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# Which One is More Efficient? German or Japanese Automobile Industry: A Meta-frontier with Technology Gap Comparison

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**Abstract**

The goal of this paper is to compare the cost efficiency of the automobile industry in Germany and Japan during the period of 1980–2014 by applying the Meta-Frontier Cost Function. Despite the constant competition and the global automobile industry crisis during 2008-2010, only a few existing studies compare the efficiency of the industry cross countries. However, these all fail to address various types of technology adopted and the environment faced by automakers across countries. The meta-frontier model became a recognized and useful tool to evaluate technical efficiency of firms applying dissimilar technologies. Overall, the results signify that the cost efficiency of the German automobile industry by average is better than that of the Japanese one and the German one uses more superior production technique though it was lower the Japanese one in the 1980s. The difference reversed in the 1990s and has been enlarging since the 1990s to the end of the observation period.

**Keywords:** meta-frontier cost function, technology gaps, automobile industry, Germany, Japan

## 1. Introduction

Prior literature paid little attention to the management of the companies in the automobile industry; in particular, comparative studies on the productivity or efficiency of automobile companies in different countries are very rare and were mostly done decades ago. They provided some guidance on understanding the efficiency of the automobile industry. However, these previous studies failed to provide the evaluation of efficiency across countries. It is suggested that the environment faced by firms varies by regions and countries in many aspects such as regulations, the management, and production practices. Thus, previous studies are lack of identifying gaps on performances resulted from various levels of production technique used by automobile companies in different countries. Battese & Coelli (1992) and Battese et al. (2004) proposed meta-frontier functions which can effectively evaluate technical efficiency for firms applying dissimilar production techniques.

Examining the competitiveness of automakers in different countries is valuable for the management of global automobile industry in light of the fierce and constant competition among automobile companies world-wide. It has also become increasingly significant to study their efficiencies especially after the automobile industry crisis of 2008-2010. The automobile industry crisis of 2008–2010 was a part of a global financial downturn. The crisis affected European and Asian automobile manufacturers; however it has more significant negative impacts on the American automobile industry. The automobile industry was weakened by steep rises in the prices of fuels from 2003 to 2008 energy crisis which discouraged purchases of sport utility vehicles (SUVs) and pickup trucks which have low fuel efficiency. The popularity and relatively high profit margins of these vehicles had encouraged the American "Big Three" automakers, General Motors, Ford, and Chrysler to make them their primary focus. With fewer fuel-efficient models to offer to consumers, sales began to slide. When gasoline prices rose above $4 per gallon in 2008, Americans stopped buying the big vehicles and the Big Three sales and profitability plummeted. Consumers turned to smaller, cheaper, more fuel-efficient imports from Japan and Europe. Eventually, the above management and business practices forced Chrysler and General Motors into bankruptcy. Chrysler filed for bankruptcy protection on 1st May 2009, followed by General Motors four weeks later.

Volkswagen overtook Toyota in global vehicle sales for January-June 2015, the first time the German automaker had come out top in the intensely competitive tallies. General Motors (GM) Corporation was the top-selling automaker for more than seven decades until being surpassed by Toyota in 2008. GM retook the sales crown in 2011, when Toyota's production was interrupted by the quake and tsunami in northeastern Japan. Toyota made a successful comeback in 2012, and has been the world's top-selling automaker for the past three years (2012-2014). It appears that the ranking is still changing and the industry crown is coveted and significant. The aim of this paper is, therefore, to conduct a comparative research of the three largest German automakers and the five main Japanese automakers to evaluate these world leading carmakers' cost efficiency and the management performance.

It is of interest to conduct a cross-country comparison of the automobile industry in the two countries. Firstly, automakers in these two countries were in much better shape than those in the US which had been acquisitioned by foreign companies or taken over by the government during the crisis of 2008-2010. Secondly, it is also our motivation to evaluate how efficiencies of automakers in these two countries evolved during the past decades to enhance their competitiveness and performances to become top-selling automakers. The empirical evidence illuminates the future management of the industry and the government policy.

Contributions of this paper is that it is the first paper to emphasize comparing cost efficiencies of automakers in these two counties from 1980 to 2014 by using the meta-frontier approach which is more appropriate than traditional methods. The empirical evidences demonstrate that the average cost efficiency of the German automobile industry was better that of the Japanese one during the period of this study. The cost efficiency of the German automobile industry progressed steadily and surpasses the Japanese on over this period though the cost efficiency of the Japanese one was more superior to that of the German one in the beginning of the observation period.

The next section of this paper reviews the prior research and emphasizes the importance of applying the meta-frontier approach in cross country/region studies. Section 3 presents the econometric model, Section 4 briefly describes the data, Section 5 analyzes the empirical results, and Section 6 concludes the paper.

