Assessing the Resource Base of US and Japanese Auto Producers: A Stochastic Frontier Production Function Approach

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ABSTRACT

The "resource-based view of the firm" has become an important conceptual framework in strategic management but has been widely criticized for lack of an empirical base. To address this deficit, we use the econometric methodology of stochastic frontier production functions to assess sources of inter-firm differences in efficiency. Using data on Japanese and US automobile manufacturers, we develop measures of resources and capabilities and test for linkages with firm performance. The results show the influence of manufacturing proficiency (as indicated by the level of WIP inventory) and scale economies at the plant and firm level. We apply the parameter estimates to account for Toyota's superior efficiency relative to General Motors and other producers.

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1. Introduction

In recent years strategic management scholars have expressed enormous interest in the resource-based view (RBV) of the firm. This perspective regards the firm as a heterogeneous bundle of resources—some superior and others perhaps inferior—plus organizational capabilities that may enable the firm to deploy its resources more efficiently than rivals. Variation in the quality of resources and capabilities leads to the generation of economic rents, which may appear as differences in profitability. Such performance differentials can persist for years or even decades when imitation is impeded.[1]

Despite its appeal as a conceptual framework, the RBV has often been criticized for lack of an empirical base. Few researchers have been able to develop measures of resources and capabilities, identify their importance in a specific industry context, and link firms' resource positions to dimensions of performance.[2] In this paper we attempt such an investigation, using historical data on Japanese and US automobile companies.

To implement our study, we utilize a new methodology from the econometrics literature. Recent advances in the estimation of stochastic frontier production functions (SFPFs) provide a framework for identifying firm-specific effects and testing hypotheses regarding the sources of inter-firm differences in efficiency. In this paper we develop measures of auto company resources and capabilities and assess their impact on firm performance, using a SFPF model. We demonstrate that SFPF methods can be useful for giving empirical content to the resource-based view of the firm.[3]

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[1] See, for example, Barney (1986), Rumelt (1987), Dierickx and Cool (1989), and Peteraf (1993).
[2] There have nonetheless been a number of important efforts in this direction, including Henderson and Cockburn (1994) and Helfat (1997).
[3] A prior study by Dutta, Narasimhan and Rajiv (1998) also uses SFPF methods to give empirical content to the RBV; however, unlike the present work they utilize a two-stage estimation approach. In the first stage, SFPF models are estimated to assess firms' capabilities relative to frontiers in three functional areas:

The performance measure in our SFPF model is labor productivity, which differs from (but is correlated with) the profit rates more typically considered by strategic management researchers.[4] From the standpoint of economic welfare, productivity is a more fundamental metric. Productivity gains, adjusted for capital investment, flow to numerous stakeholders: consumers (if prices fall), workers (if wages rise), and shareholders (if profits grow). Profits can be a misleading indicator of business performance when comparisons are drawn across countries where competitive conditions differ. Indeed, among the automotive companies in our sample, Toyota is commonly regarded as a superior competitor, yet Toyota's profit rates fall below those of General Motors, considered a poor performer in recent decades.[5]

The international automotive industry provides a rich and dynamic context for assessing the determinants of firm performance. Previous studies have demonstrated striking differences in efficiency among auto producers in Japan and the US (Womack, Jones and Roos, 1990; Lieberman, Lau and Williams, 1990). Toyota, for example, has maintained manufacturing superiority for decades, whereas GM, once the world's most efficient automaker, now lags behind its major rivals. As a group the Japanese caught up to and surpassed the American level of labor productivity in the 1970s. Later, Ford and Chrysler revitalized while several of the Japanese firms stagnated, thus confirming that productivity differences stem from firm-specific rather than national factors.

To explain such differences among producers and shifts over time, our study incorporates measures of firm-level resources and capabilities that might be expected to play a large role in the auto industry. These include investment in plant and equipment, firm size and scale of plant, degree of vertical integration, and proxies for skills in manufacturing and product design.

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marketing, R&D and operations. In the second stage, Tobin's Q and other financial performance ratios are regressed on the capability measures. While such multi-stage methods may be necessary to incorporate financial measures of performance, the single-equation approach of the present study is simpler and more direct.

[4] Banker et. al (1996) and Lieberman and Chacar (1997) characterize the relation between productivity and profitability and give examples for firms in the telecommunications and automotive industries.

[5] Over the period from 1983 to 1997, the ratio of operating income (after depreciation) to sales was slightly higher, on average, for General Motors (6.0%) than for Toyota (4.9%). Nevertheless, Toyota has been

The organization of this paper is as follows. Section 2 introduces our auto company measures in the context of the resource-based view. We first compare the productivity performance of Japanese and US automotive firms and then consider how the companies have differed in various dimensions of resources and capabilities. Section 3 presents the stochastic frontier production function model and describes how our measures are incorporated. Section 4 presents the estimation results. In Section 5 the estimates are used to make inter-firm comparisons. We show, for example, that Toyota's efficiency advantage over GM has been largely due to superior manufacturing proficiency and plant-level economies of scale. Section 6 demonstrates that the factors identified in our analysis have also influenced profitability. A final section summarizes the findings and concludes.

2. Auto Company Performance and the Resource-Based View

This study aims to explain differences in auto company performance based on measures that capture firms' resource positions and their evolution over time. Our sample includes eight Japanese automobile manufacturers and the "Big-Three" American producers from the mid-1960s through 1997.[6] In this section we describe the measures used in the study and their connection with resource-based view of the firm.[7]

2.1. Value-added per Worker (Labor Productivity)

The dependent variable in our study is labor productivity, defined as real value-added per worker. For each firm and year, real value-added was computed by dividing

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enormously profitable by Japanese standards: in each year since 1983, Toyota's operating income has exceeded the operating income of all other Japanese automakers combined.

[6] The sample includes all of the major firms that produced passenger cars under their own name in the US and Japan with the exception of Mitsubishi, for which the data are incomplete. For Honda, we omit observations prior to 1975, when the firm's output consisted primarily of motorcycles. The initial year of the other Japanese producers varies slightly, depending on data availability.

[7] The Japanese financial and employment data are from annual issues of the *Daiwa Analysts' Guide*, with supplementary detail for the 1965-1976 period obtained directly from Daiwa Securities Corporation. These Japanese data are limited to domestic motor vehicle operations. The US data are from the companies' annual financial reports and *Compustat*. For US firms, the data on value-added, employment, and capital investment include international operations, as it was not possible to identify values specific to automotive businesses in the United States.

nominal value-added[8] by the domestic producer price index for motor vehicles.[9] Yen values were converted to US dollars using purchasing power parity exchange rates.[10] Dividing by employment gives value-added per worker, $(Y/L)_{it}$, a standard measure of labor productivity.

Figure 1 plots this measure for each of the eleven companies. It shows that the labor productivity rankings of the companies have changed considerably over time. In the mid-1960s the average labor productivity of the Big-Three was roughly twice the Japanese level. By the early 1970s Toyota and Nissan had caught up to the Americans, and by the late 1970s all of the Japanese firms had done so. Moreover, starting in the early 1980s, Toyota began to exhibit labor productivity substantially higher than that of all other firms (with the possible exception of Honda). Concurrently, General Motors began to fall behind its major rivals, becoming the producer with lowest labor productivity during much of the 1990s.

