, the impact of family firm characteristics on performance has also recently received much attention, but the impact of family ownership on firm performance remains inconclusive. The negative impact can be explained by family agency theory (Chu, 2009) where management rights and ownership lead to prioritization of the family's goals over the firm's goals (Carney, 1998; Kepner, 1983; Kets de Vries, 1993; Lansberg, 1983; Westhead et al., 2001). In contrast, a positive impact may arise from the six competitive advantages of family firms(Anderson & Reeb, 2003; Cavery, 1998; Demsetz & Lehn, 1985; Jensen & Meckling, 1976; McConnell & Servaes, 1990; Morck et al., 1988; Schulze et al., 2003; Shleifer & Vishny, 1986), information symmetry (Eisenhardt, 1989; Kets de Vries, 1993; Smith & Amoako-Adu, 1999), the embedded advantage of relationships (Human & Provan, 1997; Silva et al., 2006), sustainability of equity (Anderson & Reeb, 2003; Burkart et al., 2003; DeAngelo & DeAngelo, 2000; Poza, 2020), entrepreneurship (Astrachan et al., 2003; Sathe, 2007; Zahra, 2005), and investment efficiency (Chu, 2009; Laverty, 2004; James, 1999; Stein, 1989).

Although it can be seen from the above studies that the family firm characteristics significantly impact firm performance, the direction of the influence is still debated. In this regard, Chu (2009) highlighted size as an explanation, emphasizing that the observations of the past literature have mostly concerned LEs, such as Fortune 500 or S&P 500 firms. Their study used a sample of 341 Taiwan SMEs, including 185 family firms, and showed a significant positive impact of family firms on performance.

In order to resolve the mixed firm size-efficiency relationship in the empirical literature, this study recognizes that it may be important to 1) consider whether the characteristics and proportion of family firms should in fact be more prominent in SMEs and be controlled for, and 2) include data on both large and small firms in the study, which is articulated as an area for improvement in future efficiency studies (Owalla, et al., 2022). Thus, this study will contribute to the literature by combining these literatures to empirically examine the relationship between firm size and performance, using both large and small firms and controlling for family firms.

There are three basic research questions in this study. The first question centers on the issue whether the traditional U-shaped pattern between scale and efficiency is characteristic for both SMEs and LEs. This paper argues that previous studies using pooled may be inappropriate if SMEs and LEs in fact exhibit heterogeneity, resulting in a characterization of both groups by the characteristic of the dominant group. Second, in the broader small business literature, family firm characteristics are often considered one of the factors affecting performance. However, the influence of family firms has been generally excluded when exploring the relationship between scale and efficiency. Is it possible that family ownership reduces firm agency problems leading to higher levels of production efficiency? This paper will contribute to the small business literature by building on past efficiency production studies to empirically examine the relationship between firm scale and efficiency, using both large and small firms and controlling for family firms.

The remaining structure of this paper is as follows. Section 2 presents a review of the theory and relevant literature which summarizes the underlying motivation and dynamics of how firm scale and family firms impact efficiency. Section 3 contains the methodology, the proposed model's design, variable measurement, and data sources. Section 4 contains the empirical analysis including descriptive statistics and empirical efficiency estimates controlling for family ownership, and Section 5 summarizes findings and draws conclusions from the study.

2. Literature review and theories

2.1 Firm scale and efficiency

There is a large body of literature which explores various theories and related empirical studies underlying the relationship between firm size and performance. Theories which suggest that size may have a positive effect on firm performance can be roughly organized into the following seven underlying causes (which are not mutually exclusive): active learning (Taymaz, 2005), passive learning (Jovanovich, 1982; Taymaz, 2005), economies of scale (Giancotti et al., 2017; Mansfield, 1962; Toma, 2020), division of labor and specialization (Taymaz, 2005; Yang & Chen, 2009), (Serrasqueiro & Maçãs Nunes, 2008; Singh & Whittington, 1975), access to finance (Alvarez & Crespi, 2003; Toma, 2020), and human capital (Alvarez & Crespi, 2003). Empirically, there are also studies across various countries supporting the hypothesis that larger firms perform better than smaller firms. These studies include Toma (2020) for Italy; Xu and Chi (2017) for the US; Assaf et al. (2011) for Australia; Coto-Millán et al. (2014) for Spain; Abbas and Siddiqui (2020) for Pakistan.

However, there are also a number of theories which suggest that smaller firms may perform better than larger ones. These theories can be organized as those which are based on: the non-hierarchical structures for SMEs (Fang et al., 2022; Taymaz, 2005); flexibility and nimbleness, (Yang & Chen, 2009); consistency of ownership and management rights; innovation, (Le & Harvie, 2010); low exit barriers (Diaz & Sánchez, 2008; Toma, 2020); laxity under monopolistic competition (Hansen, 1992; Kimberly, 1976; Yang & Chen, 2009). Empirical studies which find support for theories related to the relatively better performance of SMEs over LEs include: Le and Harvie (2010) for Vietnam, Kagin et al. (2016) for Mexico; Diaz and Sánchez (2008) for Spain.

In addition, some studies have asserted that the relationship between firm size and performance is not only monotonically positive or negative but that positive and negative coexist. These studies support the possibility that the relationship between firm size and performance is not just monotonic but U-shaped. These include Yang and Chen 2009 for Taiwan; Chen and Ghosh (2014) for Taiwan; Schiersch (2013) for Germany, and Ferreira and Féres (2020) for Brazil. The diverse findings of these studies suggest that more research is needed to understand and disentangle the complexities of the relationship between firm scale and performance. Table 1 summarizes the key characteristics and findings of these recent technical efficiency studies.[1]

---Insert Table 1 about here---

2.2 The impact of family firms on performance

As mentioned, regarding the relationship between family firm characteristics and performance, there have been a series of theoretical and empirical papers in the literature, which can be roughly divided into those studies which predict a positive and those which predict a negative relationship between size and performance. Theories underlying the positive relationship can be summarized as follows. First, agency theory suggests that the separation of ownership and control in may lead to entrenchment, expropriation, and moral hazard problems (Anderson & Reeb, 2003; Cavery, 1998; Chu, 2009; Demsetz &

[1] For a review of earlier efficiency studies see Yang and Chen (2009). Due to the size of this literature, this review excludes studies using an alternative approach such as productive or profit efficiency (Arbelo et al. (2021a, 2021b), Cowling & Tanewski (2019), Hasan et al. (2020), Bartoloni et al. (2021) and others).

Lehn, 1985; Jensen & Meckling, 1976). Entrenchment refers to managers prioritizing the maintenance of their own authority over firm decision making. Therefore, based on the management rights derived from ownership, a family firm may be regarded as an ideal organizational to solve the classic agency problems arising from separation and control of the modern firm (Chu, 2009; McConnell & Servaes, 1990; Morck et al., 1988; Schulze et al., 2003; Shleifer & Vishny, 1986, Fang et al. (2022). The second argument for a positive relationship stems from informational advantages. Generally, external shareholders and professional managers face information asymmetry regarding the condition of the firm. Family managers should be better informed on the workings of the firm and family, which gives them a relative advantage in firm management and control (Chu, 2009; Eisenhardt, 1989; Kets de Vries, 1993; Smith & Amoako-Adu, 1999). The third is the relation-embedded advantage. Third, family firms also have the ability to introduce the family's private resources, trust, or social networks for the use of the firm. Small-scale family firms, in particular, often rely on this potential advantage to cope with competition in the industry (Chu, 2009; Human & Provan, 1997; Poza, 2020; Silva et al., 2006). The fourth derives from the sustained presence of family shareholders. Compared with non-family firms, family firms consider the inheritance prospects of future generations, and may pay more attention to the survival of firm, particularly guarding the sources of competitiveness and core competencies. At the same time, due to the atmosphere of trust between family firms and stakeholders, they may also enjoy the competitive advantages of this soft power, such as the availability and lower cost of financing (Anderson & Reeb, 2003; Burkart et al., 2003; Chu, 2009; DeAngelo & DeAngelo, 2000; Poza, 2020). The fifth theory supporting a positive relationship, stems from investment efficiency. Family firms may be better able to avoid the temptation of managerial myopia or short termism and avoid the problem of long-term stable development being crowded out by short-term investment projects (Chu, 2009; James, 1999; Laverty, 2004; Stein, 1989). The sixth is stems from the entrepreneurial cultural advantage, where the entrepreneurial paradigm of family firms can also be transformed into corporate advantages (Astrachan et al., 2003; Chu, 2009; Sathe, 2007; Zahra, 2005). Table 2 presents a list of relevant studies on the role of family ownership on firm performance.