## 2. Literature Review

There are relatively few existing studies on automobile industry productivity or efficiency regardless of the importance of the industry in the economy and the daily life. Most of these focus only on firm-level or one-country issues. Such as Cusumano (1988) studied the Japanese auto industry evolution. Pries (1999, 2003) conducted the analytical study on firm-level car-manufacturer performances in Germany. Takeishi (2006) studied the management performance of the Japanese automobile industry. In addition, most previous studies adopted either a non-parametric or parametric methodology to assess cross-country automobile industry efficiencies. For instance, Fuss & Waverman (1990) examined both results of using the above approaches. They identified and proposed that the parametric cost-function model result is more useful. Lieberman et al. (1990) compared the productivity and management between Japanese and US automobile producers with conventional productivity techniques (the measurement of total factor productivity based upon the Cobb-Douglas production function). Oliver et al. (1996) collected the data by conducting the questionnaire survey throughout 71 auto component companies in 8 countries and analyzing their performances by employing SPSS software. Ark et al. (1993) presented the comparative productivity performance in manufacturing industry of Germany, Japan, and the US. They developed the "Unit Value Ratio" (a census concept of value added and commonly defined as gross value of output minus costs) and applied the expenditure-based PPP (Purchasing Power Parity) for international comparison. Denny et al. (1992) used the relative efficiency level (measured on a base of unity and is less than one if Country A's industry is relatively less efficient than Country B's industry. In other words, with the same resources, Country A is producing less output than Country B) to compare manufacturing industries in Canada, Japan and the USA. Although, they also recognized that there were serious limitations in attempting to calculate relative efficiency levels due to the lack of the adequate and appropriate data for internationally comparison.

Jorgenson & Kuroda (1992) studied the competitiveness of Japan and the US industrial productivity with emphasizing the data to be transformed through PPP as aforementioned for comparison. Thus, the relative efficiency (binary comparison), the PPP, and the parametric and non-parametric measures were widely applied in previous cross-country comparative researches. Other researches, such as: Jones & Paris (1978) is an earlier study of conducting international comparisons on motor industry. Muller (1992) compared the German and Japanese automobile industry management efficiency based on more than 250 interviews was analytical. Carr (1993) mainly used two factors: average return on capital employed (ROCE) and sales growth to compare the performances among British, German, Japanese and the USA's vehicle components industries. Though previous studies provided some guidance on understanding the efficiency of the automobile industry, they failed to assess the efficiency across countries, regions and industries. It is suggested that the environment faced by firms varies by regions and countries in many aspects such as regulations, the management, and production practices. Thus, earlier studies are lack of identifying gaps on performances resulted from various levels of production techniques used by automobile companies in different countries. The meta-frontier model was proposed by Battese & Coelli (1992) and Battese et al. (2004). This model can effectively evaluate technical efficiency for firms applying dissimilar production techniques.

It is very interesting to notice that the meta-frontier approach has not yet been applied in the automobile-industry related research though it has been employed in many fields in the past decade such as Bos & Schmiedel (2007), Chen & Song (2008), Matawie & Assaf (2008), Witte & Marques (2009), Mulwa et al. (2009), Moreira & Bravo-Ureta (2009), Assaf et al. (2010), Oh (2010), Kontolaimou & Tsekouras (2010), Lin (2011), Mariano et al. (2011), and Chen & Yang (2011). This highlights the significance of applying the meta-frontier approach to scrutinize the efficiency of global automakers from an unexplored perspective. The basic notion of the meta-frontier model is on the basis of the assumption that each firm is able to access to the indifferent production technique, however each may choose a different process, depending on specific circumstances, such as regulation, environments, production resources, and relative input prices.

In this paper, we construct the Cobb-Douglas cost function with the application of the meta-frontier approach proposed by Battese & Coelli (1992), and Battese et al. (2004). This approach is able to effectively measure technical efficiencies (CE) for automakers utilizing non-identical technologies and the technology gap ratios (TGRs). It further can identify how the cost frontiers of individual countries deviate from the meta-frontier cost function. The meaning of the technical efficiency is the capability of optimal use of available resources either by yielding maximum output for a given input combination or by employing minimum inputs to generate a given output (Lovell, 1993).

## 3. The Meta-frontier Cost Model

We postulate the model with the application of the regional stochastic frontier cost approach incorporated by Huang et al. (2010) and Liu & Chen (2012), with the framework of time-varying and inefficiency effects. Thus, for the *j*th country, the stochastic cost frontier model for the automaker *i* at time *t* can be presented below.

$$TC_{it(j)} = f(Y_{it(j)}, W_{it(j)}; \beta_j) e^{v_{it(j)}+u_{it(j)}},\ i = 1, \ldots, N,\ t = 1, \ldots, T,\ j = 1, \ldots, R \quad (1)$$

where $TC$ represents the realized total cost; $Y$, $W$ and $\beta$ represent the vector for outputs, input prices and unknown technology parameters, respectively. $v_{it(j)}$ is a random variable which is presumed to be $N(0, \sigma^2_{v(j)})$. Furthermore, the term $u_{it(j)}$ can be parameterized as follows according to Battese & Coelli (1992):

$$u_{it(j)} = u_{ij} \exp[-\eta_j \ (t - T)] \quad (2)$$

where $u_{it}$ is non-negative random variable which is assumed to account for cost inefficiency in production and is assumed to be iid (independent and identically distributed) as truncation at zero of the $N(\mu_j, \sigma^2_{u_j})$ distribution; $\eta_j$ is a parameter to be calculated. Also, a negative or positive value of $\eta_j$ signifies that the cost inefficiency of the *j*th type of firms increases or decreases over the time.