To explain these differences in performance, we developed a series of resource measures. Barney (1991) has proposed that resources contribute to sustained competitive advantage only when they are rare, valuable, difficult to imitate, and difficult to substitute. Many of the resources identified in our study satisfy these criteria. Moreover, most of our measures show persistent differences among firms over long periods of time. Some measures also exhibit gradual convergence, suggesting a slow process of imitation.

2.2. Investment per Worker

Worker productivity normally rises with investment, reflecting the substitutability of capital for labor. This basic relation is standard in productivity studies. Over the three decades of our sample the auto companies substantially upgraded their plant and

[8] Value-added equals the firm's sales during the fiscal year, minus the costs of purchased materials and services. This is equivalent to the sum of all payments to labor and capital, plus indirect taxes. For the Japanese companies, we used value-added figures provided by Daiwa Securities Corporation. For the US companies, we computed value-added by summing the factor payments.

[9] For Japan, we used the domestic wholesale price deflator for transport equipment from Bank of Japan, *Price Indexes Annual*. For the US, we used the Bureau of Labor Statistics producer price index for passenger cars.

equipment, as automated machinery replaced human effort in many areas of vehicle assembly. Given advances in robotics, for example, operations such as body welding and painting are now almost completely automated.

Figure 2a plots our estimates of real capital stock per employee (*K/L*) for the Japanese companies; Figure 2b gives equivalent values for the American producers.[11] In Japan, capital stock per employee rose steadily from the mid-1960s through the late 1980s. Many international comparison studies have attributed the Japanese productivity advantage in manufacturing industries to higher investment per worker (e.g., Norsworthy and Malmquist, 1981; Jorgenson and Kuroda, 1992). The graphs suggest that capital stocks in the Japanese automotive industry ultimately reached a plateau, although Toyota, the most capital-intensive firm, has continued to invest.

The pattern for the US is very different from that shown for Japan. Figure 2b shows that for the US producers, there was virtually no growth in capital stock per worker until the late 1970s, when investment began to accelerate. This shift was particularly strong for Chrysler, whose capital stock per worker roughly quadrupled.[12] GM's investment rate has lagged behind that of Chrysler and Ford, whose fixed capital per employee began to exceed the average Japanese level by the mid-1990s. Thus, the gap in capital investment that existed between American and Japanese automakers in the late 1970s and 1980s was eventually eliminated.

By conventional standards, a firm's stock of plant and equipment would be considered an important resource. It does not, however, qualify as such under the RBV as it fails to meet Barney's criteria: a larger capital stock (per worker) is neither rare,

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[10] These PPP rates are based on OECD estimates for the 1980s (OECD, 1987), which were extrapolated (using the relative price indexes for the two countries) to cover all years of the sample.
[11] We constructed a real capital stock series for each firm using a perpetual inventory capital adjustment equation: $K_t = (1\text{-}d)\, K_{t-1}$ + *deflated gross investment*, where gross investment is defined as the change in the firm's undepreciated capital stock since the preceding year, and *d* is the rate of economic depreciation, which we assumed to be equal to 10%. For Japanese firms, we deflated gross investment using the gross domestic expenditure deflator for non-residential investment reported by the Economic Planning Agency. For US firms, we used the GDP deflator for non-residential fixed investment from the 1998 *Economic Report of the President*. Our measure with 10% depreciation rate is consistent with a weighted average over asset categories of the economic depreciation rates reported by Hulten and Wykoff (1981). Results were similar for alternative measures of capital stock.

difficult to imitate, nor difficult to substitute. An automotive firm cannot gain a sustained competitive advantage by simply increasing its rate of investment. Therefore, we include the capital stock per worker, *K/L*, as essentially a control variable in our study.

2.3. Firm Size

Economies of scale are significant in the automotive industry. Such economies arise at the firm level and also at the plant level. One indicator of the importance of firm-level scale economies is the huge number of automotive mergers that have occurred in recent years, continuing a trend stretching back to the early days of the industry.[13] Larger firm size allows for potential cost savings in vehicle and engine production, as well as product design and marketing. Surprisingly, scale economies have seldom been regarded as a "resource" in the RBV literature. Nevertheless, as we argue below, scale advantages often satisfy Barney's criteria, and they are among the key sources of competitive advantage in the automotive industry.

One measure of firm size is total employment. (In our statistical analysis we test employment and vehicle output as alternative proxies for firm-level scale economies; these measures are incorporated into different components of the SFPF model.) Figure 3 plots the annual number of employees on a logarithmic scale, which shows the enormous differences in firm size across our sample. Daihatsu, Fuji, Isuzu and Suzuki have remained very small; their employment has always been below 20,000. By comparison, GM's (worldwide) employment has exceeded 600,000 for decades. These size differentials have been remarkably persistent; it would seem virtually impossible for the small Japanese producers to achieve the scale of Toyota or the Big-Three, except via merger.

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[12] For Chrysler, the initial growth came from reductions in employment, followed a few years later by an increase in investment.

[13] In the 1990s most automotive mergers were international. A prime example is the acquisition of Chrysler by Daimler Benz in 1998. In Europe, Ford acquired Jaguar and the car division of Volvo, GM acquired Saab, BMW acquired Rover, and Volkswagen acquired SEAT and Rolls Royce. Japanese firms largely resisted these trends until late in the decade when Toyota acquired Daihatsu, and Ford and Renault took operating control of Mazda and Nissan. For much of their history, the smaller Japanese automakers have maintained alliances with larger producers, who have held equity stakes.

Greater firm size can be categorized as a strategic resource, based on Barney's criteria. The prevalence of mergers, as well as statistical evidence presented later in this study, demonstrates that larger scale is valuable in the automotive industry. Scale is also rare in the sense that only a few firms (e.g., GM, Ford, and perhaps Toyota) may have reached a fully-efficient size. The persistent differentials shown in Figure 3 attest to the difficulty of imitation. While small firms can substitute for some of the benefits of greater firm size by striking alliances with other automakers (e.g., joint marketing agreements are common, and shared plants are occasionally built), such arrangements are imperfect. Thus, firm-level economies of scale would seem to satisfy all of Barney's criteria. Indeed, we argue that larger firm size is one of the key resources in the automotive industry.

2.4. Plant Size

Our analysis distinguishes between firm-level and plant-level economies of scale. Engineering studies (e.g., Pratten, 1971) once indicated that plant-level economies are effectively achieved above a threshold volume of about 200,000 annual vehicles per assembly plant. In the 1960s, however, the Japanese modified the conventional organization of automotive assembly plants by combining on-site stamping with two or more vehicle assembly lines to give a much higher-volume plant. If this new plant organization is more cost-effective, we should find efficiency gains related to output per plant above the 200,000 range.

Figure 4 plots the average vehicle output per domestic assembly plant for the firms in our sample.[14] It shows that Toyota has maintained the largest plant scale, with output in the range of 400,00 to 800,000 vehicles per plant. The Big-Three fall in the lowest range, reflecting their policy of allowing plants to proliferate once annual volume reaches about 200,000 units. GM remains the world's largest vehicle producer, but

[14] For each firm these values were obtained by dividing total domestic production of vehicles by the number of domestic assembly plants. Data on vehicle production and manufacturing plants are from company annual reports, *Wards Automotive Reports*, and the Japanese Automobile Manufacturers Association.

almost all of the Japanese firms have operated their assembly plants at higher average volume than GM since the early 1980s.