---Insert Table 2 about here---

Finally, empirical evidence for attributing a positive contribution of family firm characteristics on performance in Taiwan include Chu (2009), which finds that the proportion of family members' shareholding and board seats (as a measure of family ownership) positively impact the firm's performance. There are also studies which suggest that family firms have a positive impact on performance in Taiwan, but only for SMEs, not for LEs (Chu, 2011).[2]

On the other hand, arguments that the relationship between family firm characteristics and performance is negative, can be summarized by two theories. One is based on the goal inversion decision problem caused by institutional overlap. This arises because the combination of ownership and management rights can easily lead to confusion by family members about their role in the firm, so that whether deliberately or not, family goals are prioritized over the firm goals. The promotion and dismissal of personnel may also show favoritism between close and distant relationships, which sacrifice the goals of the company, and crowd out opportunities for external professional managers to make greater contributions (Carney, 1998; Chu, 2009; Kepner, 1983; Kets de Vries, 1993; Lansberg, 1983; Westhead et al., 2001). The second theory refers to potential setbacks caused by family ownership and control. For example, since family firms are prone to confusion over role cognition due to the excessive concentration of ownership, this may lead to family entrenchment and expropriation behavior, which are not conducive to optimal corporate governance and performance. The former refers to the fact that family shareholders can use their management rights for personal gain, such as bidding for leases with firms through special shares or special dividends with preferential voting rights, for instance diverting scarce resources from profitable projects, or non-monetary compensation for the personal utility of family members (Chu, 2009; DeAngelo & DeAngelo, 2000; Demsetz, 1983; Fama & Jensen, 1983; Gomez-Mejia et al., 2001; Morck et al., 1998; Shleifer & Vishny, 1997). Empirically, some studies have found evidence to support the family firm's negative effect on performance. For example,

[2] In a related study, Miralles-Marcelo et al.'s (2014) found that for Portugal and Spain, family firms have a positive impact on accounting performance, especially for small-scale and long-established firms.

Hamelin (2013) found that in France, increases in family firm ownership negatively impact firm performance. Thomsen and Pedersen (2000) examined some of the largest firms in Europe from 1990 to 1995 and found that family firms had a negative impact on the value of the firm but a positive impact on the sales.

Therefore, based on the mixed findings in the literature regarding the scale-efficiency relationship and the direction of impact of family on firm performance, this paper tests three related research hypothesis. The first issue centers on whether the traditional U-shaped pattern between scale and efficiency is characteristic for SMEs and for LEs respectively. This paper argues that previous studies using pooled may have caused mixed results due to heterogeneity between firm size groups, resulting in a characterization of both groups by the nature of the dominant group. With the expansion of scale, SMEs may show a negative marginal impact of scale on efficiency initially during start-up, but later when the marginal benefits of scale economy and specialization develop, this may reverse resulting in a U-shaped efficiency curve. For LEs, after the initial expansion, the positive and negative marginal effects of scale on efficiency may both gradually fade over time and the U-shaped curve may flatten out exhibiting a linear relationship. To detangle this issue, this study provides the following set of refutable hypotheses:

H1: SMEs exhibit a U-Shaped relationship between firm size and efficiency

H2: LEs exhibit a linear relationship between firm size and efficiency

In addition, since the broader small business literature, notes that family firm characteristics may affect firm performance, the model will include a term for examining the family effect. Theory suggests that family ownership may in fact reduce firm agency problems leading to higher levels of production efficiency. Thus, the third hypothesis considers whether family firms may increase efficiency.

H3: Family firms increase firm efficiency

2.3 Defining key variables: SMEs and family firms

While there is a need for a clear definition of SMEs, generally speaking, each country seems to adopt its own definition. In Taiwan, according to the Ministry of Economic Affairs (2022), firms that employ 199 or fewer employees are SMEs. However, there is variation in the definition between studies in the literature. For example, Yang & Chen (2009) defines Taiwanese SMEs as firms with less than 200 employees, while Chu's (2009) Taiwanese study defines SMEs as those firms with fewer than 499 employees. Batra & Tan (2003) examined the efficiency performance of manufacturers in six economies, including Colombia, Indonesia, Malaysia, Mexico, Guatemala, and Taiwan. Their study employed a definition of SMEs as those firms with 250 or fewer employees. In this study, we define a SME as a one that employs fewer than 200 employees to be consistent with not only the official definition, but with several earlier Taiwanese studies (Yang & Chen, 2009).

In the literature, a family firm often refers to a firm that uses contractual mechanisms such as ownership, top management, or board positions to coordinate the interests of family owners and managers (Pieper et al., 2008).[3] Theoretically however, there is no absolute standard or consensus for identifying family firms.

As family-owned SMEs are often unincorporated organizations, there may be limited public data available on ownership and board structure. As a result, the existing literature on family firms usually focusses large-scale family firms in the listed market, directly impacting the selection bias of firm samples used in research. The 2018 Global and Taiwanese Family Firms Survey Report reported that of the 69 sample family firms in Taiwan, 54% plan to transfer management and ownership to the next generation, yet only 6% have a robust, formal, and communicated succession plan. Under this circumstance, these businesses may only have a history of family firms and a lack of actual family firms (PricewaterhouseCoopers Business Consulting Services Taiwan Ltd., 2018). Under the standard of equity dispersion and the number of directors and supervisors in securities regulations, "the essence" of family firms tends to be diluted, and it is less suitable to be identified as family firms. In this study, we adopt a relatively strict qualitative nature on the definition spectrum of the family firm, where a family firm is defined as one where an individual or family is either the sole proprietor or has ownership as a partner. This definition has the advantage that it will minimize the risk of judgment errors caused by arbitrary, ambiguous, or overly broad judgment criteria.

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3 An excellent discussion on how to define family firms can be found in Chua et al., (1999).

3. Model specifications, data source, and variable construction

This study's approach to examining the size and efficiency relationship is based on early efficiency and production theory first detailed in Farrell (1957). Here efficiency is defined as relative ratio of the actual output level to the technologically feasible maximum output level given the same input. In this model, various input levels correspond to their maximum output levels under the same technical conditions. The trajectory that connects the maximum output levels is what is referred to as the "technological frontier".Quantitative methodology for constructing the technological frontier can be roughly dichotomized into non-parametric and parametric approaches. The non-parametric approach is data envelopment analysis (DEA), and the parametric approach, which is used in this study, is the stochastic frontier analysis (SFA). The SFA involves constructing a frontier by fitting a set of parameters with the least square residual combination between the observations and the technological frontier to estimate through regression analysis. The resulting Stochastic Frontier (SF) model has since become a popular method to estimate production efficiency (e.g., Arbelo et al., 2021a; Yang & Chen, 2009). The main reason for its popularity and use in this study is the design of the residual combination. In addition to the bilateral residuals inheriting the essential advantages of classical OLS regression, the unilateral residuals bring about the rationality and functionality of production efficiency estimation. Based on the above discussion, the following subsections will outline the specifications of the SF model, as well as the data sources and variable constructions.

3.1 Model specificationsThis study adopts the empirical stochastic frontier analysis (SFA) model of Aigner et al. (1977) and Meeusen and van den Broeck (1977) with the one-stage estimation of the inefficiency regression suggested by Kumbhakar et al. (1991) as follows:

$$\begin{cases} \ln Y_i = f\left(\ln X_i^j \middle| \beta^j\right) + v_i - u_i \\ u_i = m\left(Z_i^h \middle| \theta^h\right) + \xi_i \end{cases}, \quad \begin{cases} i = 1,\ 2,\ \dots N,\ j = 1,\ 2,\ \dots J,\ h = 1,\ 2,\ \dots H \\ v \sim iid\ N\left(0, \sigma_v^2\right),\ u \sim N^+\left(m\left(Z^h \mid \theta^h\right), \sigma_u^2\right), \\ \xi \sim iid\ N\left(0, \sigma_\xi^2\right),\ \sigma^2 = \sigma_u^2 + \sigma_v^2,\ \gamma = \sigma_u^2 / \sigma^2 \end{cases} \tag{1}$$

In the equation, Y is firm output where the subscript represents the i-th firm. X is an input vector, the superscript denotes the j-th input, and the β is the coefficient to be estimated. $f(.)$ means the functional relationship between X and Y. $v \sim iid\ N(0, \sigma_v^2)$ is a random error, following a bilaterally independent and irrelevant normal distribution with a mean of 0 and a variance of σ_v^2, to capture the deviation from the output frontier that is not attributable to human factors. $u \sim N^+(m(Z^h | \theta^h), \sigma_u^2)$ is a unilateral normal distribution that is non-negative and independent of v. The mean of u is $m(Z^h | \theta^h)$, and the variation is σ_u^2, which captures the deviation from the output frontier caused by controllable human factors.

We can interpret the model as follows. Here u_i is a measure of the production inefficiency for firm i, which represents the relative ratio of the actual output to the due output in production that lies between 0 and 1. The larger the value, the lower the efficiency, and vice versa. Based on the measurement of the inefficiency score, we can then conduct a regression analysis to examine the impact of scale on inefficiency. Moreover, Z is a vector of the firm characteristics and industrial environmental variables that may affect the output inefficiency, which include firm scale variables. θ is the coefficient to be estimated, and the superscript denotes the h-th factor. $\xi \sim N(0, \sigma_\xi^2)$ is a random error, following an independent and irrelevant normal distribution with a mean of 0 and a variance of σ_ξ^2. To clarify the proposition of this study, we further specify the above equation as follows:

$$\begin{cases} \ln Y_i = \beta + \sum_{j=1}^{J} \beta^j \ln X_i^j + \frac{1}{2} \sum_{j=1}^{J} \sum_{j=1}^{J} \beta^{jj} \ln X_i^j \ln X_i^j + v_i - u_i \\ u_i = \theta + \left\{ \left[\theta^S S_i + \theta^{SD} \left(S_i \times D_i^{LE} \right) \right] + \left[\theta^{SS} S_i^2 + \theta^{SSD} \left(S_i^2 \times D_i^{LE} \right) \right] \right\} \\ \qquad + \left\{ \theta^F D_i^{FE} \right\} + \left\{ \sum_{h=1}^{H-3} \theta^h Z_i^h \right\} + \xi_i,\ D^{FE},\ S \text{ and } S^2 \notin (H-3) \end{cases} \tag{2}$$

The first line in equation (2) is the production frontier in transcendental logarithmic (translog) functional form, which is the more commonly used model by SF studies. Specifically, the translog refers to a second-order approximation of Taylor's expansion, which has been proven to be the most general functional form compared to others, such as Cobb-Douglas (CD) or constant elasticity of substitution (CES). According to the standard model, all the input and output variables in the equation are required to be in a natural logarithmic form. Adopting the translog functional form for this study is based in part on our desire to avoid choosing a more biased functional form (Christensen et al., 1973).

