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Cost Efficiency Estimations and the Equity Returns for the US Public Solar Energy Firms in 1990–2008

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Cost efficiency estimations and the equity returns for the US public solar energy firms in 1990–2008

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This paper provides a direct estimate of the cost efficiencies of firms in the US solar energy industry. It suggests that the cost efficiency in the industry is associated with the risk-bearing behaviour of firms. Less efficient firms maintain low price-cost margins and high labour–capital ratios in order to compete with their efficient peers. The study then establishes the linkage between cost efficiency and stock returns. It shows that the change in cost efficiency, rather than cost efficiency itself, possesses a stronger explanatory power for stock returns. A buy-and-hold strategy for stock portfolios of different efficiency levels is then analysed. The 3-year returns of the inefficient firm portfolios tend to outperform the efficient firm portfolios. The finding further shows that the improvement in cost efficiency of the inefficient firms is larger than that of the efficient firms. Previous literature has indicated that inefficient firms have higher failure rate, so they are forced to improve cost efficiency.

Keywords: solar energy; cost efficiency analysis; stochastic frontier model; stock returns.

1. Introduction

Solar energy is considered the cleanest, most abundant, renewable energy source available. It provides a cost-effective solution for daytime energy needs as well as peak shaving benefits. It can be used to decrease the overdependence of the USA on foreign sources of oil and natural gas. The USA has some of the richest solar resources shining across the nation.

In the past two decades, the US solar energy industry experienced an unprecedented growth. One reason for the emergence of the solar energy industry is that there are strong social (Bansal & Roth, 2000) and institutional (Hoffman, 1999; Delmas, 2002; Seo & Creed, 2002; Wade-Benzoni *et al.*, 2002) elements stimulating the push towards 'greening'. Along with this trend, government initiatives have played an important role in the USA, Germany, Japan, Spain and several countries. For example, during the period 2000–2004, the US Department of Energy Solar Energy Technologies Program investment averaged about 50% of total investment in the US solar sector. The US federal government and many states have created residential taxes for solar energy. The US Congress signed into law in 2005 tax incentives and loan guarantees for energy production of various types. The state of California enacted the largest solar program outside of Germany through the passage of the California Solar Initiative in 2006. Several other states improved programs in 2006–2007 that expand incentives or require the use of solar as part of their renewable portfolio standard. The continual improvement in solar energy Research & Development has created a wide range of technologies that are now entering the marketplace. The non-governmental investments in the past 10 years created significant momentum and will help solar become an increasingly important source of energy in the near future. Given the exponential growth, analysing the solar energy industry is critical to creating knowledge about firm management and investment decisions.

There have been many trend analyses and investment reports on solar energy production. To name a few, the National Renewable Energy Laboratory (2006) (NREL) assessed the concentrating solar power and its potential economic return and environmental benefits for the State of California. NREL (2008) reported the venture capital, private equity, mergers and acquisitions and public equity investing activities. Interstate Renewable Energy Council (2008) reported the trends of US solar installations by state for photovoltaic, solar thermal and solar thermal electric technologies. Many institutional investors such as Morgan (2008) have produced many financial evaluations for the industry as well as for individual firms.

Some firms in the industry operate at cost efficient levels and others do not. What are the economic reasons that cause the differences? Analyses on cost efficiency have been studied for a wide range of mature industries and have provided insights for decision making. They measure the performance of other firms relative to the best practice. This paper, to our knowledge, probably is the first one to document and analyse the variance of cost efficiency in the industry. Given the increasing importance of the solar energy industry, it is expected that more significant economic analyses will follow for policy and investment guidance.

In order to find the best practice firms and to understand the difference among firms, this paper uses the stochastic frontier analysis (SFA) to estimate the cost efficiency frontier. Originated by Aigner *et al.* (1977) and Meeusen & van den Broeck (1977) and developed by many researchers (e.g. Battese & Coellli, 1995; Kim & Schmidt, 2000; Greene, 2005; Horrace & Schmidt, 2000; Horrace, 2005), the stochastic frontier analysis has found extensive use in various areas, such as food service sector (Assaf & Matawie, 2008; Cuesta, 2000), mining industry (Tsolas, 2010), health economics (Grassetti *et al.*, 2005) or running performance (Sterken, 2005). The stochastic frontier analysis locates firms that are on the frontier and measures the inefficiencies of firms that are away from the frontier. The estimation in the study shows that an average firm incurred costs that are about 37% above the minimum cost. This finding appears to be in the same range of estimations for other industries.