As a potential resource, larger plant scale satisfies Barney's criteria. Figure 4 shows that high-volume plants are comparatively rare, and we later provide statistical evidence that they are valuable. Such plants are also difficult for competitors to imitate; GM, for example, is locked by historical investment into a plant configuration that cannot easily be converted to Toyota-style plants. Thus, plant-level scale economies represent a potentially important source of competitive advantage for Toyota and a few other Japanese producers. Moreover, the relative magnitude of plant-level versus firm-level scale economies raises a vital managerial issue: if plant-level economies are key, then medium-sized firms such as Honda may be able to forego mergers if they can maintain advantages at the level of individual manufacturing plants.

2.5. Shop floor manufacturing capabilities

Toyota's competitive superiority has generally been attributed not to plant-level economies of scale but rather to the firm's manufacturing proficiency on the shop floor. Toyota pioneered its revolutionary production system in the 1950s and has been refining its methods ever since (Fujimoto, 1999). Key features of the Toyota production system were adopted throughout Japan in the 1970s, spreading to the US about a decade later.

For our statistical analysis we require a measure of manufacturing capabilities. One common indicator of proficiency on the shop floor is the level of work-in-process (WIP) inventory. Prior studies have shown that the WIP/sales ratio reflects the "leanness" of the firm's production system and serves as a proxy for adoption of "just-in-time" manufacturing practices.[15]

Figure 5 plots the WIP/sales ratio for the automakers in our study. Toyota, which began its campaign to cut inventories during the late 1950s, had the lowest WIP levels in

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[15] For a sample of 52 Japanese automotive suppliers and assemblers, Lieberman and Demeester (1999) show that WIP reductions preceded productivity gains, and lower WIP levels were associated with higher labor productivity. See also Womak *et al*. (1990).

the 1960s and 1970s and is tied with Honda in later years. Several other Japanese assemblers, including Mazda, Daihatsu, Fuji Heavy Industries and Suzuki, had large and widely-fluctuating inventories in the late 1960s and early 1970s. By the late 1970s these fluctuations were eliminated in Japan as manufacturing processes were brought under control, and inventory levels were trending downward. The one exception is Fuji (Subaru), whose WIP inventory ratio remained the highest in Japan and began rising again in the late 1980s.[16]

Furthermore, Figure 5 shows that in the 1960s the WIP levels of US producers were in the highest range of the Japanese, orders of magnitude above Toyota, where they remained until the early 1980s. Over the next decade, however, WIP inventories fell substantially in the US as the Big-Three began to understand and adopt the Japanese manufacturing practices.[17]

Superior shop-floor capabilities confer significant strategic advantage in a manufacturing-intensive industry such as autos, where they satisfy Barney's criteria. Prior studies have validated the WIP/sales ratio as an indicator of manufacturing proficiency, whose value is obvious for an automotive firm. Figure 5 shows large inter-firm variation and persistence in this ratio, although magnitudes have been converging as lean production methods have become standard in the auto industry. Nevertheless, the skill levels represented by Toyota and a few others remain rare.

2.6. Vertical Integration

Historically, an important difference between Japanese and US auto companies has been their degree of backward integration into parts production. The Americans, led by GM, maintained substantial in-house parts manufacturing operations, whereas the Japanese assemblers have been known for extensive subcontracting and close

[16] The WIP inventories of Fuji Heavy Industries, Nissan and GM (Hughes) have been adjusted to remove inventory related to aerospace products, which have much higher WIP requirements than auto assembly.

[17] The inventory data are not quite comparable for the US and Japanese producers. In their financial reports, the US companies give a single combined figure for WIP and raw materials inventory, which causes the US inventory ratios to be overstated in our sample. Using Census data, which separates these

collaboration with suppliers. Thus, firms in the two countries have maintained very different types of capabilities with respect to the interface with parts production. In the early years of the auto industry vertical integration was considered a superior strategy, but as the industry has matured the advantage has shifted to Japanese-style subcontracting (Womack, Jones and Roos, 1990; Dyer, 1996).

Prior studies suggest that the automotive assemblers differ in their capabilities in dealing with suppliers (whether independent or in-house), and that these differences have a significant impact on firm performance (Helper and Sako, 1995; Dyer, 1996). Unfortunately, we lack measures of such capabilities that can be tested in our statistical model. We can, however, observe each firm's degree of vertical integration, as indicated by its annual value-added as a proportion of sales (V/S). To avoid spurious correlation with short-term output changes, we take a lagged, four-year moving average of this ratio, which is shown in Figure 6.

For many years the US automakers had about twice the integration ratio of the Japanese assemblers. Since the late 1980s, however, there has been a convergence, as the Japanese have increasingly integrated backward while the Americans have shed their internal parts operations. Indeed, shortly after the end of our sample in 1997, GM and Ford spun-off their parts divisions as independent companies, leaving the parent firms with integration levels comparable to the Japanese.

We include the value-added/sales ratio in our analysis as it is our only measure relating to the firm's interface with suppliers. Nevertheless, we do not claim that the degree of vertical integration, *per se*, represents a meaningful set of resources or capabilities from the standpoint of the RBV. It seems likely that the auto companies continue to differ in their proficiency in dealing with suppliers, even though integration levels have now substantially converged in the US and Japan.

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two types of inventory, Lieberman and Asaba (1997) show that the average WIP/sales ratio of US auto assembly plants may now be slightly lower than in Japan.

2.7. Product Design

Product development and design represents another important area of automotive operations where firms differ in their capabilities (Clark and Fujimoto, 1991; Nobeoka and Cusumano (1997); Cusumano and Nobeoka, 1998). Design performance has multiple dimensions, including development time and cost, rate of new product introduction, and degree of product appeal to consumers. Comprehensive data on these dimensions are not available, but we were able to collect information on superior design quality as perceived by the staff of *Car and Driver* magazine, a trade publication. In annual issues beginning in January 1983, *Car and Driver* has identified a set of "10 best cars" from the regular production models sold in the US.[18] The criteria used by *Car and Driver* emphasize final product quality rather than design capabilities; nevertheless, we found award rates to be highly correlated with adoption of the "rapid design transfer strategy" identified by Nobeoka and Cusumano (1997) as a superior approach for multi-product design and development.

Table 1 shows the number of winners by year for the firms in our sample. Honda, Nissan, Toyota and Mazda have accounted for a nearly half of all winning vehicles since 1983. Honda, in particular, has been an outlier in these ratings, accounting for more than twice as many "top 10" cars as any other firm.[19]

2.8. Cumulative output

Models of the "learning curve" or "experience curve" commonly use cumulative output as a proxy for the level of organizational learning (Argote, 1999). In effect, the overall capabilities of the firm or business unit are assumed to be an increasing function of its cumulative output. This relation has been found to be approximately linear in logarithms, so that the rate of learning tends to diminish over time. While learning

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[18] The selection criteria include multiple categories such as "design," "ride," "value," "driveability," and "handling."

[19] Data from Nobeoka (1993) show that Honda used the "rapid design transfer strategy" for 35% of its new models over the 1980-91 period, more than twice the rate of the number two firm (Toyota). Unfortunately, Nobeoka's data on product development strategy are available for too short a period to be included in our analysis.

curves are commonly observed in many industries, the locus of accumulated knowledge is often unclear; it may be at the level of specific plants, or firms, or the industry as a whole. For this study we derive a measure of learning at the firm level, based on the cumulative historical production of vehicles by each firm.[20]

Figure 7 plots the logarithm of cumulated output (ΣQ) for each of the companies over the sample period. All three US firms had substantial production prior to the 1960s, so their subsequent growth is incremental. The Japanese producers began with low levels of cumulative output and experienced rapid growth, particularly in the early years of the sample. Toyota ultimately surpassed the cumulative volume of Chrysler, but otherwise most of the company rankings are stable over time. Throughout the sample period, GM remains the most "experienced" firm.