The second and third lines in equation (2) refer to the inefficient regression, which includes the firm scale (S), the square term of firm scale (S^2), a categorical dummy of firm scale (D^{LE}), a categorical dummy of family firm (D^{FE}), and the other firm characteristics and environmental variables. The purpose of the model design is to capture the pure or direct relationship between firm scale (S) and inefficiency (u) while controlling the influence of the family firms and the other variables, which the following essential partial differentiation can express:

$$\frac{\partial u_i}{\partial S_i} = \begin{cases} \theta^S + 2\theta^{SS} S_i, \ if \ D_i^{LE} = 0 \\ \left(\theta^S + \theta^{SD}\right) + \left(2\theta^{SS} + 2\theta^{SSD}\right) S_i, \ if \ D_i^{LE} = 1 \end{cases} \tag{3}$$

The first line of equation (3) performs the calculation on the condition that the dummy variable of firm scale D^{LE} is equal to 0 for the SMEs. The second line bases the calculation on the condition that D^{LE} is equal to 1 for the LEs. The empirical work will also sort out the estimated results without controlling the family firm characteristic as a control group to observe the differences and check the research proposition.

3.2 Data source and variable construction

This study uses the firm-level dataset of the manufacturing industry under the 4-digit code from the 2016 industrial and commercial census of the Directorate-General of Budget, Accounting, and Statistics (DGBAS), Executive Yuan of Taiwan. There are 166,626 observations in total. In the SF model of equation (2), the output variable (Y) is total output, and the input variables (X) are capital input, labor input, and intermediate input. The total output is the value added measured as the sum of operating income minus the sum of expenses on raw materials, energy, and electricity, commonly used in the literature, and the same with Yang and Chen (2009). The capital input is measured as the annual actual net assets of firms. The labor input is measured as the yearly salary expenditures. The intermediate input is measured as the sum of raw materials and fuel consumption plus processing fees, water, electricity, gas fees, and other operating expenses.

For the inefficiency regression, the firm scale (S) is measured as the number of laborers employed by firms, and the square of firm scale (S^2) captures the nonlinear relationship between firm scale and efficiency. The dummy variable of firm scale (D^{LE}) is based on 200 employees. Those firms with more than or equal to 200 employees are regarded as LEs, set to 1, and those with fewer than 200 employees are SMEs, set to 0.

It is worth noting that adopting the number of employees as the measure of firm size, is a common practice in empirical economics research (Taymaz, 2005; Yang and Chen, 2009, Chen and Ghosh, 2014). One reason for this is that the measure of number of employees has relatively low volatility. Other variables such as, performance, revenue or market value tend to fluctuate with market prosperity and industrial competition, making the measure of firm size more volatile.

Regarding construction of the dummy variable of the family firm (D^{FE}), this study adopts the most conservative criterion, that is, a firm is classified as a family firm if it is a sole proprietorship or partnership, and in this case D^{FE} takes the value of 1; and 0 otherwise.

Concerning the other control variables, there are seven variables related to the firm characteristics. Firm age (*Age*) is the number of years between the firms' opening and 2016. The impact of this feature on inefficiency may be negative because it reflects the experience and familiarity of firms with business operations (Hill & Kalirajan, 1993). The impact may be positive as it also reflects firms' rigidity problem over time (Biggs et al., 1996). Meanwhile, the estimated result could be trivial as the positive and negative effects may offset each other (Lundvall & Battese, 2000). At the same time, to capture the non-monotonic correlation, we include the square term of the firm age (Age^2) to fit the potential marginal increasing or decreasing effect. Welfare (*Welfare*) is the average welfare expenditure per firm employee. This characteristic relates to a firm's incentive for employees to show loyalty or exert effort, and its impact on inefficiency is expected to be negative (Yang & Chen, 2009).

Further, exporting intensity (*EXI*) is the proportion of exporting revenue in a firm's total revenue. In innovation economics, exports could be essential for obtaining production knowledge and technological progress, especially for small open developing economies. The empirical literature has also highlighted the positive contribution of export intensity to productivity (Hill & Kalirajan, 1993; Batra & Tan, 2003; Yang & Chen, 2009; Chen & Ghosh, 2014; Abbas & Siddiqui, 2020), and its impact on inefficiency is expected to be negative. The outsourced intensity (*OSDI*) refers to the proportion of the firm's total revenue from original equipment manufacturer (OEM) business. There are two practical industry implications for undertaking OEM business. One is that the firm's technical capabilities are recognized to a considerable extent before it can obtain commission orders. The other is that engagement in OEM business is often accompanied by a new product or new design. It is an effective way to acquire technology, so its impact on inefficiency is expected to be negative. The outsourcing intensity (*OSII*) refers to the proportion of a firm's total revenue gained through outsourcing, which is usually a rational decision between outsourcing and self-production. Outsourcing means that a firm can improve its efficiency or reduce its production costs, so its impact on inefficiency is expected to be negative. R&D intensity (*RDI*) is the ratio of a firm's R&D expenditure to its operating revenue. It is the same as several variables mentioned above in that it is one of the ways to acquire production technology. The difference is that here, the production technology is not obtained from outside but developed internally, so its impact on inefficiency is expected to be negative (Batra & Tan, 2003; Yang & Chen, 2009). Big data dummy (D^{BD}) is a dummy variable used to capture whether firms use big data in their operations.

Six variables are included in the model to control for industry environmental conditions using a 4-digit industry classification measure. The minimum efficient scale (*IMES*) measures the degree of barriers to entry in an industry. It takes the number of laborers employed in the industry as the scale and is measured using the average scale of the firms larger than the median scale to the average scale of all the firms in the industry. From the perspective of labor input, the larger the ratio, the higher the barrier to entry into the industry. All the firms' average R&D intensity measures the industrial R&D intensity (*IRD*). With higher R&D intensity of the industry, the R&D investment cost and technical threshold may be higher, so it can be regarded as another measure of the degree of industrial entry barriers (Bunch & Smiley, 1992). However, it is also a measure of innovation opportunities because the high R&D intensity of the industry means that the market is highly variable, and manufacturers have relatively more opportunities to access the market through technological innovation (Marsili, 2002). The expected relationship with inefficiency is tentatively uncertain. The industrial capital intensity (*IKL*) is also a measure of the degree of industrial entry barriers. It measures the industrial capital-to-labor ratio. From the perspective of capital input, the stronger the ratio, the higher the entry barrier of the industry. When the industry's barrier to entry is higher, the incumbent SMEs have more niches in which to survive. Given the existing advantages, incumbent firms may find it relatively easy to relax regarding production efficiency. Therefore, the relationship between the above two variables and inefficiency is expected to be negative.

The industrial average profitability ratio (*IAPR*) is measured as the average profitability of all the firms in the industry. Industries with high profit margins can provide more space for firms to survive, and the competition is relatively less ruthless. At the same time, the efficiency required for the survival of SMEs will be milder. Thus, the effect on inefficiency is expected to be positive. The average industrial scale (*AIS*) is measured using the total number of laborers employed in the industry. The larger the scale, the greater the survival space that the industry can provide for existing, new, or differently scaled firms, and the market competition is reduced. Therefore, it is expected to have a positive relationship with inefficiency. The suboptimal industrial ratio (*SIOR*) is measured as the quotient of the total number of laborers employed by firms with fewer employees than the minimum efficient scale and the total number of employees in the industry. A higher ratio indicates that the industry is friendlier to the survival of SMEs and may also suggest that, from an ex post facto perspective, SMEs have a survival advantage. Therefore, the impact on inefficiency should be positive in a less competitive environment. Table 3 summarizes the definitions and measurements of the above variables.

---Insert Table 3 about here---

4. Empirical results

4.1 Summary statistics

Tables 4 and 5 provides the basic summary statistics of key variables used in this study. The manufacturing firms are classified into SME and LE groups according to their firm scale, and also into family firm and non-family firm groups for a one-way ANOVA differences test.

Table 4 reveals that among the 166,626 firms in Taiwan's manufacturing industry, 1,688 are LEs and 164,938 are SMEs. The numbers indicate that SMEs dominate Taiwan's economic landscape. SMEs account for 98.99% of all the manufacturers, and only 1.01% are LEs. In addition, there are 57,271 family firms and 109,355 non-family firms, indicating that slightly more than one-third of the manufacturers are family firms. This number underscores another characteristic of industrial development in Taiwan: a considerable proportion of firms operate within a sole proprietorship or partnership structure. Such an ownership structure fully integrates the owners' and firms' risks and finances. The characteristic is also intuitively associated with the limitations of risk tolerance and capital availability, which may limit scale expansion.