The difference in the cost efficiency presents an interesting question: how do the less efficient firms stay or even survive in the market to compete with their efficient peers? In the literature, there are a couple of theories supporting the survivorship of inefficient firms. One popular theory is risk bearing. An inefficient firm may take on more risk in order to meet shareholders' financial expectation. The second theory is low price-cost margin. An inefficient firm may sacrifice price-cost margins to stay competitive. In other words, low price-cost margin also implies high risk bearing. The third theory is relatively high labour–capital ratio. This study examines each of the three economic hypotheses. It is shown that many firms are committed to a high level of financial leverage—more than 43.16% firms in the data sample have the financial leverage ratio of more than 1.0, and more than 22% firms have the ratio of more than 2.0. The inefficient firms show low levels of price-cost margins and high levels of labour–capital ratios.

Given the interest of the investment communities, the next research topic is the linkage between cost efficiency and equity returns. There are a number of hypotheses as to why firm cost efficiency may affect stock returns. Firms may pursue short-term or long-term investment decisions that will alter the level of cost efficiencies in each year. Variance in cost efficiency is perceived by investors as risk factor. In an efficient market framework, the risks will be priced through the equilibrium rate of return. Inefficiently, operating firms might be forced to commit to higher levels of risk, such as lowering price-cost margins, regardless of the underlying economic conditions. In contrast, a cost efficient firm may have relatively higher profits and may be less vulnerable to outside competition or demand shocks.

Therefore, the required rate of return for a cost efficient firm will be lower than an inefficiently operating firm.

If cost efficiency is reflected in equity return, it is expected that there should exist a statistically significant correlation. Kwan & Eisenbeis (1996) show a positive association between cost efficiency and equity return in the banking industry. Although it is generally agreeable that the cost efficiency in every time period has a high level of 'informativeness' for stock returns, this paper suggests that the change in cost efficiency from one time period to another is more important than the cost efficiency itself. The empirical study shows that the change in cost efficiency does have better explanatory power than the cost efficiency itself. Beccalli *et al.* (2006) find similar results for the European banking industry.

Can the cost efficiency provide guidance for stock portfolio formation? There are potentially many ways to form a portfolio. This study examines a simple buy-and-hold strategy in the 3 years following portfolio formation. Firm stocks are ranked into quartiles according to their cost efficient scores prior to the portfolio formation year. It finds that inefficient firms tend to outperform firms that are most efficient. At the same time, the average cost efficiency level of the inefficient firms is rising. The result is interestingly consistent with findings by previous literature such as Habib & Ljungqvist (2005) and Nguyen & Swanson (2009). The reason that the relatively inefficient firms outperform the efficient firms is largely due to cost efficiency improvements. Previous literature suggests that the low-efficient firms tend to have higher failure rates, so the remaining firms are forced to stay competitive. The improvement is reflected in the stock rate of return.

The paper proceeds as follows. Section 2 discusses the cost frontier model and the explanatory variables for cost efficiency. Section 3 explains the estimated cost efficiencies with stock returns. Section 4 discusses data sources. Section 5 presents the empirical results. Section 6 concludes.

2. Cost frontier constructions

2.1 *Cost minimization firm*

The economic principle suggests that firms pursue cost minimization. The cost minimization concept assumes that firms minimize total operating costs subject to exogenously given prices of variable inputs, quantities of variable outputs, quantities of fixed inputs and outputs, environmental factors, their own managerial inefficiency and random error. A stochastic cost frontier model is adopted here. The stochastic frontier model focuses not only on average performance but also on extreme performance. The zone below the cost frontier is unattainable; therefore, all productive units are either on or above the frontier. Those on the frontier have the lowest cost for a given level of output. This is the frontier of 'best practices'. This approach potentially provides a more precise measure of efficiency. The stochastic frontier function is defined as (Kumbhakar & Lovell, 2000):

$$\mathrm{TC} = f(X_i, \beta)\exp(\nu_{it} + u_{it}), \tag{1}$$

where TC is the total operating cost. The set of X variables includes the output characteristics of sales revenue, total assets, and input characteristics of the price of labour, inventories, long-term debts and cost of goods sold. Unlike data envelopment analysis which is a non-stochastic method, stochastic frontier model includes an error term partitioned into a random component ν_{it} and a component u_{it} representing technical efficiency.

The frontier is dependent upon variables selected. There are extensive discussions on input variables (e.g. Assaf & Matawie, 2008; Cuesta, 2000; Tsolas, 2010; Nguyen & Swanson, 2009; Habib & Ljungqvist, 2003). The choice of the variables here is based on underlying theory and previous empirical research. For the model estimation, we use the model developed by Battese & Coellli (1995) to specify the stochastic frontier cost function with the behaviour inefficiency component and to estimate all parameters together in the one-step maximum likelihood estimation. Employing a log transformation, the following estimating equation is obtained:

$$\begin{aligned}\ln(\mathrm{TC}_{it}) = \beta_0 + \beta_1 \ln(\mathrm{Inventories}_{it}) + \beta_2 \ln(\mathrm{CostGoodsSold}_{it}) \\ + \beta_3 \ln(\mathrm{Revenue}_{it}) + \beta_4 \ln(\mathrm{Labour\_Rate}_{it}) \\ + \beta_5(\mathrm{LongTerm\_Debt}_{it}) + \beta_6 \ln(\mathrm{Assets}_{it}) + \nu_{it} + u_{it},\end{aligned} \quad (2)$$

where ν_{it} is the standard two-sided white noise error and is distributed $N(0, \sigma_\nu^2)$. u_{it} is proxy for systematic inefficiency and is the primary variable of interest. It is the one-sided error half-normally distributed $N(0^+, \sigma_u^2)$. Equation (2) further assumes that $\mathrm{cov}(\nu_{it}, u_{it}) = 0$ and $\sigma^2 = \sigma_\nu^2 + \sigma_u^2$. This controls the stochastic error ν_{it} around the frontier to be independent of the firm inefficiencies u_{it}. In other words, good or bad luck is assumed to be unrelated to cost inefficiencies.

If all firms operate at the optimal cost efficiency level, u_{it} should be 0 and the stochastic frontier model provides no additional value to an ordinary least squares (OLS) model. The hypothesis test $u_{it} = 0$ can determine whether the SFA specification is identical to the OLS. If the null hypothesis is rejected, the deviations from the frontier are attributed to systematic inefficiencies.

The precise definitions of the variables are given in the Data Appendix. The rationales, economic meaning and predicted signs of the remaining variables are as follows:

- β_1: High level of inventories directly impact the stocking and administrative costs. The sign is expected to be positive.
- β_2, β_3: The signs of both the log of cost of goods and the log of revenue are expected to be positive.
- β_4: The price of labour is the average labour rate of firm i in time t. It is estimated by subtracting the cost of goods sold and the interest payment from the net sales, then dividing by the number of employees. The sign is expected to be positive.
- β_5, β_6: The solar energy industry employs heavily two types of capital—debt capital and physical capital. Both long-term debt and total assets have positive impacts on a firm's operational expenses.
- β_0: The intercept.

Multicollinearity tests for equation (2) reveal a high degree of correlation between ln(Revenue), ln(Cost Goods Sold) and ln(Inventories). Therefore, the log of revenue and the log of cost of goods sold are removed from the equation. The final model for estimation is

$$\begin{aligned}\ln(\mathrm{TC}_{it}) = \beta_0 + \beta_1 \ln(\mathrm{Inventories}_{it}) + \beta_4 \ln(\mathrm{Labour\_Rate}_{it}) \\ + \beta_3(\mathrm{LongTerm\_Debt}_{it}) + \beta_5 \ln(\mathrm{Assets}_{it}) + \nu_{it} + u_{it}.\end{aligned} \quad (3)$$

The cost efficiency (CE) score of a firm is defined in terms of the ratio of the observed total operating cost (TC_{it}) to the corresponding minimum total operating cost (TC_{it}^*) expressed as:

$$\mathrm{CE}_{it} = \frac{E(\mathrm{TC}_{it} | u_{it}, X_{it})}{E(\mathrm{TC}_{it}^* | u_{it} = 0, X_{it})}. \quad (4)$$

The observed total operating cost represents the actual cost, whereas the minimum total operating cost represents the frontier cost or the least cost level. CE takes the values 1 or higher. A score of 1.63 means the firm's incurred costs are 63% above the minimum cost that the best-performing firm has achieved. The higher value of cost efficiency CE represents the more inefficient firm.

2.2 *Cost efficiency explanatory variables*

If cost inefficiency appears to exist in the market, the next question is: how do the less efficient firms stay in the market to compete with the efficient peers? Why do such firms continue to survive, especially when the market is very competitive? What are the characteristics associated with the cost inefficient firms? Empirically, we are seeking a set of characteristic variables Z that associate with the cost efficiency u_{it}:

$$\ln(\mathrm{CE}_{it}) = u_{it} = Z_{it} \cdot \phi + \omega_{it}. \tag{5}$$

In equation (1), the X variables determine the location of the frontier, and here the Z variables explain departure from the frontier. Z_{it} is a $(1 \times m)$ set of variables, ϕ is a $(m \times 1)$ vector of unknown coefficients to be estimated, and ω_{it} denotes the unexplained component. ω_{it} is obtained by the truncation of $N(0, \sigma_u^2)$ such that the minimal point is $-Z_{it}\phi_{it}$. Since $\omega_{it} \geqslant -Z_{it}\phi_{it}$, this guarantees $u_{it} \geqslant 0$. Regarding the criterion for the selection of the Z variables, in general, a researcher can decide it to be on the basis of econometric principle, such as maximizing the log likelihood or on the basis of economic theory. The latter one is chosen in this study. Also it is shown that the results are confirmed by econometric tests in Section 5.