Cumulative output is an extremely general measure of organizational capabilities, and hence the link with the RBV is ambiguous. The measure reflects the early disadvantage and rapid growth of Japanese producers; however, their "stock" of experience remains well below that of GM and Ford through the end of the sample period. We include cumulative output in our study because it has been a standard approach in the literature, and it is conceivable that such a generalized measure of capabilities may be superior to the more specific measures presented above.

2.9. Correlation matrix

Table 2 presents a correlation matrix of the measures in the study. Many of the measures are strongly correlated, in large part because they are trended over time. Net of trend, the correlations are much lower, but they reduce our ability to distinguish among effects in the SFPF model. Moreover, some SFPF specifications failed to converge.

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[20] We collected information on the annual number of motor vehicles (excluding motorcycles) produced by each firm since 1920. We then computed ΣQ in two different ways: first, by taking a simple cumulative sum of historical output through the start of each year, and second, by allowing the stock to annually depreciate by 10% or more. The latter recognizes that organizational "forgetting" occurs, as documented by Argote, et. al (1990) and Benkard (1999). With higher rates of depreciation this measure becomes virtually equivalent to current output, or firm scale. Experiments with inter-firm "spillover" learning failed to yield meaningful results.

3. Stochastic Frontier Production Function Model

In this study we use the Stochastic Frontier Production Function methodology as our primary investigative technique.[21] This framework assumes the existence of a best practice frontier corresponding to fully-efficient operation in the industry under investigation. The objectives of the methodology are to estimate the shape of this frontier and identify factors that cause individual firms to fall below it.

Specifically, the SFPF model has the following structure. We first specify an idealized deterministic, parametric production possibility frontier common to all firms. This frontier defines the maximum level of output that can be obtained from any vector of resource inputs in the absence of uncertainty. To this frontier we add a stochastic component that consists of two types of disturbance or error terms. The first is a regular *symmetric* disturbance that represents statistical noise in a typical regression. This term captures the effects of occurrences such as successful or unsuccessful advertising campaigns, strikes, damaged products, etc., that affect the production outcome. Thus, it is hypothesized that the realized production of a firm is bounded above by the sum of the parametric production function and the symmetric random error term. This is the stochastic production frontier. The second disturbance or error term, which is firm specific, is a *one sided* deviation from this idealized frontier, and is referred to as technical *inefficiency*. The greater the amount by which the realized production falls short of the stochastic frontier, the greater the level of technical inefficiency.[22]

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[21] The SFPF technique was independently developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van der Broeck (1977). In addition to SFPF, the econometrics literature offers three techniques for the analysis of productive efficiency: Total Factor Productivity (TFP) Indices, Data Envelopment Analysis (DEA), and Least-Squares Econometric Production Models. The DEA approach, which is based upon linear programming methods, is suitable for analysis of multi-output production such as hospital and banking services. DEA does not, however, provide any statistical inference for estimated parameters. The SFPF and least squares methodologies allow for such inference with respect to factors that potentially determine the productivity. The SFPF approach has the further advantage that it incorporates a model of the inefficiency effects that allows inter-firm differences to be examined. For an overview and comparison of these methodologies, see Coelli, Rao and Battese (1998).

[22] Greene (1993) contains a detailed survey of different econometric techniques for estimating SFPF and the accompanying technical efficiency.

Given a sample of N firms for T time periods, the stochastic frontier production frontier model can be written as:

$$Y_{it} = F(K_{it}, L_{it} : b)\ e^{Vit}\ e^{-Uit} , \qquad (1)$$

where Y_{it} denotes output for the i-th firm in the t-th time-period. The production possibility frontier has the functional form *F(.)*, where K_{it} and L_{it} are the capital and labor inputs of firm *i* in period *t*, and *b* is a vector of unknown parameters to be estimated.[23] Equation (1) contains two error terms, V_{it} and U_{it}. The V_{it}'s are the independent and identically distributed symmetric, random errors, which have a normal distribution with mean zero and unknown variance σ^2_v. The U_{it}'s are the one sided, non-negative unobservable random variables associated with the technical inefficiency of production, such that, for a given technology and levels of inputs, the observed output falls short of its potential output. The U_{it}'s are assumed to be distributed as non-negative truncations of the normal distribution with unknown variance σ^2.

In this study we assume that *F(.)* has a Cobb-Douglas functional form, with technical progress that occurs at a constant rate *m* over time i.e.,

$$F(K_{it}, L_{it} : b) = e^{m\,t} K_{it}^{\ b_1} L_{it}^{\ b_2}. \qquad (2)$$

The time trend reflects the potential outward movement or growth in the frontier after controlling for the factors that can be observed in the data.[24]

The stochastic frontier specification can be written in per-capita terms by combining Equations (1) and (2), taking logarithms, and dividing by labor, as:

$$\ln (Y/L)_{it} = m\,t + q\ \ln (K/L)_{it} + g\ \ln (L)_{it} + V_{it} - U_{it} , \quad (3)$$

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[23] We follow the standard economics convention in regarding labor and capital as the principal resource inputs in the production function of the firm. The list of resources could be expanded (e.g., energy and materials inputs are sometimes included in economic studies), and labor and capital could be subdivided into categories, given suitable data.

[24] We chose the Cobb-Douglas production function specification as it is a commonly used functional form, which can be consistently estimated using single equation methods [see Zellner, Kementa and Dreze (1966)]. We also tried a trans-log specification, but the model failed to converge.

where *Y* represents value added, *K* is the capital use by the firm, *L* is the number of employees, and V_{it} and U_{it} are the random variables described above. The coefficient, *q*, which is equal to b_1, is the elasticity of output with respect to capital. The coefficient, *g*, which is equal to b_1+b_2 -1, represents the deviation from constant returns to scale or the "excess" scale parameter, where a positive value of *g* signifies increasing returns to scale.[25]

The dependent variable in this transformed model is value added per employee, or labor productivity. Thus, Equation (3) allows a statistical assessment of potential determinants of labor productivity. The production function links labor productivity to capital and labor resource inputs; we expect that productivity will rise with investment per worker (*K/L*), and possibly with the size of the firm (*L*). In addition, labor productivity will be influenced by the other resources and capabilities of the firm, as represented by the factors in U_{it}.

To test various measures in U_{it}, we utilize the technique introduced by Battese and Coelli (1995), which allows estimation of firm-specific effects and tests of hypotheses regarding the determinants of inter-firm differences in efficiency. Battese and Coelli specify technical inefficiency effects U_{it}'s as following:

$$U_{it} = z_{it}\, d + W_{it}\,, \qquad (4)$$

where z_{it} is a vector of explanatory variables collected in our study. Here, δ is a vector of unknown parameters to be estimated and W_{it}'s are unobservable random variables[26].