---Insert Table 4 about here---

In Table 5 the average firm scale of LEs is, unsurprisingly, significantly higher than that of SMEs, and the average difference between them can be a hundredfold. From the perspective of output, the output level Y of LEs is nearly 6.58 billion New Taiwan dollars or (NTD), and that of SMEs is nearly 36.61 million NTD, with a gap of 179.71 times. From the perspective of investment, the capital investment K of LEs is nearly 16.64 billion NTD, and that of SMEs is nearly 55.79 million NTD, with a gap of 298.18 times. The labor input L of LEs is nearly 659.07 million NTD, and that of SMEs is nearly 4.33 million NTD, so the gap is 152.26 times. The intermediate investment M of LEs is nearly 39.87 billion NTD, and that of SMEs is nearly 26.35 million NTD, indicating a gap of 151.29 times. Fourth, the average firm scale of non-family firms is also larger than that of family firms. The output level Y of non-family firms is nearly 153.28 million NTD, and that of family firms is nearly 6.64 million NTD, with a gap of 23.09 times. The capital input K of non-family firms is nearly 336.93 million NTD, and that of family firms is nearly 7.64 million NTD, with a difference of 44.10 times. The labor input L of non-family firms is nearly 16.16 million NTD, and that of family firms is nearly 1.025 million NTD, showing a difference of 15.77 times. The intermediate investment M of non-family firms is nearly 98.98 million NTD, and that of family firms is nearly 4.42 million NTD, with a difference of 22.39 times.

---Insert Table 5 about here---

Here we note that the salary that SMEs offer to their employees is significantly lower and (only slightly more than half) that of LEs. Employment of LEs is nearly 805.37 persons, while that of SMEs is nearly 10.15 persons, a gap of 79.35 times. However, after dividing the salary expenditure by the labor employment, the average salary of LEs is nearly 818.34 thousand NTD, and the average salary of SMEs is nearly 426.49 thousand NTD. These figures indicate that the salary of LEs is 1.92 times that of SMEs; that is, SMEs pay only 52.11% of LEs' salary. It is interesting to note that the average salary that family firms offer to their employees is slightly more than half that offered by non-family firms. The difference is 8.4 times. However, after dividing the salary expenditure by the labor employment, the average salary of non-family firms is nearly 619.11 thousand NTD and that of family firms is nearly 329.62 thousand NTD. This reveals that non-family firms' salary is 1.88 times that of family firms; that is, family firms pay only 53.24% of the salary of non-family firms.

It is important to note that, probably because the salary level of SMEs is significantly lower as mentioned above, that the labor productivity of SMEs is also lower than that of LEs. Taking output level Y divided by wage input L, the average output of labor (AP_L) for LEs is 9.98, and that for SMEs is 8.46. Looking at the output level divided by the number of laborers employed, the average output of labor (AP_L) for LEs is 8.17 million, and that for SMEs is 3.61 million. Eighth, a similar situation appeared in family firms. In terms of the output level divided by the labor input, the average output of labor (AP_L) for non-family firms is 9.48, and that for family firms is 6.47. By dividing the output level by the labor employment, the average output of labor (AP_L) for non-family firms is 5.87 million, and that for family firms is 2.13 million.

It is also clear that LEs tend to be more capital intensive. Taking the capital input divided by the labor input, the capital per labor input K/L of LEs is 25.24, while that of SMEs is only 12.89. Dividing the capital input by the number of laborers employed, the capital used per laborer of LEs is 20.66 million, while that of SMEs is only 5.49 million. Tenth, likewise, the capital intensity of family firms is relatively low. Taking the capital input divided by the labor employment, the capital use per laborer for non-family firms is

12.90 million, while it is only 2.46 million for family firms. Eleventh, even though LEs tend to have higher capital intensiveness, as mentioned above, their capital productivity is not necessarily higher. Taking the output level divided by the capital input, the average output of capital (AP_K) for LEs is 0.39 and that for SMEs is 0.66. Twelfth, family firms face a similar situation; the average output of capital (AP_K) for the non-family firms is 0.45 and that for non-family firms is 0.87. Thirteenth, LEs' average age is significantly higher than that of SMEs: LEs are 31.46 years old, and SMEs are 18.65 years old on average. However, the gap between non-family firms and family firms is less than half a year, with the average age of non-family firms is 18.85 and that of family firms is 18.65.

4.2 Frontier estimations and efficiency analysis

Technical efficiency in production for manufacturing firms using the model specifications of equations (1) and (2) and maximum likelihood estimation (MLE) are listed in Table 6.

---Insert Table 6 about here---

Table 6 reveals that the coefficients of the input factors are statistically significant, which means that the input and output variables adopted in this study capture the firm's production behavior, whether the modes include or exclude D^{FE} variable. We can interpret the family effect on efficiency as follows. Since D^{FE} is negative and significant this means that the impact of D^{FE} on technical inefficiency is negative. The result implies that the technical inefficiency of family firms is lower, or that family firms are relatively more efficient than non-family firms.

As a check on the robustness of these findings, an alternative measure of performance, Net Operating Income/#Employees, was also used as the dependant variable. Empirical results in Appendix 1 Table A1 reveal that alternatively using net operating income per employee does not significantly change results.

Table 7 compares the efficiency of the sub-industries in the manufacturing industry, and it also shows that the efficiency scores of family firms are higher. The log-likelihood function ratio L-LR also shows that, at the 1% statistical level, the chi-square test of the two modes significantly rejects the null hypothesis that the estimated coefficient is 0. At the same time, taking the model without D^{FE} as the control and the model with D^{FE} as the experiment, the two models were subjected to the nested chi-square test. It can also be seen that the estimation with D^{FE} is a significantly better fit than that without D^{FE}. This result reveals the importance of including D^{FE} variable in the inefficiency regression, which also guides us to base our subsequent analysis directly on the estimates including D^{FE}. Moreover, the estimated γ coefficient shows that most of the components in the residual of this SF model are related to artificially controllable inefficiency. The percentages for the two models are 91.267% and 94.112%, respectively, and the rest are random occurrences.

The second key finding relates to our question regarding whether there is a U-shaped phenomenon between firm scale and efficiency. In the model with D^{FE}, the coefficient of its first-order term is significant, which means that, when the scale of the manufacturer expands by one person, the inefficiency score will increase by an average of 0.0026. However, such an effect is not monotonic, and the coefficient of its quadratic term is significant, revealing the nonlinearity of the effect. More specifically, the inefficiency that increases due to the expansion of the scale will have a marginal decrease in its magnitude, and vice versa, while the results for the model without D^{FE} are similar. After a simple partial differential calculation, it is clear that other things being equal, the effect of the scale expansion on the efficiency moves from negative to positive, turning positive after reaching 134.56 employees.

Here, it is worth noting that the model estimation results show that the U-shaped phenomenon mentioned above only applies to SMEs. The reason is that, when the dummy of LEs is additionally included and used as the cross term, the coefficient of the first-order term has a significantly negative value, and the coefficient of the square term shows a significantly positive value, which is exactly opposite to the sign direction of the coefficient of the dummy that is not for LEs. We then use the two sets of Wald tests, as shown below, to verify this result, and the results are also provided in Table 6:

$$Wald\ test\ \left(H_0 : \theta^{S} + \theta^{SD} = 0\right) = \frac{\theta^{S} + \theta^{SD}}{\sqrt{Var\left(\theta^{S} + \theta^{SD}\right)}} \tag{4}$$

$$Wald\ test\ \left(H_0 : \theta^{SS} + \theta^{SSD} = 0\right) = \frac{\theta^{SS} + \theta^{SSD}}{\sqrt{Var\left(\theta^{SS} + \theta^{SSD}\right)}} \tag{5}$$

After the calculation of formula (4) and formula (5), we find that the value of $\theta^{S}+\theta^{SD}$ is -0.000091, which is significantly different from zero. The $\theta^{SS}+\theta^{SSD}$ is 0.0000000022, which is *not* significantly different from zero. Such results clearly point out that, for LEs, the effect of firm scale on inefficiency is linear and monotonic; that is, expansion in scale makes a continuous positive contribution to efficiency, which is different from the case of SMEs.

In addition, the D^{FE} variable is negative and significant, indicating that holding other things unchanged, the efficiency of family firms is not worse than that of non-family firms, and the inefficiency score is 0.3029 less than that of non-family firms. In the range from 0 to 1, this value is non-trivial. At the same time, it is also necessary to mention that, in the model with D^{FE}, the output elasticity of factors is 1.003, indicating that the production is at the stage of increasing returns to scale (IRS). However, if D^{FE} is not included, the output elasticity of factors is 0.998, indicating that the production would be shown as being at a stage of diminishing returns to scale (DRS). This finding suggests that ignoring the characteristics of D^{FE} in the model may lead to a biased recognition of the economies of scale and a misjudgment of the returns to scale.

Based on the estimation of the models with D^{FE} and without D^{FE} or family firms, we can depict the curve of the relationship between scale and efficiency for the SMEs and LEs, respectively. For SMEs, the relationship between size and efficiency is U-shaped. Our interpretation is that with the expansion of the scale in the initial stage, the existing advantages of small firms gradually weaken and are eventually replaced by the challenges of work distribution, coordination, and management, and the loss of efficiency slowly appears. The U-shape remains even after controlling for family firms, but the relationship becomes relatively moderated. One possible reason for this could be the dual identity of SMEs and family firms in some cases. Finally, for LEs, the relationship between scale and efficiency is clearly not U-shaped but rather exhibits a positive monotonic relationship.