Independent variables of this cost frontier function therefore include one output and two input variables. In theory, due to the homogeneity constraint of cost functions, some properties can be evaluated consequently if the parameters are calculated and obtained. This model with panel data therefore can be written as follows:

$$\ln\left(\frac{TC_{it(j)}}{w_{1it(j)}}\right) = \beta_{0(j)} + \beta_{1(j)} \ln y_{1it(j)} + \beta_{2(j)} \ln\left(\frac{w_{2it(j)}}{w_{1it(j)}}\right) + u_{it(j)} + v_{it(j)} \quad (3)$$

where the unknown technology parameters $\beta$ of the Cobb-Douglas cost function can be calculated and obtained by adopting the maximum likelihood method (MLE). The estimation of cost efficiency ($CE_{it(j)}$) or overall economic efficiency ($EE_{it(j)}$) for the automaker *i* of the *j*th country in the year of *t* is measured by the ratio of frontier minimum cost to observed cost. That is to say that it can be estimated as $CE_{it(j)} = \exp(-u_{it(j)})$ and its value is between 0 and 1.

The concept of the meta-frontier approach proposed by Battese et al. (2004) suggests that there is merely one data-generation process for automakers producing cars with a given technology for each country. The overall cross-country data is individually generated from the respective frontier models in the different countries. The meta-frontier is assumed to take the same functional form as the individual stochastic frontiers in the different countries. The meta-frontier can be defined as a deterministic parametric function enveloping the deterministic parts of the individual cost frontiers such that its values must be less than or equal to the deterministic components of the stochastic cost frontiers of the different countries involved. Thus, the meta-frontier cost function model for the whole automakers concerned in the two countries can be displayed below:

$$TC_{\mathrm{it}}^{*} = f(Y_{it},\ W_{it};\ \beta^{*}),\ i = 1, \ldots, N,\ t = 1, \ldots, T \tag{4}$$

$TC_{\mathrm{it}}^{*}$ represents the optimal level of production cost by adopting the best available technology. $\beta^{*}$ represents the corresponding parameter vector of the related meta-frontier cost function. This function should satisfy the circumscription as shown in Equation (5) below:

$$f(Y_{it},\ W_{it};\ \beta^{*}) \leq f(Y_{it(j)},\ W_{it(j)};\ \beta_j) \tag{5}$$

The meta-frontier cost function model which is presented in Equation (5) projects the minimum possible production cost for generating a given level of outputs. That is to say, it is the minimum cost correlated to the most efficient production technique. The inequality restraint of Equation (5) is required to hold for the two countries and time periods. The meta-frontier is therefore, an envelope curve beneath the individual cost frontiers of the different countries. Thus, the meta-frontier cost efficiency ($CE_{it}^{*}$) for the automaker *i* in the year *t* can be estimated by the ratio of the meta-cost to the actual cost. This can be displayed in Equation (6) below.

$$CE_{it}^{*} = \frac{f(Y_{it}, W_{it}; \beta^{*})e^{vit(j)}}{TC_{it}} \tag{6}$$

The lower the $CE_{it}^{*}$ is, the actual output level automaker *i* is farther away from the meta-frontier cost and vice versa according to Equation (6). Furthermore, the term: the technology gap ratio (TGR) can be obtained from the right-hand side of the equation (6). In other words, $TGR_{it}$ indicates the technology gap ratio for automaker *i* of year *t* as displayed in Equation (7) below.

$$TGR_{it} = \frac{f(Y_{it}, W_{it}; \beta^{*})}{f(Y_{it(j)}, W_{it(j)}; \beta_j)} \tag{7}$$

$TGR_{it}$ estimates the technology-gap size for the country *j* whose present technology chosen by its automakers lags behind the technology available for all countries, represented by the meta-frontier cost function. The assessment of TGR uses the ratio of the potentially minimum cost that is defined by the meta-frontier cost function to the cost of the frontier function for country *j*, given the observed output and input prices. Also, equation (5) implies the value of the TGR is between zero and one. Therefore, the lower the average value of the TGR is for a country, the less advanced the production technology it adopts and vice versa.

The meta-cost efficiency measure of equation (6) can be rewritten as follows:

$$CE_{it}^{*} = CE_{it(j)} \times TGR_{it} \tag{8}$$

It is suggested that $CE_{it}^{*}$ is composed of two factors by Equation (8). One is the conventional technical efficiency measuring the deviation of an automaker's actual cost from the country specific cost frontier. The other is a new one measuring the deviation of the country specific cost frontier from the meta-frontier cost function. Both values of the CE and the TGR lies between zero and one so the value of $CE_{it}^{*}$ is also in the same range. The meta-cost frontier efficiency value of an automaker signifies how well it performs relative to the predicted performance of the best practice automakers that apply the best technology available for all countries to produce a given output mix. Thus, automakers operating on the meta-cost frontier serve as a benchmark for all automakers concerned because they adopt the best available technology during the production process.