Next, the technical efficiency (*TE*) of the i-th firm in the t-th year is defined as:

$$TE_{it} = exp\,(-U_{it}) = exp\,(-z_{it}\, d - W_{it}) \qquad (5)$$

[25] The per capita specification, (3), is equivalent to (2), and we obtained identical results for both forms. Prior SFPF studies (e.g., Caves and Barton, 1991) have commonly used the per-capita form, which reduces potential heteroskedasticity and has the advantage that the dependent variable can be interpreted as labor productivity.

[26] W_{it}'s, which are assumed to be independently distributed, are obtained by truncation of the normal distribution with mean zero and unknown variance, σ^2, such that U_{it} is non-negative (i.e. $W_{it} \geq -z_{it}\delta$). In other words, the technical inefficiency effects can also be interpreted as independent non-negative truncations of normal distributions with unknown variance, σ^2, and means, $z_{it}\delta$.

The technical efficiencies are predicted using the conditional expectations of $exp(-U_{it})$ given the composed error term of the stochastic frontier (cf. Battese and Coelli (1995)). Following the suggested parameterization by Battese and Coelli, we define $\sigma^2_S \equiv \sigma^2 + \sigma^2_v$ and $\gamma \equiv \sigma^2/\sigma^2_S$, and we estimate σ^2_S, γ, vector β and δ by maximum-likelihood estimation (MLE) methods.

We incorporate the various measures of capabilities within the technical inefficiency component of the stochastic frontier as follows:

$$U_{it} = d_0 + d_1 \ln (W/S)_{it-1} + d_2 \ln (Q)_{it} + d_3 \ln (\Sigma Q)_{it} + d_4 \ln (Q/N)_{it} + d_5 \ln (V/S)_{it-1,4} + d_6 \ln (CD)_{it} + W_{it} \ , \quad (6)$$

where W/S_{it} is the work-in-process inventory to sales ratio, Q_{it} is the total number of motor vehicles produced by the firm in its home market during year t, ΣQ_{it} is the firm's cumulative domestic vehicle production through the start of year t, Q/N_{it} is the average vehicle output per assembly plant in year t, $V/S_{it-1,4}$ is the four-year moving average of the value-added to sales ratio, and CD_{it} is a two-year moving average of the number of citations awarded the firm by *Car and Driver*.[27] A positive value of the *d* coefficient associated with any of these variables indicates that as the level of that variable goes up, the level of technical *inefficiency* also goes up and vice-versa. For example, a positive coefficient for *W/S* implies that technical inefficiency rises with the level of WIP inventory. We expect, potentially, a positive coefficient for *W/S* and negative coefficients for *Q/N*, *CD*, *Q* and ΣQ. The sign for *V/S* is not clear from a theoretical standpoint.

We attempt to distinguish among sources of economies of scale, which may arise at the plant level, or the firm level, or both. If scale economies arise at the plant level, we should find higher efficiency for firms with larger average output per assembly plant $(Q/N)_{it}$. If scale economies exist at the firm level, they may appear as a positive

[27] Given that all CD_{it} values are zero prior to the start of the *Car and Driver* ratings, we included a separate dummy variable (set equal to 1 for these early years, and zero otherwise).

regression coefficient for total labor input in the production function ($\gamma > 0$), or as an efficiency effect ($d_2 < 0$) related to the firm's annual vehicle output, Q_{it}.

4. Results

Table 3 gives maximum likelihood estimates of the parameters of the SFPF model, as specified by the production function in (4) and the technical inefficiency effect defined by equation (6). All regressions include the parameters of the production function and the WIP/sales ratio in the inefficiency model, given the strong link between WIP inventory and manufacturing productivity documented in prior studies. Each equation adds additional inefficiency factors to this basic specification. In light of the correlation among measures, we add these factors individually and in various combinations.[28]

4.1. Stochastic Frontier

The first three parameters in Table 3 relate to the production frontier, which defines the maximum potential output of each firm at any point in time. The frontier is specified as a function of firms' labor and capital inputs and is assumed to be shifting outward at a constant rate over time.

Across the regressions in Table 3, the capital elasticity coefficient, q, averages approximately 0.3, which implies that a 10% increase in capital per worker led to a 3% increase in output. The "excess" returns to scale parameter, γ, is about 0.09, indicating significant increasing returns to scale in the production function (i.e., a 10% increase in firm size was associated with an increase of 0.9% in output per worker). The time trend, m, is positive and significant, implying that the frontier level of efficiency shifted outward at an average annual rate of about 2.5% per year. This can roughly be interpreted as the rate of growth of total factor productivity associated with the industry frontier. The

[28] The model failed to converge with some combinations of parameters. We were, for example, unable to include total vehicle output and average output per plant in the same regression. (These measures are correlated as they differ only by the count of assembly plants.)

estimated parameters of the production frontier change only slightly with different specifications of the inefficiency model.

4.2. Inefficiency Model

The coefficients of the explanatory variables in the inefficiency model, δ, are of prime interest in this study. They allow tests of hypotheses regarding capabilities that enable firms to approach the frontier level of efficiency. They also provide quantitative indicators of the determinants of inter-firm differences in efficiency.

The coefficient, δ_1, is positive in all regressions and generally highly significant, implying that higher levels of WIP were associated with lower levels of efficiency, as expected. The coefficient falls when the measures of volume per plant and vertical integration are added, probably due to colinearity.

Regression 1 includes the total number of vehicles produced by the firm in each year, a potential indicator of firm-level economies of scale. (It can be viewed as an alternative to the scale economies denoted by the parameter γ in the production frontier.) The associated coefficient, δ_2, has the expected negative sign but is insignificant. Thus, we find evidence of firm-level economies of scale in the production function ($\gamma > 0$) but not in the inefficiency term.[29]

Regression 2 includes the *cumulative* number of vehicles produced, the proxy for learning curve effects. Its coefficient, δ_3, is not statistically significant. This suggests the absence of any simple connection between cumulative output and efficiency for the firms in our sample. Moreover, the sign of the coefficient is positive, signifying that more "experienced" firms were less productive. This result may be unsurprising, given that General Motors was the "most experienced" firm through the end of the sample period.[30]

[29] When the production function is specified as constant returns to scale (i.e., when γ is omitted from the specification), δ_2 becomes significant. Thus, if excluded from the production function, firm-level scale economies show up as part of the inefficiency model.

[30] Insignificant coefficients were also obtained when we modified the learning measure to incorporate depreciation of knowledge. In addition, we tried truncating the measure above arbitrarily-defined thresholds in order to eliminate the difference between GM and other firms with very large cumulative output, but this did not eliminate the lack of significance and "wrong" sign of the variable.

We conclude that firm-level cumulative output does not serve as an effective proxy for organizational learning among the automotive companies in our sample.

The coefficient for average vehicle output per assembly plant indicates the extent to which scale economies arose at the plant level. In all specifications, δ_4 is negative and highly significant, indicating that efficiency was higher for firms that produced more vehicles per plant. Thus, there is strong evidence of plant-level economies of scale. By operating plants at high rates of vehicle output, smaller firms could potentially enjoy greater overall scale economies than their larger rivals.

Regressions 4, 5 and 7 include the value-added/sales measure of backward integration into parts production. This measure is weakly significant when included with volume per plant. The positive sign of δ_5 implies that more integration into parts production was associated with greater inefficiency. This is consistent with current views on the advantages of subcontracting, and the recent shedding of in-house parts production by GM and Ford. As noted earlier, the value-added/sales measure provides no information on firms' proficiency in dealing with suppliers, whether located in-house or at arms-length. Such skills may be more important than the degree of integration, *per se*.