Table 7 further shows the average efficiency scores of Taiwanese manufacturing firms based on the 2-digit industrial classification code. It should be noted here that, according to the requirements of the DGBAS, the estimated scores in this study have been further integrated and presented by the 2-digit code to remove the identification information. Findings indicate that the average efficiency of Taiwanese manufacturers is above 80%. However, from the perspective of scale, the efficiency performance of LEs or SMEs is not necessarily higher. In fact, there is only one industrial classification with a significant difference, and the rest are not significant. Specifically, for industries with codes 26, 27, and 28, which include electronic component manufacturing, computer, electronic product, and optical product manufacturing, and electrical equipment and equipment manufacturing, SMEs performed less efficiently than LEs. However, from the perspective of family firm attributes, the efficiency of family firms is significantly higher than that of non-family firms. In Table 7, the results are statistically significant for all the industries. Finally, Table 8 provides information about the estimated efficiency scores under the model without D^{FE} for reference. It is important to note that whether we use the frontier model construction or the efficiency score estimation, the inclusion of D^{FE} is indeed statistically important. However, compared with the empirical result obtained when ignoring the D^{FE}, the outcomes do not change or reverse the overall conclusion of this study.

---Insert Table 7 and 8 about here---

5. Conclusions

This paper contributes to the small business literature, by providing a robust empirical examination of the relationship between scale and efficiency for SMEs and LEs controlling for family firms. Specifically, the study reveals a number of findings and conclusions which add to our understanding of how firm size and family ownership impact firm production efficiency.

First, findings support our hypotheses that the effect of firm scale on production efficiency conforms to a U-shaped curve, but only for SMEs. For LEs, after expanding to a certain point, the positive and negative marginal effects of scale on efficiency gradually become smaller and cancel each other out, and the U-shaped curve gives way to a linear trajectory. From a policy perspective these findings are important because it may be possible to develop policy to better support small firms at the point where they face efficiency loss on the road to scale growth.

In addition, past studies which have examined the impact of family firms on production efficiency tend to be either negative or inconclusive. Using a different approach, the empirical results of this study show a positive and significant impact of family firms on efficiency for both size groups of firms, which provides a compelling argument in the entrepreneurship literature for family control as a positive influence on the firm. It is also important to note that the family firm characteristic (DFE) must be controlled for in estimating the production function because the bias caused by omitting this variable can cause a misjudgement regarding the economies of scale in production.

Further, in examining the efficiency scores for 13 sub-industries of manufacturing, estimates indicate that there is no significant difference in the efficiency performance between SMEs and LEs -their efficiency levels are more than 80% on average for both size groups. Finally, results clearly show that the efficiency of family firms is better than that of non-family firms, supporting the various theories on why family ownership may improve firm performance.

With regard to study limitations and future prospects, we note that due to limitations on the availability of ownership data we adopted a relatively stringent definition of family firms for manufacturing firms in Taiwan. We hope that future research studies may be able to access a richer data set on firm ownership structures in order to examine other more nuanced measures of family ownership and control. In addition, future studies might consider accessing data on service firms to extend our understanding of these industries.

Declaration

The authors report there are no competing interests to declare.

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Table 1
Selected Studies of Firm Size–Technical Efficiency

Study	Country, period, industry, number of observations (N) and periods observed (T)	Estimation methodology	Correlation with technical efficiency (+, - , or no)
Assaf et al. (2011)	Australian, 2007, restaurant industry, $N = 105$, $T = 1$	Double-bootstrap data envelopment analysis	+
Coto-Millán et al. (2014)	Spanish, 2009–2011, airport industry, $N = 35$, $T = 3$	Data envelopment analysis	+
Xu and Chi (2017)	U.S., 2007–2014, hotel industry, $T = 8$	Window data envelopment analysis	+
Chuang et al. (2019)	U.S., 2000–2013, retail industry, $N = 118$, $T = 14$	Stochastic frontier analysis	+
Toma (2020)	Italian, 2006–2015, pharmaceutical industry, $N = 189$, $T = 10$	Nonparametric two-step approach	+
Díaz & Sánchez (2008)	Spanish, 1995–2001, non-manufacturing industry, $N = 1{,}898$, $T = 7$	Stochastic frontier analysis	-
Le and Harvie (2010)	Vietnam, 2002, 2005, 2007, non-state SMEs, $N = 926$, 2,228, 2,050 , $T = 3$	Stochastic frontier analysis	-
Kagin et al. (2016)	Mexico, 2002–2007, farm industry, $N = 1{,}348$, $T = 6$	Stochastic frontier analysis	-
Arbelo et al. (2021a)	Spanish, 2013–2017, manufacturing industry, $N = 1{,}232$, $T = 5$	Stochastic frontier analysis	-
Lauterbach & Vaninsky (1999)	Italia, 1994, Listed firms, $N = 280$, $T = 1$	Data envelopment analysis	No
Lam et al. (2016)	U.S., 2006–2012, Listed firms, $N = 281$, $T = 7$	Stochastic frontier analysis	No
Taymaz (2005)	Turkey, 1987–1997, manufacturing industry, $N = 12{,}788$, $T = 11$	Stochastic frontier analysis	+ in 22, - in 10, and no in 36
Yang and Chen (2009)	Taiwan, 2001, electronics industry, $N = 7{,}590$, $T = 1$	Stochastic frontier analysis	+ in 1, - in 6, and no in 3
Bhandari & Maiti (2007)	India, 1985-1986、1990-1991、1996-1997、1998-1999, and 2001-2002, textile industry, $N = 17{,}065$, $T = 2$	Stochastic frontier analysis	Depends on the years
Chen and Ghosh (2014)	Taiwan, 2001, computer, communications, and audio and video electronics products manufacturing industry, $N = 2{,}931$, $T = 1$	Stochastic frontier analysis	Depends on the scale stage

Abbas and Siddiqui (2020)	Pakistani, 2009–2018, manufacturing industry, N = 30, T = 10	Stochastic frontier analysis	+
Schiersch (2013)	German, 1995–2004, manufacturing industry, N = 20,353, T = 10	Stochastic frontier analysis	U-shaped
Liaquat et al. (2017)	Pakistan, 2005–2006, textile industry, N = 75, T = 2	Stochastic frontier analysis	U-shaped
Ferreira and Féres (2020)	Brazilian, 2006, farm industry, T = 1	Stochastic frontier analysis	U-shaped

Note: Sorted by this study. "+" represents that LEs are more efficient while "-" denotes SMEs are more efficient, and "no" signifies the difference is not significant.

Table 2
Selected studies of family enterprise–performance relationships

Study	Country, period, industry, number of observations (N) and periods observed (T)	Estimation methodology, performance measurement	Correlation with performance (+, - , or no)
Daily & Dollinger (1992)	U.S., 1988, SMEs of manufacturing industry, N = 186, T = 1	Survey techniques, sales growth, rate of improvement of net margin, rate of improvement operating margin, a subjective scale of perceived performance relative to the firm's major competitor	+
Anderson & Reeb, (2003)	U.S., 1992–1999, Listed firms of the S&P 500, N = 403, T = 8	Two-way fixed effect model, the return on assets (ROA) and Tobin's Q	+
Tanewski et al. (2003)	Australia, 2002, SMEs of manufacturing and service industry, N = 237, T = 1	Survey techniques and SEM, product innovation and process innovation	+
Villalonga & Amit (2006)	U.S., 1994–2000, Listed firms of Fortune 500, N = 508, T = 7	OLS, Tobin's Q	+
Martínez et al. (2007)	Chilean, 1995–2004, Listed firms, N = 175, T = 10	OLS, the return on assets (ROA)	+
Chu (2009)	Taiwan, 2002–2006, Listed small and medium-sized family firms, N = 341, T = 5	OLS, the return on assets (ROA) and Tobin's Q	+
Lauterbach & Vaninsky (1999)	Italia, 1994, Listed firms, N = 280, T = 1	OLS, technical efficiency, and net income	-
Hamelin (2013)	France, 1997–2003, Listed SMEs, N = 22,237, T = 7	2SLS, sales growth rate	-
Chrisman et al. (2004)	U.S., 1998, SMEs of Small Business Development Center, N = 1,141, T = 1	OLS, sales growth	No
Morck et al. (1988)	U.S., 1980, Listed firms of Fortune 500, N = 371, T = 1	OLS, Tobin's Q	Depends on the ages
Le and Harvie (2010)	Vietnam, 2002, 2005, 2007, non-state SMEs, N = 926, 2,228, 2,050, T = 3	SFA, technical efficiency	Depends on the years
Chu (2011)	Taiwan, 2002–2007, Listed family firms, N = 786, T = 6	OLS, the return on assets (ROA)	+ for all, + for SMEs and no for LEs
Miralles-Marcelo et al. (2014)	Portugal and Spain, 1999–2008, Listed firms, N = 170, T = 10	GMM, the return on assets (ROA) and market-to-book ratio of assets	+ for market-to-book ratio of assets, no for return on assets

Thomsen and Pedersen (2000)	Europe, 1990–1995, largest nonfinancial firms, $N = 435$, $T = 6$	OLS, price-to-book (P/B) ratio, return on assets (ROA) and sales growth rate	- for price-to-book value ratio, + for sales growth rate, and no for return on assets

Note: Sorted by this study. "+" represents that FEs are more efficient while "-" denotes Non-FEs are more efficient and "no" signifies that the difference is not significant.