To obtain the technology parameters estimates of $\hat{\beta}_j$, $j = 1, 2, \ldots, R$, we apply the stochastic frontier model which allows for temporal variant technical efficiency proposed by Battese et al. (2004). In addition, the estimates of $\hat{\beta}^{*}$ in the meta-frontier cost function can be obtained by employing two different mathematical programming techniques. These two techniques include one that is dependent on the sum of absolute deviations of the meta-frontier values from those of the country frontiers (minimum sum of absolute deviations), and the other depends on the sum of squares of the same distances (minimum sum of squared deviations).

The "minimum sum of absolute deviations" is also known as linear programming (LP). Vector $\hat{\beta}^{*}$ can be estimated by filling the $\hat{\beta}_j$ into the equations shown below:

$$\text{Min. } L \equiv \sum_{t=1}^{T}\sum_{i=1}^{N}\left|\ln f\left(Y_{it(j)}, W_{it(j)};\ \hat{\beta}_j\right) - \ln f(Y_{it}, W_{it}; \beta^{*})\right| \tag{9}$$

$$s.t.\ \ln f(Y_{it}, W_{it}; \beta^{*}) \leq \ln f\left(Y_{it(j)}, W_{it(j)};\ \hat{\beta}_j\right) \tag{10}$$

Clearly, the estimated meta-frontier vector minimizes the sum of the absolute logarithms according to Equation (9) and (10). The weights of the deviations for all automakers concerned are the same. Furthermore, equation

(9) indicates that all the deviations are positive and all the absolute deviations are exactly equal to the differences.

The "minimum sum of squared deviations" is to measure $\hat{\beta}^*$ by solving a quadratic programming (QP) issue. It can be presented in Equation (11) and (12) below.

$$\text{Min. } L \equiv \sum_{t=1}^{T}\sum_{i=1}^{N}\left[\ln f\left(Y_{it(j)}, W_{it(j)};\ \hat{\beta}_j\right) - \ln f(Y_{it}, W_{it}; \beta^*)\right]^2 \quad (11)$$

$$s.t.\ \ln f(Y_{it}, W_{it}; \beta^*) \leq \ln f\left(Y_{it(j)}, W_{it(j)};\ \hat{\beta}_j\right) \quad (12)$$

It is suggested that the lesser (or larger) the TGR is for an automaker, the lower (or higher) the weight it owns according to equation (11) and (12). It also indicates that the weights for each country are different.

The estimation of parameter $\hat{\beta}^*$ of the meta-frontier function can be obtained by employing the above two approaches. On the other hand, we use the bootstrapping method in calculating the standard errors of the meta-frontier function due to the fact that underlying data generation process is unknown. The bootstrapping method is to provide a better finite sample approximation according to Huang et al. (2010) because the analytic estimates of the standard errors of the estimators are difficult to obtain.

**4. Data Description**

Inputs and outputs variables of this paper are chosen with the application of the cost function approach. The total cost is the dependent variable. Independent variables include the input variable: price of labor, price of capital. These are quite standard and well-established in efficiency estimation (Bauer et al., 1998; Altunbas et al., 2000; Altunbas et al., 2001; Beccalli, 2004; Weill, 2004; Bos & Schmiedel, 2007). The price of labor is calculated as the ratio of salaries and benefits expenses to the number of employees.

Fuss & Waverman (1990) emphasized that the motor vehicle industry is characterized by quasi-fixed factors such as capital plant and equipment in the form of product-specific manufacturing facilities. These quasi-fixity manifests significantly affect measured cost and efficiency differences, we, therefore, calculate the price of capital as the ratio of the sum of depreciation, depletion, and amortization to the net value of property, plant, and equipment.

On the other hand, the output variable: sales revenue is also employed as an explanatory variable. Carr (1993) used sales revenue to evaluate performances of vehicle component companies. Sales revenue, in other words, as the value of gross output is also adopted by Ark et al. (1993) and Ito (2004) to measure the productivity as well.

All the data are downloaded from the *Datastream* (electronic data bank) and some others are supplemented form the annual reports of each company. In order to be consistent on the data during the period of this study, we chose the three largest German automakers and five main Japanese automakers (company names and their observation period are listed in Table 1).