The measure of design quality collected from *Car and Driver* is included in regressions 6 and 7, but it is statistically insignificant. Thus, there is no evidence that firms with more quality awards had higher levels of efficiency. We also obtained insignificant results for a quality measure obtained from issues of *Consumer Reports*.[31]

To summarize the findings in Table 3, our estimates of the production function show that greater capital investment led to higher labor productivity, as expected. Moderate economies of scale existed at the firm level, and the best practice frontier was shifting gradually, presumably as the result of technical progress not captured by the factors in our model. Furthermore, estimates of the efficiency model show the presence of scale economies at the plant level, and a strong connection between WIP inventory and

[31] *Consumer Reports* gives annual automobile ratings with an emphasis on reliability and frequency of repair. For each manufacturer, we recorded the proportion of models that received a "recommended" rating in each year.

efficiency. Less conclusive evidence suggests that firms with more vertical integration were less efficient. There is no indication of a general "learning curve" effect or a link between firm efficiency and our Car and Driver measure of design quality.

4.2. Japan-only Sample

Conceivably, the results in Table 3 may be influenced by US-Japan differences in financial reporting. All measures for the Japanese companies are limited to operations within Japan, whereas financial measures for the Big-Three include international operations. In addition, accounting procedures and diversification differ somewhat between countries. Therefore, we also estimated the SFPF model using only the data for the Japanese companies, which constitute the bulk of our sample. These results are presented in Table 4.

The estimates for Japan are qualitatively similar to those for the combined sample, but they differ in a number of ways. In Japan, the frontier level of efficiency rose at an average annual rate of about 4% per year (versus 2.5% for the combined sample) which is consistent with technological catch-up by the Japanese. The capital coefficient is smaller for the Japanese sample, perhaps because investment growth in Japan was strongly correlated with time ($r = 0.9$). Compared with Table 3, scale economies in Japan appear greater at the firm level (γ) but smaller at the plant level (δ_4). The WIP inventory coefficient is larger and highly significant in all Japanese specifications. However, the sign of the vertical integration measure is the opposite of Table 3, and the design quality measure approaches significance, but with the "wrong" sign. These differences may be due to the fact that for some measures, such as *L*, *W/S* and *V/S*, much of the variance occurs between the US and Japanese companies. But on the whole, the two sets of estimates are similar enough to suggest that those for the full sample are not spurious.

5. Explaining Differences in Performance Among Firms

5.1. Toyota versus GM

We now apply the parameter estimates from Table 3 to draw comparisons among firms. One challenge is to account for the substantial differences in performance that have existed between Toyota and General Motors since the 1970s. Figure 8 plots the estimated technical efficiency of Toyota and GM in each year, based on the coefficients in regression 5. The top margin of this graph corresponds to the efficiency frontier. Our estimates imply that Toyota has operated close to the frontier since the late 1970s, whereas GM has been falling away from the frontier.

Table 5 demonstrates how the regression coefficients can be linked with the underlying data to draw comparisons among firms. The calculations in the table provide a breakdown of the labor productivity differential between General Motors and Toyota, based on the average values of the relevant variables for the two producers over the 1965-97 period. The first three columns of the table show that GM and Toyota differed substantially along the dimensions considered in this study. On average, GM's output (value-added) per worker was only 62% of Toyota's. GM had more than 13 times as many employees as Toyota, but with only 79% as much investment per worker. GM's assembly plants had about one-fourth the average volume of Toyota's. Within its plants, GM held about ten times more WIP inventory, as a fraction of sales. GM also maintained substantially more backward integration into parts production: internal operations represented 46% of final sales revenue for GM, as compared with 18% for Toyota.

Taking the logarithm of these ratios and multiplying by the applicable regression coefficients, it is possible to make an estimate of the contribution of each factor in explaining the overall differential in output per worker.[32] The results of these calculations are shown in the final columns of Table 5. The labor productivity

[32] Note that the regression, composed of equations (3) and (6), is linear in logarithms for the variables of interest. The difference between Toyota's and GM's output per worker, log Y/L, is equal to differences in the (logged) explanatory variables multiplied by their respective estimated regression coefficients, plus the difference in prediction errors (or the unexplained portion). In Table 5, we convert the data into logarithms, take differences in the values for Toyota and GM, and plug them into the regression equation.

differential between Toyota and GM equals -0.48 in log terms. Based on the coefficients from regression 3 of Table 3, this differential can be attributed about equally to Toyota's superior positions relating to WIP inventory (-.29) and output per plant (-.23), with an additional small effect due to Toyota's higher investment (-.09). Our estimates suggest, however, that these disadvantages were partly offset by GM's greater economies of scale at the firm level (+0.24).[33] Thus, the four factors in combination may account for about three-fourths (=0.37/0.48) of the labor productivity differential between GM and Toyota. A similar calculation, including the effect of vertical integration, is shown in the last column of the Table, based on the coefficients from regression 5. Inclusion of the vertical integration measure leads to a drop in the WIP effect, which no longer appears as the most important explanatory factor.

5.1. Toyota versus Others

The contrast between GM and Toyota is perhaps the most dramatic in our sample, but similar comparisons can be drawn between Toyota and other rivals. Figure 9 shows the results when the calculations from Table 5 are applied to the other companies. On average during the 1965-97 period, Toyota enjoyed substantial advantages in labor productivity relative to most producers based on nearly all of the factors considered in this study: capital investment, firm and plant scale, and WIP. From the graph it appears that Toyota's largest advantages have been related to plant-level economies of scale. Toyota suffered disadvantages in firm-level scale economies relative to US producers, but enjoyed such advantages relative to its Japanese rivals.

6. Connection to Profit Rates

As a supplementary analysis, we investigated whether the efficiency factors identified in the SFPF model were linked to company profits, the performance dimension

[33] GM's advantage in firm scale is likely to be overestimated, as the calculation compares GM's worldwide employment with the domestic employment of Toyota. Also, it is possible that scale economies may be diminishing over the range of firm sizes in our sample which would also lead to an overestimate of the GM-Toyota differential. Otherwise, the estimates in Table 2 imply large but offsetting scale economy advantages at the firm versus plant level.

typically addressed by the resource-based view. To perform this analysis we regressed the rate of operating profit on the resource and capability measures.

Table 6 presents the regression results. The dependent variable is the firm's annual operating profit, net of depreciation, as a proportion of value-added.[34] The explanatory variables include the measures tested previously in the SFPF model, plus control measures to adjust for the strong cyclicality of profits in the automotive industry. These consist of the two-year growth rate of domestic vehicle production, and the one-year growth rate of the firm's own sales. We also include a dummy variable to capture differences in average profit rates between the two countries. Despite the inclusion of controls for cyclical fluctuations, the regression error terms are serially correlated. On the assumption that this autoregression is first-order, we report AR1 estimates, which were qualitatively similar to the standard OLS.

In Table 6 the cyclical controls are highly significant, as expected. The US dummy is positive, denoting higher rates of profit for US firms, net of other factors. While investment per worker contributed positively labor productivity, it was negatively associated with operating profits. The table also shows a significant link between profits and economies of scale, but unfortunately, correlation among measures makes it impossible to determine whether the relevant economies are at the firm level, plant level, or both. In particular, "number of vehicles produced" and "volume per plant" appear positive and significant only when one measure is included without the other. Less ambiguous is the effect of WIP/sales, whose coefficient is consistently negative and significant, implying a connection between profits and manufacturing proficiency. The value-added/sales ratio is generally negative, suggesting that integration into parts production was a drag on profits; however, the coefficient is insignificant. The *Car and Driver* design quality measure is also insignificant. These findings suggest that the key factors identified in the SFPF analysis of auto company efficiency also had an impact on firm profitability. Most importantly, profits were positively related to manufacturing proficiency and some type of economy of scale.