Table 3
Definitions and Construction of Key Variables, and Summary Statistics

Variables	Meanings	Construction of the Variables	Mean (std. deviation)	Mean (std. deviation)
Y	Total output	ln[(Operating income minus the sum of expenses on raw materials, energy, and electricity) / 1,000]	L[a]: 6,578,403.94 (35,462,487.52) S[b]: 36,605.0074 (180,968.5307)	F[c]: 6,637.27 (2,2671.44) N[d]: 153,278.58 (4,482,900.42)
K	Capital input	ln[(Net assets actually used at the end of the year) / 1,000]	L: 16,635,348.46 (108,888,098.88) S: 55,789.13 (462,172.73)	F: 7,639.99 (27,131.69) N: 336,927.13 (13,689,274.52)
L	Labor input	ln[(Total salary expenditure) / 1,000]	L: 659,065.41 (2,610,909.78) S: 4,328.435 (11,580.038)	F: 1,025.11 (1,577.63) N: 16,164.94 (334,418.27)
M	Intermediate consumption	ln[(Total value of raw materials and fuel consumption for domestic use + Payment of outsourcing processing fees] / 1,000	L: 3,987,104.033 (19,464,259.879) S: 26,352.42 (145,370.68)	F: 4,419.719 (17,616.011) N: 98,976.96 (2,472,439.86)
S	Firm's scale	Number of laborers employed	L: 805.37 (2,088.89) S: 10.15 (19.97)	F: 3.11 (3.90) N: 26.11 (278.19)
S^2	Square of firm's scale	(Firm's scale)^2	L: 5,009,517.82 (60,799,937.45) S: 501.68 (2,556.65)	F: 24.91 (506.84) N: 78,070.375 (7,576,879.021)
D^{LE}	Dummy for LEs	Categorical dummy variable; 1 is for LEs and 0 is for SMEs	L: - S: -	F: 0.000035 (0.005909) N: 0.015 (0.123)
D^{FE}	Dummy for family firms	Categorical dummy variable; 1 is for family firms and 0 is for non-family firms	L: 0.0010 (0.0340) S: 0.35 (0.48)	F: - N: -
Age	Firm's age	(2016 – The starting year of firm +1) + [(12 - Starting month) / 12]	L: 31.46 (14.72) S: 18.65 (11.79)	F: 18.65 (11.75) N: 18.85 (11.96)
Age^2	Square of firm's age	(Firm's age)^2	L: 1,205.90 (1,080.42) S: 486.74 (553.90)	F: 485.79 (567.42) N: 498.34 (565.68)
Welfare	Firm's welfare expenditure	(Total welfare expenditure / 1,000) / Number of employees	L: 121.96 (74.59) S: 50.051 (53.121)	F: 40.13 (20.76) N: 56.359 (64.069)
EXI	Firm's export intensity	Exporting revenue / total operating revenue	L: 52.47 (36.21) S: 5.85 (18.23)	F: 0.54 (5.66) N: 9.35 (22.61)
OSDI	Firm's outsourced intensity	Outsourced processing fee revenue / Total operating revenue	L: 0.037 (0.059) S: 0.035 (0.282)	F: 0.026 (0.050) N: 0.040 (0.344)
OSII	Firm's outsourcing intensity	(Revenue from the outsourcing business) / (Total operating revenue)	L: 0.030 (0.155) S: 0.14 (0.34)	F: 0.20 (0.39) N: 0.11 (0.30)
RDI	Firm's RD intensity	R&D expenditure / Total operating revenue	L: 0.033 (0.057) S: 0.025 (3.83)	F: 0.00018 (0.00724) N: 0.039 (4.703)
D^{BD}	Dummy for big	Categorical dummy variable; 1 signifies a firm that uses big data in	L: 0.12 (0.32)	F: 0.00037 (0.01915)

	data used	its operation and 0 otherwise	S: 0.0045 (0.0671)	N: 0.0085 (0.0917)
IMES	Industrial MES	(Average size of the largest 50% of firms in industry) / (Average size of all firms in terms of number of employees)	Overall industry: 0.89 (0.90)	
IRD	Industrial RD intensity	Average R&D intensity of firms in the industry	Overall industry: 0.025 (0.287)	
IKL	Industrial capital intensity	The average of [(Book value for fixed capital stock) / (Salary expenditure)] in industry	Overall industry: 8.16 (5.90)	
IAPR	Industrial average profitability ratio	Average industrial profit rate of firms in the industry	Overall industry: 3.64 (11.19)	
AIS	Average industrial scale	Average industrial scale in terms of the number of employees	Overall industry: 199.44 (152.31)	
SIOR	Industrial suboptimal ratio	(Total number of industrial employees for firms smaller than MES) / (Total industrial scale in terms of the number of employees)	Overall industry: 71.35 (54.36)	

***Source*:** Manufacturing survey of the 2016 industrial and commercial census in Taiwan, Directorate-General of Budget, Accounting and Statistics.
Notes: All the figures are provided with two-digit significance. [a] Means and standard deviations for large firms. [b] Means and standard deviations for small and medium-sized firms. [c] Means and standard deviations for family firms. [d] Means and standard deviations for non-family firms.

Table 4

Frequencies of Firms by Size and Family Ownership in Sample Data

Categories	Family	Non-Family	Overall
SME	57,269	107,669	164,938
LE	2	1,686	1,688
Overall	57,271	109,355	166,626

Source: Own calculations.

Table 5
Summary Statistics of Key Variables

Variables	Overall	SME	LE	D. test	Family	Non-Family	D. test
Y	102,876.52	36,605.0070	6,578,403.94	5,601.76 ***	6,637.27	153,278.58	61.28 ***
	(3,632,361.83)	(180,968.5310)	(35,462,487.52)		(22,671.44)	(4,482,900.42)	
K	223,747.89	55,789.13	16,635,348.46	3,819.39 ***	7,639.99	336,927.13	33.14 ***
	(11,091,015.61)	(462,172.74)	(108,888,098.88)		(27,131.69)	(13,689,274.53)	
L	10,961.23	4,328.435	659,065.41	10,358.30 ***	1,025.11	16,164.94	117.38 ***
	(271,014.60)	(11,580.038)	(2,610,909.78)		(1,577.64)	(334,418.27)	
M	66,476.70	26,352.42	3,987,104.033	6,796.58 ***	4,419.719	98,976.96	83.77 ***
	(2,003,493.33)	(145,370.68)	(19,464,259.879)		(17,616.011)	(2,472,439.86)	
S	18.21	10.15	805.37	23,705.94 ***	3.11	26.11	391.44 ***
	(225.64)	(19.97)	(2,088.89)		(3.90)	(278.19)	
S^2	51,245.38	501.68	5,009,517.82	1,120.14 ***	24.91	78,070.375	6.08 **
	(6,138,263.50)	(2,556.65)	(60,799,937.45)		(506.84)	(7,576,879.021)	
D^{LE}	0.010	-	-		0.000035	0.015	891.67 ***
	(0.100)	-	-		(0.006000)	(0.123)	
D^{FE}	0.34	0.35	0.0010	891.67 ***	-	-	-
	(0.48)	(0.48)	(0.0340)		-	-	
Age	18.78	18.65	31.46	1,961.06 ***	18.65	18.85	10.79 ***
	(11.89)	(11.79)	(14.72)		(11.75)	(11.96)	
Age^2	494.024	486.74	1,205.90	2,738.86 ***	485.79	498.34	18.46 ***
	(566.310)	(553.91)	(1,080.42)		(567.42)	(565.68)	
Welfare	50.78	50.051	121.96	3,032.01 ***	40.13	56.359	3,484.47 ***
	(53.87)	(53.121)	(74.59)		(20.76)	(64.069)	
EXI	6.326	5.85	52.47	10,612.81 ***	0.54	9.35	8,419.24 ***
	(19.077)	(18.23)	(36.21)		(5.66)	(22.61)	
OSDI	0.035	0.035	0.037	0.03	0.026	0.040	90.37 ***
	(0.280)	(0.282)	(0.059)		(0.050)	(0.344)	
OSII	0.14	0.14	0.030	181.10 ***	0.20	0.11	2,951.20 ***
	(0.34)	(0.34)	(0.155)		(0.39)	(0.30)	
RDI	0.025	0.025	0.033	0.01	0.00	0.039	3.85 **
	(3.810)	(3.830)	(0.057)		(0.00)	(4.703)	
D^{BD}	0.0060	0.0045	0.12	3,967.75 ***	0.00037	0.0080	438.18 ***
	(0.0750)	(0.0670)	(0.32)		(0.01900)	(0.0920)	
IMES	0.89	-	-	-	-	-	-
	(0.90)	-	-		-	-	
IRD	0.025	-	-	-	-	-	-
	(0.287)	-	-		-	-	
IKL	8.16	-	-	-	-	-	-
	(5.90)	-	-		-	-	
IAPR	3.64	-	-	-	-	-	-
	(11.19)	-	-		-	-	
AIS	199.44	-	-	-	-	-	-
	(152.31)	-	-		-	-	
SIOR	71.35	-	-	-	-	-	-
	(54.36)	-	-		-	-	
No. of obs.	166,626	164,938	1,688	-	57,271	109,355	-

Notes: The figures in this table are means and those in the parentheses are standard deviations. All the figures are provided with two-digit significance. "D. test" is the abbreviation of "Difference test." ***, **, and * denote coefficient significance at the 1%, 5%, and 10% level, respectively.