Table 1. Sample Companies for the Empirical Estimation

| Country | Firm | Period |
|---|---|---|
| Germany | Volkswagen | 1980-2014 |
| | BMW | 1980-2014 |
| | Benz | 1980-2014 |
| Japan | Toyota | 1980-2014 |
| | Honda | 1980-2014 |
| | Mitsubishi | 1989-2014 |
| | Mazda | 1980-2014 |
| | Suzuki | 1991-2014 |

Table 2. Sample Statistics

| Variable | All sample | Group1-Germany | Group2-Japan |
|---|---|---|---|
| Total Cost | 3,124,043,673 | 64,293,024 | 5,196,777,983 |
| | (4,658,493,912) | (45,150,621) | (5,078,321,905) |
| Sales Revenues | 7,941,604,438 | 11,569,996,220 | 5,483,661,618 |
| | (18,660,486,242) | (28,293,580,995) | (5,473,550,503) |
| Price of Labor | 39,048.9467 | 266.7410 | 65,320.7635 |
| | (35,488.2580) | (130.0694) | (19,947.7500) |
| Price of Physical Capital | 0.1914 | 0.2516 | 0.1506 |
| | (0.0873) | (0.0766) | (0.0686) |
| Number of observations | 260 | 105 | 155 |

*Note*. Figures of the brackets represent the standard deviation.

Table 2 displays the descriptive statistics of the selected automakers in the Germany and Japan. Substantial differences can be identified from the means and standard deviation of variables from this Table. Automakers in the two countries could have adopted distinctly different technologies and production procedures so they generated non-identical products. That is to say, efficiencies and performances of automakers of these two countries were based upon various norms and by various measures and they should not be contrasted directly. This evidently supports the application of the meta-frontier model.

## 5. Empirical Results

This paper attempts to focus on comparing the overall cost efficiency in Japanese and German automobile industries by employing data of five main Japanese automakers and the three largest German automakers. The cost efficiency (CE*, CE, and TGR) of the individual firm is also produced and listed in the Appendix. The parameter estimates of the stochastic cost frontier for automakers in Germany and Japan are displayed in Table 3. The *LR* test method is adopted to examine the technological heterogeneity among various groups. We obtain that the value of *LR* test statistics is 179.8, which is significant at the 1% level by using the dataset of Germany, Japan and all sample. (Note 1) This indicates that the null hypothesis is rejected. In addition, this outcome corresponds with the assumption of our paper that automakers in Germany and Japan adopt different production technologies and own distinct frontiers. That is to say, if we do not take the above existing heterogeneity issue into account explicitly and only use regression analysis by combining the whole data, the result of the estimation cannot identify the technical relationship and the production properties of inputs and output precisely.

Table 3. Parameter Estimates of the Cobb-Douglas Cost Frontiers

| Variable | Group1-Germany | | Group2-Japan | | All sample | |
|---|---|---|---|---|---|---|
| Intercept | 8.6677 | *** | -2.4167 | *** | 9.4536 | *** |
| | (0.3124) | | (0.9333) | | (0.4069) | |
| lny | 0.0325 | *** | 0.7037 | *** | 0.0733 | *** |
| | (0.0101) | | (0.0468) | | (0.0106) | |
| ln(w2/w1) | -0.2915 | *** | 0.1997 | *** | 0.1758 | *** |
| | (0.0387) | | (0.0197) | | (0.0127) | |
| $\sigma^2(=\sigma_u^2+\sigma_v^2)$ | 0.7165 | | 0.1022 | *** | 1.6024 | *** |
| | (1.1569) | | (0.0120) | | (0.1748) | |
| $\gamma=\sigma_u^2/(\sigma_u^2+\sigma_v^2)$ | 0.9505 | *** | 0.7410 | *** | 0.9643 | *** |
| | (0.0804) | | (0.0701) | | (0.0068) | |
| $\mu$ | 0.5344 | | 0.5503 | *** | 2.4861 | *** |
| | (1.2077) | | (0.1643) | | (0.5069) | |
| $\eta$ | 0.0006 | | -0.0224 | *** | -0.0137 | *** |
| | (0.0026) | | (0.0063) | | (0.0021) | |
| Log likelihood function | 17.7857 | | 49.9724 | | -22.1475 | |
| LR test of the one-sided error | 219.9897 | | 46.1234 | | 468.7046 | |
| Number of observations | 105 | | 155 | | 260 | |

*Notes*.

1. Numbers in the brackets are the standard deviation.

2. ***significant at the 1% level.

Furthermore, a linear program (LP) is an optimization problem in standard form, in which all the functions involved are affine. The feasible set is thus a polyhedron, that is, an intersection of half-spaces. Polyhedral functions are functions with a polyhedral epigraph, and include maxima or sums of maxima of linear or affine functions. Such functions can be minimized via LP. Quadratic programs (QPs) offer an extension of linear programs, in which all the constraint functions involved are affine, and the objective is the sum of a linear function and a positive semi-definite quadratic form. QPs generalize both LPs and ordinary least-squares: the objective function is the same as in ordinary least-squares, and the problem includes polyhedral constraints, just as in LP. We, therefore, adopt the QPs and the QPs results are displayed and analyzed as follow.

Basic summary statistics of QP coefficient estimates and the bootstrapped standard deviation are shown in Table 4. In addition, the estimates of the cost efficiency and the technology gap with the application of QP parameter estimates are displayed in Figures 1 to 3.