[34] Similar results were obtained using net operating profit as a fraction of sales. Using value-added in the denominator has the advantage that it adjusts for differences in vertical integration.

7. Conclusions

In this study we have shown that the methodology of stochastic frontier production functions offers a promising approach for elaborating the resource-based view of the firm. The SFPF framework allows identification of an industry's best practice frontier and the factors that may cause individual firms to fall below it. Using the quantitative estimates of the model, comparisons can be drawn among firms.

Our SFPF analysis has identified several types of resources and capabilities that account for much of the variation in firm efficiency in the international automotive industry. These include capabilities on the manufacturing shop floor (as indicated by the level of WIP inventory) and economies of scale at both the plant and firm level. These factors also appear to be linked to firm profitability.

Other differences among firms appear less important, perhaps because our measures are poor proxies for firms' true capabilities. The findings suggest that more integrated firms are less efficient, which is consistent with recent decisions by US automakers to shed their parts operations. However, our measures are unable to capture firms' capabilities in dealing with suppliers (whether in-house or arms-length), which may be more critical than vertical integration, *per se*. Moreover, we did not observe significant effects relating to product design, and we found no evidence of a general "learning curve" for organizational capabilities related to firm-level cumulative output.

Barney (1991) has noted that in order to provide a sustained competitive advantage, resources must be rare, difficult to imitate, valuable and appropriable. Few would question that proficiency on the manufacturing shop floor is consistent with these criteria. Our classification of firm and plant scale as "strategic resources" may be more controversial. Yet as we have argued, in the automotive industry such scale-based advantages fit Barney's criteria. Indeed, the frequency of global automotive mergers in recent years attests to the continuing importance of firm-level economies of scale.

Furthermore, we have shown that the SFPF model can be used to draw inter-firm comparisons. Our estimates suggest that Toyota's labor productivity advantage over GM stems mostly from Toyota's skills in shop floor manufacturing and plant-level economies of scale. Across the full sample of producers we have drawn similar comparisons. These imply that in aggregate, differences in firm capabilities have been much more important than capital investment in accounting for differences in labor productivity.

Our approach points to important differences in the use of the term "resources" in the fields of economics and strategic management. Economists generally regard capital and labor as the primary resources of the firm. By comparison, under the RBV of strategic management, capital and labor are regarded as essential resource inputs, but not as strategic resources that confer competitive advantage. (Together, however, these inputs define the scale of the firm, which is a source of advantage in the automotive industry and others.) In our SFPF approach we have taken a traditional economic perspective by specifying the production function in terms of aggregate capital and labor. Yet the production function is a general concept that can be expanded to accommodate a range of more specific inputs. One way to conceptualize the SFPF model in the context of the RBV is to consider "resources" (both strategic and non-strategic) as inputs defining the production frontier, whereas "capabilities" determine firms' efficiency of resource use and hence may be considered as components of the inefficiency model.

These findings, based on the SFPF methodology, add empirical content to the resource-based view and help to illuminate the sources of performance variation in the automotive industry. Nevertheless, numerous caveats apply. Given the limitations of our data, important categories of capabilities are omitted from the model. Those that are included are represented by proxies, and the resulting coefficients may be subject to measurement biases. While we believe the SFPF methodology is useful, the development of better measures remains a continuing challenge for research relating to the resource-based view.

References

Aigner, D.J., C.A.K. Lovell, and P. Schmidt (1977). Formulation and estimation of stochastic frontier production function models, Journal of Econometrics 6, 21-37.

Argote, L. (1999). Organizational Learning: Creating, Retaining and Transferring Knowledge, Kluwer, Boston.

Argote, L, S.L. Beckman and D. Epple (1990). The persistence and transfer of learning in industrial settings, Management Science, 36, 140-154.

Banker, R. D., H. H. Chang and S. K Majumdar (1996). "A Framework for Analyzing Changes in Strategic Performance," Strategic Management Journal 17:9 693-712.

Barney, J. B. (1986). "Strategic Factor Markets: Expectations, Luck, and Business Strategy." Management Science 32: 1231-1241.

Barney, J. B. (1991). "Firm Resources and Sustained Competitive Advantage." Journal of Management 17(1): 99-120.

Battese,G.E.and T.J. Coelli (1995). A model of technical inefficiency effects in a stochastic frontier production functions for panel data, Empirical Economics 20, 325-332.

Benkard, C. L. (1999). "Learning and Forgetting: The Dynamics of Aircraft Production," NBER working paper #W7127.

Car and Driver. Diamandis Communications, New York, January issues, 1983-98.

Caves, R. E., and D. Barton (1991). Efficiency in U.S. Manufacturing Industries, MIT Press, Cambridge, MA.

Clark, K. and T. Fujimoto (1991). Product Development Performance: Strategy, Organization and Management in the World Auto Industry, Harvard Business School Press, Boston, MA.

Coelli, T.J., Rao and G. Battese (1998). An Introduction to Efficiency Analysis, Kluwer.

Cusumano, M. and K. Nobeoka (1998). Thinking Beyond Lean: How Multi-Project Management Is Transforming Product Development at Toyota and Other Companies, Simon and Schuster, New York?.

Daiwa Securities Research Institute (annual issues). Analyst's Guide. Tokyo, Japan.

Dierickx, I., and Karl Cool (1989). “Asset Stock Accumulation and Sustainability of Competitive Advantage.” Management Science 35: 1504-1511.

Dutta, S., O. Narasimhan and S. Rajiv (1998). “Success in High Technology Markets: Is Marketing Capability Critical?” Marketing Science, forthcoming.

Dyer, J. H. (1996). “Does governance matter? Keiretsu alliances and asset specificity as sources of Japanese competitive advantage, Organization Science, **7**(6), 649-666.

Fujimoto, T. (1999). The Evolution of a Manufacturing System at Toyota, Oxford University Press, New York.

Greene, W.H. (1993). The econometric approach to efficiency analysis, in H. Fried, C.A.K. Lovell and S. Schmidt (eds), The Measurement of Productive Efficiency: Techniques and Applications, Oxford University Press, Oxford.

Helfat, C. (1997). “Know-how and Asset Complementarity and Dynamic Capability Accumulation: The Case of R&D.” Strategic Management Journal 18(5): 339-360.

Helper, S. R. and M. Sako (1995). “Supplier Relations in Japan and the United States: Are They Converging?” Sloan Management Review (Spring): 77-84.

Henderson, R., and I. Cockburn (1994). “Measuring Competence? Exploring Firm Effects in Pharmaceutical Research.” Strategic Management Journal 15(Special Issue): 63-84.

Hulten, C. R. and F. C. Wykoff (1981). The Measurement of Economic Depreciation, in C. R. Hulten, ed., Depreciation, Inflation, and the Taxation of Income from Capital, The Urban Institute Press, Washington.

Jorgenson, D. W. and M. Kuroda (1992). “Productivity and International Competitiveness in Japan and the United States, 1960-1985,” Economic Studies Quarterly, 43, December, pp. 313-325.