Table 6
SFA Estimations for Manufacturing Firms in Taiwan

Variables	Dependent var: Net Operating Income/#Employees With D^{FE}		Dependent var: Net Operating Income/#Employees Without D^{FE}	
	Coefficient	Std. Err.	Coefficient	Std. Err.
C	1.1690 ***	(0.0089)	1.2607 ***	(0.0086)
lnK	-0.0577 ***	(0.0028)	-0.0713 ***	(0.0029)
lnL	0.5004 ***	(0.0031)	0.5015 ***	(0.0031)
lnM	0.5339 ***	(0.0024)	0.5284 ***	(0.0024)
lnK^2	0.01243 ***	(0.00069)	0.01470 ***	(0.00070)
lnL^2	0.14000 ***	(0.00091)	0.14079 ***	(0.00093)
lnM^2	0.17109 ***	(0.00058)	0.17189 ***	(0.00060)
$lnK\times lnL$	0.0328 ***	(0.0012)	0.0317 ***	(0.0012)
$lnK\times lnM$	-0.0329 ***	(0.0010)	-0.0336 ***	(0.0010)
$lnL\times lnM$	-0.3221 ***	(0.0012)	-0.3228 ***	(0.0012)
S	0.00226 ***	(0.00031)	0.00556 ***	(0.00031)
S^2	-0.0000168 ***	(0.0000022)	-0.0000374 ***	(0.0000022)
$S\times D^{LE}$	-0.00235 ***	(0.00031)	-0.00578 ***	(0.00031)
$S^2\times D^{LE}$	0.0000168 ***	(0.0000022)	0.0000374 ***	(0.0000022)
D^{FE}	-0.3029 ***	(0.0072)	-	-
Age	-0.02744 ***	(0.00057)	-0.03203 ***	(0.00060)
Age^2	0.000370 ***	(0.000011)	0.000478 ***	(0.000011)
Welfare	0.000170 ***	(0.000017)	0.000145 ***	(0.000017)
EXI	-0.00117 ***	(0.00013)	-0.00087 ***	(0.00013)
OSDI	0.1130 ***	(0.0034)	0.1121 ***	(0.0036)
OSII	0.0106	(0.00 89)	(0.1225) ***	(0.0093)
RDI	0.00049 **	(0.00024)	0.00101 ***	(0.00024)
D^{BD}	-0.071	(0.050)	-0.074 **	(0.033)
IMES	8.57 ***	(0.25)	-2.69 ***	(0.35)
IRD	-0.693 ***	(0.023)	-0.251 ***	(0.026)
IKL	-0.02162 ***	(0.00069)	-0.03006 ***	(0.00064)
IAPR	-0.03043 ***	(0.00082)	-0.01818 ***	(0.00089)
AIS	0.000000078 ***	(0.000000019)	-0.000000819 ***	(0.000000024)
SIOR	7.60 ***	(0.26)	-4.35 ***	(0.36)
Δ	-18.82 ***	(0.55)	5.97 ***	(0.77)
σ^2	0.1785 ***	(0.0010)	0.2157 ***	(0.0011)
Γ	0.91267 ***	(0.00068)	0.94112 ***	(0.00069)
Wald test ($\theta^S+\theta^{SD}=0$)	-0.000091 ***	(0.000010)	-0.0000907 ***	(0.0000093)
Wald test ($\theta^{SS}+\theta^{SSD}=0$)	0.0000000022	(0.0000354648)	0.0000000022	(0.0000625350)
ξ ($\xi_K+\xi_K+\xi_M$)	1.003 (0.038+0.296+0.670)		0.998 (0.038+0.295+0.665)	
L-LR statistics	61,715.40		59,256.054	
LLR test $\chi2$ (0.01, 30)=50.89[a]	762,846.48***		-	
LLR test $\chi2$ (0.01, 29)=49.59[a]	-		759,927.79***	
LLR test $\chi2$ (0.01, 1)=6.63[b]	9837.39***			

Notes: "D^{FE}" refers to the abbreviation of dummy variable of family firms. "Std. Err." is the abbreviation of standard error. All the figures are provided with two-digit significance. a: Log-likelihood ratio test with a null hypothesis (H_0) supposing that all the coefficient estimations are zero except for the intercepts of the frontier and inefficiency regressions, while the alternative hypothesis (H_1) supposes otherwise. b: Log-likelihood ratio test with a null hypothesis (H_0) supposing the effect of the D^{FE} variable in the "with D^{FE}" regression is trivial compared with the "without D^{FE}" regression, while the alternative hypothesis (H_1) supposes otherwise. The LR statistic is defined by $\lambda=-2\{\ln[L(H_0)]-\ln[L(H_1)]\}$.

Table 7

Efficiency Estimations and Comparisons (with Controlling Family-Owned Firms; D^{FE})

Industry categories	Firm size categories	Mean efficiency	Diff. test	No. of obs.	Family firm categories	Mean efficiency	Diff. test	No. of obs.
Oil and gas mining, sand and stone mining and other mining, and non-metallic mineral product manufacturing	LE	0.816	–0.960	39	Family	0.884	31.21***	962
	SME	0.870		3,652	Non-Family	0.865		2,729
Food and feed manufacturing, beverage manufacturing, and tobacco manufacturing	LE	0.880	–1.000	114	Family	0.904	318.47***	4,080
	SME	0.885		8,261	Non-Family	0.870		4,295
Textile, garment, and apparel manufacturing and leather, fur, and product manufacturing	LE	0.873	–2.780	99	Family	0.898	87.12***	4,142
	SME	0.885		10,796	Non-Family	0.877		6,753
Wood and bamboo product manufacturing, pulp, paper, and paper product manufacturing, and printing and data storage media reproduction	LE	0.901	–0.280	40	Family	0.911	93.45***	6,431
	SME	0.902		15,840	Non-Family	0.896		9,449
Rubber product manufacturing and plastic product manufacturing	LE	0.891	–0.260	81	Family	0.908	177.72***	4,000
	SME	0.896		13,259	Non-Family	0.891		9,340
Base metal manufacturing and metal product manufacturing	LE	0.896	–1.960	183	Family	0.912	625.43***	20,222
	SME	0.903		47,484	Non-Family	0.897		27,445
Electronic components manufacturing, computer, electronic product, and optical product manufacturing, and electrical equipment and equipment manufacturing	LE	0.890	13.53***	600	Family	0.894	56.60***	1,710
	SME	0.860		14,801	Non-Family	0.860		13,691
Manufacturing of automobiles and their parts and other means of transport and their parts	LE	0.885	–2.580	153	Family	0.902	50.77***	1,722
	SME	0.886		6,119	Non-Family	0.880		4,550
Furniture manufacturing and other manufacturing	LE	0.884	1.500	67	Family	0.897	102.31***	2,499
	SME	0.878		7,198	Non-Family	0.868		4,766
Machinery and equipment manufacturing and industrial machinery and equipment repair and installation	LE	0.890	–1.110	160	Family	0.912	324.46***	8,826
	SME	0.898		27,070	Non-Family	0.893		18,404
Electricity and gas supply industry and water supply industry	LE	0.906	0.044	6	Family	0.923	3.37*	64
	SME	0.890		624	Non-Family	0.890		566
Wastewater and sewage treatment industry, waste removal, treatment and resource recovery and treatment industry, and pollution remediation industry	LE	0.783	–0.620	5	Family	0.919	56.83***	2,076
	SME	0.906		5,213	Non-Family	0.899		3,142
Manufacturing of petroleum and coal products, manufacturing of chemical raw materials, fertilizers, nitrogen compounds, plastic and rubber materials, and man-made fibers, manufacturing of other chemical products, and manufacturing of pharmaceuticals and medical chemicals	LE	0.877	1.450	141	Family	0.880	9.68***	537
	SME	0.860		4,621	Non-Family	0.850		4,225

Notes: * and ** denote coefficients significant at 1% and 5%, respectively. The difference test employed in the table is one way ANOVA test with F-statistics. The positive and negative sign for the value of different tests are used for comparison; a positive sign denotes that the mean efficiency of LEs (or family firms) is higher than that of SMEs (or non-family firms), and vice versa.