In the literature, there are at least three theories supporting the survivorship of inefficient firms. One popular feature is risk bearing. An inefficient firm can take higher risks to survive by earning economic rents (Ferguson & Shockley, 2003; Cefis & Marsili, 2006) or to meet shareholders' return targets (Gorton & Rosen, 1995; Boujelbene & Zribi, 2009). The second characteristic associated with cost inefficiency is low price-cost margins. In order to compete with more efficient firms, an inefficient firm might set a lower output price or have higher input costs. Harris (1986) showed that lower price-cost margin is caused by higher risk taking. Clarke *et al.* (1984) showed that price-cost margins could be positively correlated with market share due to cost efficiency differentials not just market power.

The third common theory for the survivorship of inefficient firms is relatively high labour–capital ratio. Inefficient firms may utilize more labour inputs or are in the process of replacing labour with technology to compete with their peers that possess higher levels of capital. Hritonenko & Yatsenko (2006) provide a theoretical model that a firm has to provide an efficient strategy in order to survive in competitive market environment. They argue that a major part of the management strategy is the rational replacement of productive capital under restricted cost resources. There are many other papers discussing the capital–labour ratio and its implications. For example, Scherer (1980), Phillips & Kirchhoff (1989) and Acs & Audretsch (1990) showed that, in capital-intensive industries, most new entrants are small and tend to operate at a suboptimal scale of output. Tsionas & Papadogonas (2006) studied the probability of firm exit as a function of technical inefficiency. Caselli (1999) and Caselli & Coleman (2002) studied the revolution of capital–labour ratio, wage and productivity. Garmaise (2008) shows that financially restricted firms use relatively more labour than physical capital.

Financial leverage is conventionally measured by financial leverage ratio—the total debts divided by the total equity value. Table 1 shows the distribution of firms' financial leverage ratios. There are more than $100\% - 56.84\% = 43.16\%$ firms that have ratio value mores than 1.0, and more than $100\% - 77.78\% = 22.22\%$ firms more than 2.0. In other words, a significant percentage of firms in the data sample committed high levels of financial leverages. Following the above discussion, the set of Z or

TABLE 1 *Distribution of firms' financial leverage ratio*

Ratio	Number of firms	Percentage of firms	Cum. (%)
<0.20	23	9.83	9.83
0.20–0.39	21	8.97	18.80
0.40–0.59	35	14.96	33.76
0.60–0.79	34	14.53	48.29
0.80–0.99	20	8.55	56.84
1.00–1.19	18	7.69	64.53
1.20–1.39	12	5.13	69.66
1.40–1.59	12	5.13	74.79
1.60–1.79	7	2.99	77.78
1.80–1.99	4	1.71	79.49
⩾2.00	48	20.51	100.00

explanatory variables for the cost efficiency includes labour–capital ratio, price-cost margin and financial leverage:

$$\ln(\mathrm{CE}_{it}) = \varphi_0 + \varphi_1 \ln(\mathrm{Labour\_Capital}_{it}) + \varphi_2 \ln(\mathrm{PCM}_{it}) + \varphi_3(\mathrm{Debt\_Seq}_{it}) + \omega_{it}. \tag{6}$$

The precise definitions of the variables are described in the Data Appendix. The rationales and predicted signs are as follows:

- φ_1: A cost inefficient firm (high CE value) should associate with relatively high labour–capital ratio. The sign is expected to be positive.
- φ_2: A cost inefficient firm might sacrifice price-cost margins in order to compete with more efficient firms. Thus, the sign is expected to be negative.
- φ_3: Debt has a lower cost because creditors take less risk. However, debt can be risky to the firm because if enough profit is not made to cover the interest and principal payments, bankruptcy can occur. A company is said to be highly leveraged if it uses more debt than equity, including stock and retained earnings. Financial analysis has several measures for leverage ratios. Perhaps, the most widely used measure of a company's leverage is the ratio between long-term debt and total equity. A cost inefficient firm might leverage more and bear more risk to survive in the market. Thus, the sign is expected to be positive.

How appropriately the Z variables explain the cost efficiency (CE) can be tested by $\gamma = \sigma_u^2/\sigma^2 \in [0, 1]$ (Aigner *et al.*, 1977). The better the Z variables are able to explain the cross-variance of CE, the lower the unexplained variance σ_u^2 will be. If the Z variables fully account for the cross-variance, the value of γ will be 0.