The measure of the TGR and the relative cost efficiency to the stochastic frontier for individual countries: CE, and the meta-frontier efficiency score: CE* are reported in Table 5. The meta-frontier approach divides the CE* into CE and TGR. This provides in-depth insights on automakers' cost efficiencies. The observed cost efficiency and the technology adopted render more information for automakers' management and government authorities to examine the efficiency of the automobile industry operation, and contribute to improve their productivity. Additionally, this can be applied to evaluate the reallocation of their resources to where they are most needed. In other words, the distinct evidences can be a valuable guide to cost reduction and enhance the productivity by employing superior technology so as to improve the competitiveness of the automaker itself and the automobile industry.

Table 4. Estimates of the Meta-frontier Cost Function

| Coefficients | Quadratic programming (QP) | |
|---|---|---|
| | Estimates | Standard Errors |
| $\beta_0$ | 9.6572 | 0.2833 |
| $\beta_1$ | 0.2167 | 0.0314 |
| $\beta_2$ | 0.2305 | 0.0374 |

*Note*. The estimated standard error of the meta-frontier parameter is obtained by bootstrapping methods.

Table 5. Estimates of Cost Efficiencies and Meta-technology Ratios

| Country | Statistics | QP | | | |
|---|---|---|---|---|---|
| | | Mean | Min. | Max. | St. Dev. |
| Germany | | | | | |
| | $CE_{(i)}$ | 0.4916 | 0.2272 | 0.9371 | 0.3177 |
| | $TGR$ | 0.4965 | 0.1011 | 1.0000 | 0.2323 |
| | $CE^*$ | 0.2805 | 0.0308 | 0.9032 | 0.2614 |
| Japan | | | | | |
| | $CE_{(i)}$ | 0.6291 | 0.3665 | 0.8238 | 0.1233 |
| | $TGR$ | 0.4285 | 0.1970 | 1.0000 | 0.1894 |
| | $CE^*$ | 0.2513 | 0.1388 | 0.4505 | 0.0680 |
| All countries | | | | | |
| | $CE_{(i)}$ | 0.5735 | 0.2272 | 0.9371 | 0.2327 |
| | $TGR$ | 0.4560 | 0.1011 | 1.0000 | 0.2100 |
| | $CE^*$ | 0.2631 | 0.0308 | 0.9032 | 0.1743 |

For all automakers concerned in the Germany and Japan, the mean value of CE is 0.5735. The CE value for Japan is 0.6291 and the value for Germany is 0.4916. These values signify that the potential cost saving for the German automakers are about 50.84% on average of their actual costs. This could be attributed to the less efficient management on the cost reduction. On the other hand, the Japanese automakers on average lie near the cost frontier. The cost efficiency of the Japanese automobile industry is better than that of the German automobile industry. It indicates that there is still room for automakers in Germany to lower their costs greatly.

In terms of the TGR, the German automobile industry led the Japanese automobile industry and the gap increased over the observation period. Interestingly, the result is on the contrary to that of the CE, the German one is more superior with a higher TGR value. In other words, the Japanese automobile industry with the value of the TGR: 0.4285 is lower than the German one with the value of TGR: 0.4965. This indicates that the German one adopted more superior production techniques than the Japanese one did. Also, it implies that the Japanese one with the TGR value: 0.4285, could shave its frontier costs by up to 57% or so in the event that the potential technology available to both countries was applied. This distinctive evidence offers us a clearer picture in regards to levels of technology difference between the two countries. There indeed exists a technology gap between the German and Japanese automobile industry. The result indicates that automakers in Japan should make efforts to apply the potential technology available to both countries in order to shift its frontier cost function down to be more competitive.

Therefore, the above results of CE and TGR values of the two countries under study can be combined and obtain the mean cost efficiency relative to the meta-frontier, the value of the CE* for the German automobile industry: 0.2805 which is better than that of the Japanese automobile industry: 0.2513. This shows that overall the German automobile industry is more efficient than the Japanese one. Therefore, the Japanese automobile industry can make further efforts in improving its cost efficiency.

In a closer investigation on changes of their efficiency during the period of this study (see Figure 1), CE* values of the Japanese automobile industry move in a narrower range: between 0.15 and 0.30 while CE* values of the German automobile industry move in a relatively wider range and trend higher and higher over the years of the observation period: between 0.15 and 0.45. It is interesting to notice that values of CE* for the Japanese automobile industry were higher than that of the German one in most years of the 1980s however it improved little from then on. On the other hand, the Germany one significantly improved over the period of this study and surpassed the Japanese one since the late 1980s. Meanwhile, in regards to the impacts of the global automobile crisis on cost efficiencies in the two countries, CE* values in both countries performed very differently. The Japanese one deteriorated soon after the crisis though it recovered slowly between 2012 and 2014. The German one, on the contrary, greatly enhanced its efficiency during and after the crisis. The difference became ever large between these two during the period of this study (see also Figure 1).