Table 8
Efficiency Estimations and Comparisons (without Controlling Family-Owned Firms; D^{FE})

Industry categories	Firm size categories	Mean efficiency	Diff. test	No. of obs.	Family firm categories	Mean efficiency	Diff. test	No. of obs.
Oil and gas mining, sand and stone mining and other mining, and non-metallic mineral product manufacturing	LE	0.834	–1.200	39	Family	0.889	2.51	962
	SME	0.885		3,652	Non-Family	0.884		2,729
Food and feed manufacturing, beverage manufacturing, and tobacco manufacturing	LE	0.883	0.130	114	Family	0.894	138.57***	4,080
	SME	0.881		8,261	Non-Family	0.870		4,295
Textile, garment, and apparel manufacturing and leather, fur, and product manufacturing	LE	0.875	–2.040	99	Family	0.891	17.91***	4,142
	SME	0.885		10,796	Non-Family	0.880		6,753
Wood and bamboo product manufacturing, pulp, paper, and paper product manufacturing, and printing and data storage media reproduction	LE	0.908	0.190	40	Family	0.907	8.63***	6,431
	SME	0.904		15,840	Non-Family	0.902		9,449
Rubber product manufacturing and plastic product manufacturing	LE	0.899	–0.071	81	Family	0.906	31.73***	4,000
	SME	0.901		13,259	Non-Family	0.898		9,340
Base metal manufacturing and metal product manufacturing	LE	0.905	–0.440	183	Family	0.912	55.33***	20,222
	SME	0.909		47,484	Non-Family	0.907		27,445
Electronic components manufacturing, computer, electronic product, and optical product manufacturing, and electrical equipment and equipment manufacturing	LE	0.899	13.820***	600	Family	0.893	25.27***	1,710
	SME	0.870		14,801	Non-Family	0.870		13,691
Manufacturing of automobiles and their parts and other means of transport and their parts	LE	0.893	2.340	153	Family	0.900	12.84***	1,722
	SME	0.892		6,119	Non-Family	0.889		4,550
Furniture manufacturing and other manufacturing	LE	0.892	2.260	67	Family	0.893	41.83***	2,499
	SME	0.881		7,198	Non-Family	0.876		4,766
Machinery and equipment manufacturing and industrial machinery and equipment repair and installation	LE	0.898	–0.410	160	Family	0.910	100.00***	8,826
	SME	0.903		27,070	Non-Family	0.901		18,404
Electricity and gas supply industry and water supply industry	LE	0.909	0.025	6	Family	0.923	2.33	64
	SME	0.900		624	Non-Family	0.890		566
Wastewater and sewage treatment industry, waste removal, treatment and resource recovery and treatment industry, and pollution remediation industry	LE	0.788	–0.860	5	Family	0.909	16.51***	2,076
	SME	0.902		5,213	Non-Family	0.898		3,142
Manufacturing of petroleum and coal products, manufacturing of chemical raw materials, fertilizers, nitrogen compounds, plastic and rubber materials, and man-made fibers, manufacturing of other chemical products, and manufacturing of pharmaceuticals and medical chemicals	LE	0.886	1.690	141	Family	0.877	4.01***	537
	SME	0.860		4,621	Non-Family	0.860		4,225

Notes: * and ** denote coefficients significant at 1% and 5%, respectively. The difference test employed in the table is one way ANOVA test with F-statistics. The positive and negative sign for the value of different tests are used for comparison; a positive sign denotes that the mean efficiency of LEs (or family firms) is higher than that of SMEs (or non-family firms), and vice versa.

APPENDIX 1

Table A1
SFA Estimations for Manufacturing Firms in Taiwan

Variables	Dependent variable: Net Operating Income/ #Employees (With D^{FE} and $D^{FE} \times D^{LE}$)		Dependent variable: Net revenue / #Employees (With D^{FE})		Dependent variable: Net revenue / #Employees (With D^{FE} and $D^{FE} \times D^{LE}$)	
	Coefficient	Std. Err.	Coefficient	Std. Err.	Coefficient	Std. Err.
Production function						
C	1.1587 ***	(0.0089)	4.320 ***	(0.025)	4.1903 ***	(0.0257)
lnK	-0.0656 ***	(0.0029)	-0.3234 ***	(0.0071)	-0.3188 ***	(0.0071)
lnL	0.5227 ***	(0.0030)	0.2055 ***	(0.0081)	0.2350 ***	(0.0082)
lnM	0.5292 ***	(0.0024)	0.7157 ***	(0.0060)	0.7158 ***	(0.0060)
lnK^2	0.02229 ***	(0.00070)	0.0113 ***	(0.0016)	0.01042 ***	(0.00157)
lnL^2	0.14389 ***	(0.00092)	0.0484 ***	(0.0023)	0.04402 ***	(0.00234)
lnM^2	0.17425 ***	(0.00061)	0.1608 ***	(0.0013)	0.15999 ***	(0.00130)
$lnK \times lnL$	0.0184 ***	(0.0012)	0.1082 ***	(0.0030)	0.1074 ***	(0.0030)
$lnK \times lnM$	-0.0411 ***	(0.0011)	-0.0258 ***	(0.0023)	-0.0251 ***	(0.0023)
$lnL \times lnM$	-0.3183 ***	(0.0012)	-0.3615 ***	(0.0028)	-0.3602 ***	(0.0028)
Inefficiency regression						
S	0.00272 ***	(0.00032)	0.03323 ***	(0.00032)	0.03339 ***	(0.00032)
S^2	-0.0000250 ***	(0.0000022)	-0.0002074 ***	(0.0000028)	-0.0002415 ***	(0.0000030)
$S \times D^{LE}$	-0.00302 ***	(0.00032)	-0.03427 ***	(0.00033)	-0.03499 ***	(0.00033)
$S^2 \times D^{LE}$	0.0000250 ***	(0.0000022)	0.0002074 ***	(0.0000028)	0.0002416 ***	(0.0000030)
D^{FE}	-0.2256 ***	(0.0072)	-0.1341 ***	(0.0083)	-0.1321 ***	(0.0083)
$D^{FE} \times D^{LE}$	-0.0103	(0.0191)	-	-	0.0253	(0.0998)
Age	-0.02639 ***	(0.00059)	-0.02038 ***	(0.00062)	-0.01826 ***	(0.00062)
Age^2	0.000372 ***	(0.000011)	0.000317 ***	(0.000012)	0.000317 ***	(0.000012)
Welfare	-0.000006	(0.000017)	-0.001705 ***	(0.000034)	-0.001797 ***	(0.000033)

EXI	-0.00241 ***	(0.00013)	-0.00286 ***	(0.00015)	-0.00301 ***	(0.00015)
OSDI	0.1149 ***	(0.0034)	0.1333 ***	(0.0056)	0.1340 ***	(0.0056)
OSII	-0.0440 ***	(0.0089)	0.0651 ***	(0.0098)	0.0690 ***	(0.0098)
RDI	0.00161 ***	(0.00024)	0.00023	(0.00048)	0.00176 ***	(0.00048)
D^{BD}	-0.088 ***	(0.034)	-0.208 ***	(0.038)	-0.301 ***	(0.038)
IMES	-0.0597 ***	(0.0054)	0.1485 ***	(0.0062)	0.1234 ***	(0.0062)
IRD	-0.134 ***	(0.020)	0.024	(0.024)	0.009	(0.024)
IKL	-0.01372 ***	(0.00069)	-0.00731 ***	(0.00079)	-0.00903 ***	(0.00079)
IAPR	-0.01060 ***	(0.00075)	-0.00065	(0.00089)	0.00057	(0.00089)
AIS	-0.000000102 ***	(0.000000029)	-0.000000574 ***	(0.000000038)	-0.000000670 ***	(0.000000038)
SIOR	-0.436 ***	(0.065)	-1.903 ***	(0.074)	-1.742 ***	(0.075)
Δ	0.159 ***	(0.015)	0.510 ***	(0.020)	0.476 ***	(0.020)
σ^2	0.15632 ***	(0.00077)	0.3559 ***	(0.0042)	0.34925 ***	(0.00390)
Γ	0.91564 ***	(0.00084)	0.7881 ***	(0.0029)	0.77482 ***	(0.00288)
Wald test ($\theta^{S}+\theta^{SD}=0$)	-0.0001225 ***	(0.0000043)	-0.00104 ***	(0.00046)	-0.00160 ***	(0.00046)
Wald test ($\theta^{SS}+\theta^{SSD}=0$)	0.0000000088	(0.0000030817)	-0.00000000043	(0.00000397761)	0.0000000077	(0.0000042864)
ξ ($\xi_L+\xi_K+\xi_M$)	1.002 (0.038+0.294+0.67)		1.015 (0.038+0.297+0.68)		1.012 (0.037+0.297+0.678)	
L-LR statistics	56,142.768		-79,653.543		-79,362.800	
LLR test $\chi2$ (0.01, 30)=50.89[a]	-		480,108.59***		-	
LLR test $\chi2$ (0.01, 29)=49.59[a]	-		-		-	
LLR test $\chi2$ (0.01, 31)=52.19[a]	751,701.22***		-		480690.08***	
LLR test $\chi2$ (0.01, 1)=6.63[b]	-		581.49***			

Notes: "D^{FE}" refers to the abbreviation of dummy variable of family firms. "Std. Err." is the abbreviation of standard error. All the figures are provided with two-digit significance. a: Log-likelihood ratio test with a null hypothesis (H_0) supposing that all the coefficient estimations are zero except for the intercepts of the frontier and inefficiency regressions, while the alternative hypothesis (H_1) supposes otherwise. b: Log-likelihood ratio test with a null hypothesis (H_0) supposing the effect of the D^{FE} variable in the "with D^{FE}" regression is trivial compared with the "without D^{FE}" regression, while the alternative hypothesis (H_1) supposes otherwise. The LR statistic is defined by λ=-2{ln[L(H_0)]-ln[L(H_1)]}.