3. Cost efficiency and stock market valuation

3.1 *Cost efficiency score and stock return*

Kwan & Eisenbeis (1996) show that the level of cost efficiency contains certain informativeness for the stock market returns. This is in concordance with the efficient market framework. However, this study suggests that the change in cost efficiency from one time period to another should have better information than the cost efficiency itself. In order to test the level of cost efficiency and the change in cost efficiency associated with the returns, the model incorporates the measure of cost efficiency firm i in year t and the change of cost efficiency from year t to $t+1$ as in equation (7):

$$\begin{aligned} \gamma_{it} - \gamma_{\mathrm{ft}} &= \theta_1 + \theta_2 \cdot (\gamma_{\mathrm{m}t} - \gamma_{\mathrm{ft}}) + \theta_3 \cdot d(\mathrm{CE})_{it} + \theta_4 \cdot \mathrm{CE}_{it} + \xi_{it}, \\ \xi_{it} &= h_i + \psi_{it}. \end{aligned} \tag{7}$$

The γ_{it} is the return on stock i in year t. γ_{ft} is the risk-free return. $\gamma_{\mathrm{m}t}$ is the return on the market portfolio. $\theta_1, \theta_2, \theta_3$ and θ_4 are the intercept and the coefficients of $(\gamma_{\mathrm{m}t} - \gamma_{\mathrm{ft}})$, d(CE) and CE, respectively. The $(\gamma_{it} - \gamma_{\mathrm{ft}})$ and $(\gamma_{\mathrm{m}t} - \gamma_{\mathrm{ft}})$ denote the excess returns (expected return minus the risk-free rate) of stock i and the market portfolio m in year t, respectively. Changes in the cost efficiency of firm i over the same period are given by $\mathrm{d(CE)}_{it}$ (d is the first difference operator). Since an improvement of cost efficiency means a decrease of the value d(CE), θ_3 is expected to be negative. The stochastic component ξ_{it} contains the unobserved firm specific effect $h_i \sim \mathrm{IID}(0,\sigma_h^2)$ that is assumed to be time invariant and the disturbance $\psi_i \sim \mathrm{IID}(0,\sigma_\psi^2)$.

The role of the firm-specific stochastic component h_i will be established by a method of estimation because it can not be determined *a priori*. This is the standard fixed or random effects models. Fixed effects model allows for unknown correlation between this component and the regressors, and random effects assume zero correlation between the firm-specific unobserved element and the regressor. The random effects model reduces the number of parameters to be estimated, thus increasing the efficiency of the estimated coefficients. Intuitively, the coefficients from the fixed and random effects model should converge to the same parameter values if the random effects model is true. That is, the fixed effects model might needlessly allow the latent time-invariant variables to correlate with the time-varying variables. To examine the appropriate estimation method, the test statistic proposed by Hausman (1978) is used. Under the null hypothesis, both fixed-effect and random effect estimators are consistent, but the random effects estimates are more efficient. Rejection of the null hypothesis advises against the use of the random effects estimator.

3.2 *Stock portfolio construction*

The relationship between firm cost efficiency and stock returns is examined with a 3-year buy-and-hold strategy. The buy-and-hold strategy has been employed widely as a testing method in the finance literature (e.g. Fama, 1998; Wylie, 2005; Guo, 2006; Baker & Belgorodskiy, 2007). In order to construct the efficient portfolios, stocks are ranked into quartiles according to their previous year's cost efficient scores. The firms in the portfolios, as well as their cost efficiency scores, remain unchanged during the 3-year holding period. The 3-year return is computed by taking the difference of the prices at the end of June of year $t+3$ and year t, then dividing by the price at the end of June of year t. In order to observe the effect of cost efficiency, the equally weighted portfolio returns is applied because it places an equal emphasis on the size of the stock.[1] If a firm is dropped out of the sample, the weight of each firm in the portfolio is re-adjusted for each period. The formation years of the portfolios in the experiment start with 1992 and end with 2005.

[1] The equally weighted return R_t^{ew} is calculated as $R_t^{ew} = \sum r_{it}/N_t$, where r_{it} is the return of stock i in year t and N_t is the number of stocks in the portfolio in year t.

TABLE 2 *Sample descriptive statistics*

	Mean	Std dev	Med	Max	Min
Total assets (AT)	1176.3	4320.1	121.8	55651.0	0.5
Long-term debts (DLTT)	505.6	1750.6	38.7	21380.3	0.0
Cost of goods sold (COGS)	573.3	1841.3	57.5	23441.0	0.0
Shareholder equity (SEQ)	684.4	3039.1	72.9	42762.0	7152.9
Total inventories (INVT)	113.4	366.1	13.6	4314.0	0.0
Number of employees (EMP)	3.3	10.1	0.4	99.9	0.0
Capital expenditure (PPENT)	377.0	1736.1	16.7	20636.4	0.0
Operating costs (XOPR)	787.2	2481.2	95.9	30937.0	0.4
EBIT	113.0	751.9	3.2	12230.0	2231.6

The statistics include mean (Mean), standard deviation (Std dev), maximum value (Max), median (Med) and minimum value (Min). The units of measurement and in thousands for the number of employees and are in millions of dollars for the rest of the variables. Capital Expenditure includes property, plant and equipment; EBIT is Earnings before interest and taxes.