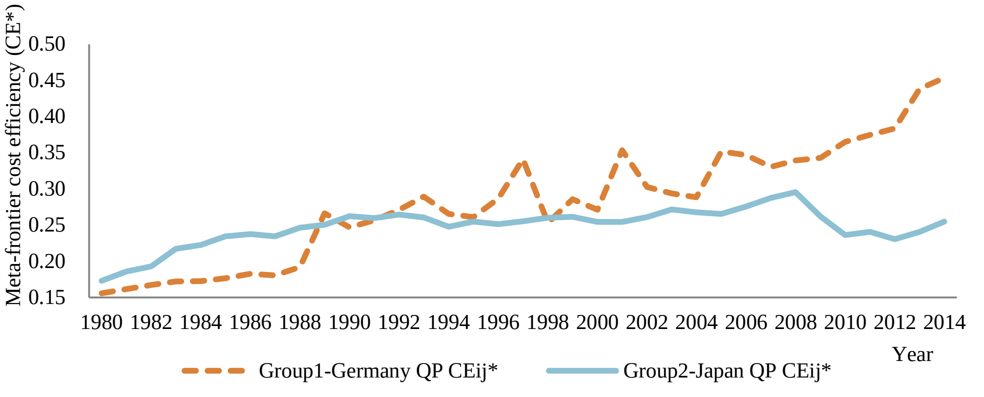


Figure 1. Mean Values of CE* for Automakers in the Two countries over 25 years

In Figure 2, the cost efficiency of the Japanese automobile industry (mostly above 0.53) led that of the German one (mostly below 0.50) with a difference throughout this period. However, the Japanese one is progressing downward significantly from 0.68 in the 1980s and the beginning of the 1990s while the German one shows little change during this period. It also shows that the CE values of Japanese automobile industry peaked in the beginning of the 1990s and then started a declining trend from the mid-1990s to 2014. On the other hand, the CE values of the German one remain unchanged before and after the global automobile crisis.

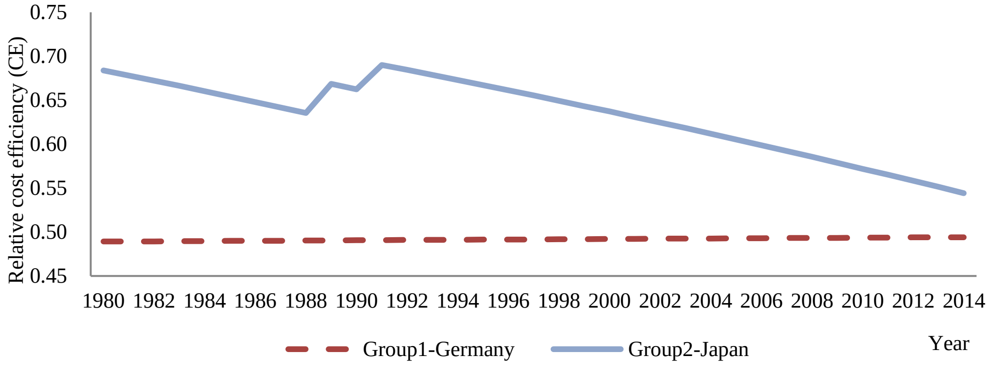


Figure 2. Mean Value of CE for Automakers in the Two Countries over 25 years

According to Figure 3, movements of TGRs in both countries are similar to those of CE*. The average values of TGRs in the German automobile industry were higher than those in the Japanese automobile industry aforementioned. TGR values of the Japanese one lagged behind those of the German one since the 1990s though it led the German one in the 1980s. TGR values of the Japanese one never caught up with those of the German one since the1990s. In addition, values of TGRs in the Japanese one dropped after the global automobile industry crisis but started picking up again after the year 2012. It appears that the German automobile industry quickly introduced more advanced production technique during the crisis to recover and maintain its competitiveness. Furthermore, values of TGRs changed drastically in the German one soon after the crisis. The gap between these two became the largest after the crisis.

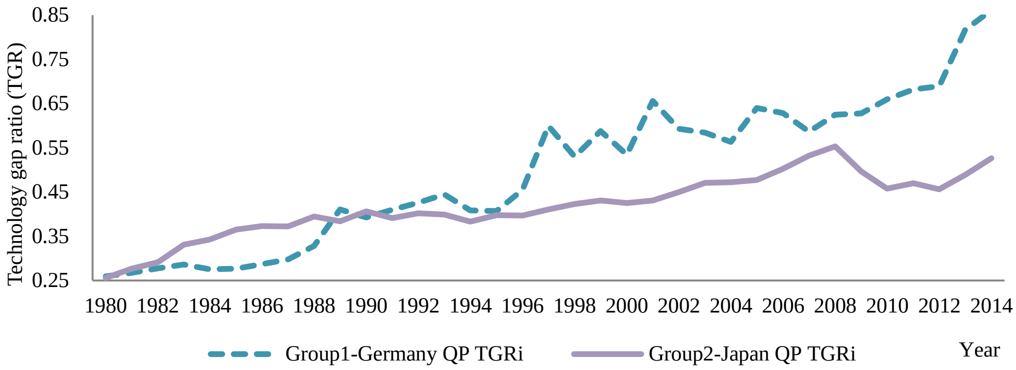


Figure 3. Mean Values of TGR for Automakers in the Two Countries over 25 years

To sum up, empirical results show the cost efficiency of the German automobile industry led that of Japanese automobile industry and the margin enlarged. It is worthwhile to note that values of CE* and TGRs of the Japanese one was better in the early years (1980s) of the observation period. However, the German one caught up with and surpassed the Japanese one since the 1990s with the increasing gaps. With the collapse of the USA's largest three automakers, the increasing efficiency of the German automobile industry has made it become more competitive while the Japanese one improved less during the period of this study. This also signifies that the Japanese automobile industry might have to make greater efforts in enhancing its cost efficiency higher in order to compete with the German one. In the perspective of the Japanese automobile industry, it has to keep adopting superior production techniques to compete with the German one in the long term. Its cost efficiency is lower than that of the German one and it needs to address the enlarging gap of the cost efficiency with the German one in order to maintain its competitive advantage.

Finally, the above empirical results may well have been reflected in the world automobile markets. Both automakers in Japan and German enjoy a sound reputation in quality while, generally speaking, the German automobile industry has a higher-technological image which can be attributed to the fact that it employs more advanced production techniques and has better cost efficiency in comparison with the Japanese one.

## 6. Conclusions

Previous studies on the efficiency of the automobile industry have contributed to a better understanding of its productivity and efficiency on firm or country level. However, they have not fully explored the critical question: how a firm can outperform foreign competitors.

This paper employs the meta-frontier approach to assess efficiencies of the automobile industry in the Germany and Japan from 1980 to 2014 in terms of the cost-efficiency and technology gap ratios. The meta-frontier approach can be used to differentiate the technology gap ratio (TGR) from the relative cost efficiency (CE) score and offers more information on automakers' cost efficiencies. Thus, this approach gains deeper insights by subdividing the measure of meta-frontier cost efficiency (CE*) into two factors: CE and TGR. The empirical evidences signify the automakers' management and governments' policies in the future.

The empirical result identifies that overall the average CE* of the German automobile industry led the Japanese one and the gap continuously increased during the period of this study. Although the technical efficiency or the relative cost efficiency (CE) of the Japanese automobile industry is higher than that of the German one in the 1980s, the difference is shrinking over the years.

The empirical investigation also indicates that values of TGRs in the Japanese automobile industry improved less over the period of this study and it deteriorated after the global automobile industry crisis though it recovered to some extent from 2012 to 2014. On the other hand, the German automobile industry sped up in employing more superior production techniques during and after the crisis to enhance its competitiveness. Therefore, values of TGRs jumped up sharply in the German automobile industry and formed the largest gap with those of the Japanese in the end of the period of this study.

It is intriguing to notice that the above findings may well have been reflected in the world automobile markets. Though German and Japanese automakers both enjoy a sound reputation in quality, the German automobile industry has a higher-technological image. This can be attributed to the fact that the German one employs more superior production techniques and has better cost efficiency in comparison with the Japanese one.

Finally, we can draw the conclusion that the Japanese automobile industry may have to improve its cost efficiency higher and adopt more advanced technology in order to compete with the German one from the future perspective of the automobile industry in these two nations, From the viewpoint of the German automobile industry, it does have a significant overall cost-efficiency (CE*) advantage over the Japanese one however it also needs to address the relatively lower cost efficiency (CE) issue to sustain its competitive advantage.

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## Notes

Note 1. The *LR* Test Statistics is calculated by the following equation: $\lambda=-2\{\ln[L(H_0)/L(H_1)]\}=-2\{\ln L(H_0)-\ln L(H_1)\}$. The $\ln L(H_0)$ of this equation is the log-likelihood-function value of the whole sample-country dataset in the model. Meanwhile, The $\ln L(H_1)$ is the sum of the Germany and Japanese log-likelihood-function values. λ is the Chi-squared distribution at 7 degrees of freedom.

## Appendix A

Table A. The Cost Efficiencies and Meta-technology Ratios of the Individual Firms

| Country | Firm | $CE_{(j)}$ | QP | |
|---|---|---|---|---|
| | | | *TGR* | $CE^*$ |
| Germany | Volkswagen | 0.2305 | 0.4259 | 0.0983 |
| | BMW | 0.9364 | 0.6607 | 0.6187 |
| | Benz | 0.3077 | 0.4029 | 0.1245 |
| Japan | Toyota | 0.5332 | 0.6863 | 0.3530 |
| | Honda | 0.5012 | 0.4635 | 0.2226 |
| | Mitsubishi | 0.7261 | 0.3394 | 0.2479 |
| | Mazda | 0.6799 | 0.2996 | 0.2019 |
| | Suzuki | 0.7763 | 0.2859 | 0.2208 |