4. Data description

Company financial data, such as sale, total assets, long-term debt and expenditures are gathered from COMPUSTAT. The solar energy industry is selected according to the North American Industry Classification System (NAICS) codes.[2] To be included in the sample, a firm must meet the following criteria. First, it must have the Center for Research in Security Prices stock prices and the COMPUSTAT accounting data for 1990–2008. Second, the firm must have appeared in the COMPUSTAT database for more than 3 years in order to see the dynamic movement. Also, the 3-year duration criterion helps to reduce survival biases (Anderson & Garcia-Feijóo, 2006). Similar to Fama & French (1992), we match stock returns for the period of July of year t to June of year $t+1$ to the accounting data of a firm for the fiscal year ending in year $t-1$. This ensures the accounting information is known before it is used. Furthermore, it is well known in the finance literature that some stocks delist. Rather than simply dropping firms from the portfolios, we assign the last available price to calculate a particular stock's overall return. Similar treatment has been adopted by Gropp (2004).

According to the Capital Assets Pricing Model, the γ_{mt} in equation (7) should be the returns on the world market portfolio. Since it is impossible to construct such an index, a proxy must be used instead. The most commonly used index is the value-weighted Standard and Poor's Composite Index. The yields on 3-month T-bills were used for the risk-free rate. Table 2 presents descriptive statistics for the final sample. There are 2074 firm-year observations for 234 firms for the period in 1990–2008. As the means and medians indicate, the sample suffers from right skewness.

5. Results

5.1 *Cost efficiency frontier estimates*

Table 3 reports the mean of parameter estimates for each independent variable. The estimates using the standard OLS technique is also presented. There is no major difference between the mean coefficients

[2] US NAICS codes selected are: 221119, 221119, 237130, 237130, 238160, 238220, 333414, 333414, 334413, 334519, 335121, 335122, 423330, 423690, 423720 and 926130.

TABLE 3 *Cost stochastic frontier model estimation*

Frontier variables	SFA	OLS	Expected sign
Dependent variable = ln(Operating expenses)			
Intercept	0.7617***	1.1126***	
	(0.0461)	(0.0310)	
ln_(TotalAssets)	0.2865***	0.2729***	+
	(0.0148)	(0.0148)	
ln_(Inventory)	0.3027***	0.2836***	+
	(0.0110)	(0.0098)	
ln_(LaborRate)	0.0010***	0.0008	+
	(0.0001)	(0.0001)	
ln_(Debt)	0.3344***	0.3612***	+
	(0.0153)	(0.0144)	
Cost-efficiency explanatory variables			
Ln(Labour–capital ratio)	0.6467***		+
	(0.1208)		
Price-cost margin	−0.0030*		−
	(0.0012)		
Debt/Seq	0.0009		+
	(0.0025)		
Diagnostics			
Frontier model likelihood-ratio test of the one-sided error = 39.63***			
$\sigma^2 = \sigma_v^2 + \sigma_u^2$	0.2937***		
	(0.0230)		
$\gamma = \sigma_u^2/\sigma^2$	0.5157***		
	0.0746		
Number of firm years	2074		

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

obtained from the stochastic frontier analysis and those from OLS. The signs of the coefficients from stochastic frontier analysis are consistent with previous expectations. The second part of Table 3 reports the diagnostics for stochastic frontier analysis. The average p value for the likelihood ratio test is statistically significant at 99% level (p value $<1\%$). Thus, the null that all firms operate at an optimal level is rejected. The SFA is superior over OLS because it not only provide similar estimates but also provide efficiency estimates.

The estimating results for the Z variables are worth noting. The labour–capital ratio is statistically significant at 99% and the price-cost margins at 90%. Both show the expected signs. The estimate for Debt_Seq, representing financial leverage, appears statistically significant. However, it should not be interpreted that firms do not commit financial leverage. (Later, Table 5 will discuss this point in greater detail.) Overall, the accountability of the set of the Z variables for the variance in CE_{it}, as measured by γ, is 100 − 51.57% = 48.43% and is statistically significant at 99%.

5.2 *Cost efficiency score results*

Each firm received a cost efficiency score in year t. The mean cost efficient score over the sample period for each firm is calculated. Table 4 reports the distribution of the mean efficiency score. The predicted

TABLE 4 *Distribution of the predicted cost efficiencies*

Cost efficiency score	Firms	%	Cum. %
1.00–1.09	1	0.43	0.43
1.10–1.19	11	4.27	4.70
1.20–1.29	50	21.37	26.07
1.30–1.39	75	32.05	58.12
1.40–1.49	43	18.38	76.50
1.50–1.59	24	10.26	86.76
1.60–1.69	5	2.14	88.90
1.70–1.79	9	3.85	92.75
1.80–1.89	7	2.99	95.74
1.90–1.99	2	0.85	96.59
2.0–2.09	2	0.85	97.44
2.10–2.19	1	0.43	97.87
2.40–2.49	1	0.43	98.30
2.50–2.59	2	0.85	99.15
2.90–2.99	1	0.43	99.58
3.5	1	0.43	100.00
Total	234	100	

cost efficiencies ranged from 1.0 to 3.5. The higher value of cost efficiency represents the more inefficient firm. The mean cost efficiency of an average firm was estimated as 1.37, meaning that an average firm in the study incurred costs that are about 37% above the minimum cost defined by the frontier. That is, over 37% of the firm's resources are wasted in comparison to the best practice firms producing the same output and utilizing the same technology. When ranking firms by the mean cost efficiency, the cut points between Quartiles 1, 2, 3 and 4 (or the 25, 50, 75 and 100%) are 1.2974, 1.3741 and 1.4813, respectively.

5.3 *Cost efficiency migration analysis*

The migration of firms in terms of cost efficiencies is another research interest. In order to analyse the migration of a firm, the mean score 1.3741 is used as the benchmark. If a firm's predicted efficiency in time t is higher or lower than the benchmark, the firm is labelled as 'inefficient' or 'efficient', respectively. We followed only the first year and the last year of a firm. If a firm is efficient or inefficient in both years, the firm is classified as a 'maintainer' or a 'lagger', respectively. If a firm moves from inefficient to efficient, the firm is classified as a 'riser'. Otherwise, a firm is classified as a 'decliner' if it moves from efficient to inefficient. The number and percent of firms for the four classifications are reported in Table 5. It appears that 33% of the firms are not efficient in the beginning and continue to be inefficient; 35% of the firms maintain an efficient level from the first year.[3]

[3] Firms are also grouped into quartiles according to the predicted efficiency scores. Migration by quartile is available upon request.

TABLE 5 *Cost efficiency migration analysis*

Maintainers: 81 firms (35%)	Decliners: 41 firms (18%)
Risers: 34 firms (15%)	Laggers: 78 firms (33%)

TABLE 6 *Z variables by cost efficiency quartile*

Quartile	Firms	Mean efficiency	Labor–capital ratio	Price-cost margins	Financial leverage
Efficient	58	1.252	0.017	0.522	0.856
2	59	1.336	0.022	0.457	0.832
3	59	1.417	0.034	0.417	0.876
Inefficient	58	1.734	0.055	0.225	1.004

5.4 *Z variables and firm characteristics*

Table 6 reports the median values of the Z variables by quartile according to the cost efficiency score. The labour–capital ratio increases by quartile, supporting the theory that less efficient firms utilize more labour units to compete with or stay in the market. The price-cost margins, in contrast, decrease by quartile. They show that the high-efficient firms are able to maintain high price-cost margins and the less efficient firms sacrifice margins to compete. Finally, Table 6 shows that, in general, the financial leverage is quite high for the solar energy industry. The financial leverage ratio for the least efficient group appears to be more than one. Since the financial leverage ratios of Quartiles 1, 2 and 3 are all around 0.85, the differences appear not statistically significant.

5.5 *Relationship between cost efficiency and stock return*

The results of estimating equation (7) are reported in Table 7. The sign of the cost efficiency change, which is the focus of the equation, is negative as expected and is statistically significant at the 99% level. The coefficient of the cost efficiency term CE is not statistically significant. Table 7 also shows that there is no statistical difference in the results of the random effects model and the fixed effects model. The Hausman test shows p value >0.20, thus the null hypothesis cannot be rejected at a statistically significance level.

5.6 *Performance of buy-and-hold strategies portfolios*

Table 8 reports the results of the buy-and-hold strategy for all the formation years. A portfolio with the highest return in a formation year is highlighted in box. Of the 15 formation years, portfolios of Quartiles 3 and 4 (least efficient) appeared the highest for five times; in contrast, portfolios of Quartiles 1 and 2 only appeared two times. The average performance of Quartile 3 across all the formation years is 0.76 with the largest standard deviation 1.79. The inefficient portfolios together (Quartiles 3 and 4) outperform the efficient portfolios (Quartiles 1 and 2) 12 ($= 5 + 7$) out of 15 times.

The results are interestingly consistent with findings by previous literatures, such as Habib & Ljungqvist (2005) and Nguyen & Swanson (2009). The result is also consistent with the rationale in equation (7). The driving factor of the portfolios of Quartiles 3 and 4 to outperform Quartiles 1 and 2 is largely due to cost efficiency gains. Table 9 reports that during the 3-year holding period, inefficient firms slowly improve their efficiency level. The average cost efficiencies of Portfolio 3 improved

TABLE 7 *Cost efficiency versus stock return model estimation*

Variables		Random effects	Fixed effects
Intercept	θ_1	0.2714	0.2714
		(0.1870)	(0.1870)
$(\gamma_{mt} - \gamma_{ft})$	θ_2	0.9286***	0.9286***
		(0.0628)	(0.0628)
d(CE)	θ_3	−0.486***	−0.486***
		(0.2118)	(0.2118)
CE	θ_4	(0.1066)	(0.1066)
		(0.1289)	(0.1289)
BIC		4539.0000	4541.0000

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 8 *Three-year returns for all formation years*

Year	Efficient	2	3	Inefficient	All firms
1991	0.53	0.77	0.34	**0.78**	0.6
1992	1.52	1.49	**2.8**	0.86	1.51
1993	1.76	0.5	**2.23**	0.28	1.04
1994	1.05	**1.6**	1.11	0.53	1
1995	0.11	−0.14	0.24	**0.44**	0.18
1996	0.25	0.45	0.48	**0.86**	0.51
1997	**1.67**	1.07	0.86	0.69	1.12
1998	0.47	0.17	**0.61**	0.27	0.4
1999	−0.31	−0.17	−0.17	**−0.1**	−0.2
2000	−0.53	−0.32	−0.39	**−0.25**	−0.41
2001	−0.01	0.02	0.25	**0.42**	0.16
2002	0.23	0.39	**1.36**	0.64	0.66
2003	0.25	0.66	0.63	**0.82**	0.57
2004	0.08	0.03	**0.53**	0.01	0.13
2005	**0.16**	0.01	0.06	0.07	0.09
Mean	0.48	0.43	0.73	0.42	0.49
Std. dev.	1.35	1.11	1.69	1.33	1.48
Number of times	2	1	5	7	

TABLE 9 *Average cost efficiency scores during three-Year holding period*

	Year_1	Year_2	Year_3	Year_3–Year_1
Efficient	1.26	1.27	1.28	0.02
2	1.34	1.36	1.36	0.02
3	1.42	1.41	1.39	−0.03
Inefficient	1.67	1.67	1.65	−0.02

from 1.42 to 1.38, and Portfolio Inefficient improved from 1.67 to 1.65. Previous findings suggest that low efficient firms tend to have higher failure rates (Strotmann, 2006; Santarelli & Vivarelli, 2007). As a consequence, the remaining firms are forced to improve their efficiencies or increase the managerial incentives (Habib & Ljungqvist, 2005) to stay competitive.

6. Conclusions

Given the increasing significance of the solar energy industry, this paper is probably the first to document the cost efficiency levels of firms in the industry. It suggests that the variance in cost efficiency level is associated with firms' risk-bearing behaviour that shows on their price-cost margin and labour–capital ratio. It further discusses the impact of cost efficiency for stock returns. The change in cost efficiency, rather the cost efficiency itself, shows better informativeness for the stock returns. Finally, it asks whether the cost efficiency provides guidance for stock portfolio formation. A simple buy-and-hold strategy in the next 3 years following portfolio formation is examined. It finds that the average returns of the inefficient firm portfolios are higher than the efficient firm portfolios. This is largely driven by improvement in cost efficiency.

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Data Appendix

TABLE A.1 *Company accounting data are from COMPUSTAT North America: Financial Statements and Fundamental Annuals*

Variable name	Source & definition
Cost of Goods Sold (COGS)	Cost of Goods Sold. Source: Income Statement
Debt_Seq	Long-term Debt (DLTT). Source: Balance Sheet Sharehold Equity (SEQ). Source: Balance Sheet Debt_seq = DLTT/SEQ.
Inventories (INVT)	Inventories. Source: Balance Sheet
Labor_Capital	Labor = Number of employed in thousands. Source: Fundamental annuals; Capital (PPENT) = Total net property, plant and equipment, Labor_Capital = EMP/PPENT Source: Fundamental annuals-Balance Sheet
Labor_Rate	Labor Rate = (Total Operating Expenses − Cost of Goods Sold − interest payment)/Number of Employees = (XPOR − COGS − INT)/EMP Source: Fundamental annuals-Income Statement
LongTerm_Debt (DLTT)	Long-term Debt. Source: Balance Sheet
PCM†	PCM = (Net sales-COGS-Interest)/Net Sales = (SALE-COGS-INT)/SALE Source: Fundamental annuals-Income Statement
Revenue (REVT)	Revenue. Source: Fundamental annuals-Income Statement
Assets (AT)	Total Assets (AT). Source: Fundamental annuals
XPOR	Total Operating Expenses (XPOR). Source: Fundamental annuals-Income Statement

†The same definition in Harris (1986).