Lieberman, M. B., and Shigeru Asaba (1997). “Inventory Reduction and Productivity Growth: A Comparison of Japanese and US Automotive Sectors.” Managerial and Decision Economics 18: 73-85.

Lieberman, M. B., and A. Chacar (1997). “Distribution of Returns Among Stakeholders: Method and Application to US and Japanese Auto Companies,” in H. Thomas and D. O’Neal, eds., Strategic Discovery: Competing in New Arenas, Wiley, 1997, pp. 299-313.

Lieberman, M. B., and L. Demeester (1999). “Inventory Reduction and Productivity Growth: Linkages in the Japanese Automotive Sector,” Management Science, 45(4): 466-485.

Lieberman, M. B., L. Lau, and M. Williams (1990). "Firm-Level Productivity and Management Influence: A Comparison of U.S. and Japanese Automobile Producers." Management Science 36.

Meeusen, W.J. and van der Broeck (1977). Efficiency estimation from cobb-douglas production functions with composed error, International Economic Review 18, 435-444.

Nobeoka, K. (1993). "Multi-project Management: Strategy and Organization in Automobile Product Development," unpublished Ph.D. Dissertation, MIT Sloan School of Management.

Nobeoka, K. and M.A. Cusumano (1997). "Multiproject Strategy and Sales Growth: The Benefits of Rapid Design Transfer in New Product Development," Strategic Management Journal 18(3): 169-186.

Norsworthy, J. R. and D. H. Malmquist (1981). "Input Measurement and Productivity Growth in Japanese and U.S. Manufacturing," American Economic Review, 73(5), December, pp. 947-967.

OECD, Department of Economics and Statistics (1987). Purchasing Power Parities and Real Expenditures, 1985, OECD,Paris.

Peteraf, M. (1993). "The Cornerstones of Competitive Advantage: A Resource-based View." Strategic Management Journal 14: 179-191.

Pratten, C. F. (1971). Economies of Scale in Manufacturing Industry, Cambridge University Press, Cambridge.

Rumelt, R. (1987). Theory, Strategy, and Entrepreneurship. The Competitive Challenge: Strategies for Industrial Innovation and Renewal. David Teece, ed. Ballinger, Cambridge.MA.

Womack, J. P., D. T. Jones and D. Roos (1990). The Machine that Changed the World: The Story of Lean Production, Rawson Associates.

Zellner, A., J. Kementa and J. Dreze (1966). Specification and estimation of Cobb-Douglas production functions, Econometrica 34, 784-95.

Table 1.

Count of Car and Driver "Best 10 Cars" Ratings

	GM	Ford	Chrysler	Toyota	Nissan	Mazda	Honda	Total for sample firms
1983	2	1	0	1	0	1	1	6
1984	2	0	1	1	0	1	2	7
1985	3	1	1	0	0	0	3	8
1986	1	2	0	1	0	0	2	6
1987	2	2	0	1	0	1	2	8
1988	1	2	0	0	0	0	5	8
1989	1	3	0	0	0	0	3	7
1990	0	1	0	1	2	2	3	9
1991	1	2	0	0	0	0	5	8
1992	1	1	0	2	2	1	1	8
1993	0	1	2	2	2	1	1	9
1994	0	1	1	1	2	1	3	9
1995	0	1	1	1	2	1	3	9
1996	0	1	2	0	2	0	3	8
1997	0	1	2	1	0	0	2	6
1998	1	0	1	1	0	1	2	6
Total	15	20	11	13	12	10	41	122
Total 1983-89	12	11	2	4	0	3	18	50
Total 1990-98	3	9	9	9	12	7	23	72

Source: *Car and Driver*, January issues.

Note: Rating applies to cars in previous year. For our SFPF analysis, we took the average count reported in the observation year and the following year.

TABLE 2: CORRELATION MATRIX

		t	Y/L	K/L	L	Q	Q/P	W/S	V/S	CumQ	C&D
Time	t	1									
Value-added per employee	Y/L	0.9	1								
Capital stock per employee	K/L	0.9	0.9	1							
Number of employees	L	-0.01	0.1	0.1	1						
Domestic vehicle production	Q	0.2	0.5	0.4	0.9	1					
Volume per assembly plant	Q/P	0.3	0.6	0.5	-0.1	0.4	1				
WIP/sales ratio	W/S	-0.4	-0.5	-0.5	0.4	0.02	-0.7	1			
Value-added/sales ratio	V/S	-0.4	-0.3	-0.3	0.8	0.5	-0.4	0.8	1		
Cumulative output	CumQ	0.4	0.5	0.5	0.9	0.9	0.2	0.1	0.5	1	
Car & Driver measure	C&D	0.4	0.4	0.4	0.2	0.3	0.3	-0.3	-0.1	0.3	1

Table 3. Parameter Estimates of the Stochastic Frontier Model (US & Japan Combined)*

		3.1	3.2	3.3	3.4	3.5	3.6	3.7
Stochastic Frontier								
Time	μ	0.0228 (7.27)	0.0269 (7.94)	0.0242 (9.08)	0.0252 (8.37)	0.0276 (9.49)	0.0235 (8.43)	0.0274 (9.47)
Capital/Labor Ratio	θ	0.3873 (6.27)	0.3209 (5.39)	0.3635 (7.12)	0.3171 (4.96)	0.2647 (4.32)	0.3597 (6.68)	0.2580 (4.21)
Employees	γ	0.0891 (6.37)	0.1056 (8.43)	0.0897 (8.38)	0.1080 (7.48)	0.1139 (8.29)	0.0972 (8.64)	0.1162 (8.35)
Inefficiency Model								
Constant	δ_0	1.216 (4.53)	0.7474 (3.50)	3.029 (6.56)	1.182 (9.15)	3.316 (7.50)	1.083 (9.63)	3.290 (7.53)
WIP/Sales Ratio (lagged)	δ_1	0.1918 (6.82)	0.1855 (7.64)	0.1229 (4.09)	0.1658 (5.51)	0.0622 (1.82)	0.1947 (7.32)	0.0662 (1.95)
Number of Vehicles Produced	δ_2	-0.0113 (-0.55)						
Cumulative Production	δ_3		0.0221 (1.78)					
Volume per Plant	δ_4			-0.1840 (-4.55)		-0.1968 (-5.11)		-0.1949 (-5.13)
Value-Added/Sales Ratio (lagged)	δ_5				0.1049 (1.45)	0.1957 (2.76)		0.1907 (2.69)
Design Quality	δ_6						0.0227 (1.00)	0.0209 (0.94)
Variance Parameters								
	σ^2_S	0.0554 (7.79)	0.0543 (9.33)	0.0524 (8.20)	0.0538 (9.02)	0.0500 (9.23)	0.0542 (8.25)	0.0494 (9.27)
	γ	0.5987 (2.93)	0.7000 (4.69)	0.5625 (3.32)	0.6328 (3.44)	0.5765 (3.56)	0.6045 (2.91)	0.5660 (3.33)
Loglikelihood Function		31.95	33.28	45.03	32.78	48.62	32.25	49.04

*All the explanatory variables in the stochastic frontier and in the inefficiency model are in logarithms, except for the design quality measure. Numbers in parentheses are t-statistics, which may be biased upward due to correlated errors.

Table 4. Parameter Estimates of the Stochastic Frontier Model (Japan Only)*

		1	2	3	4	5	6	7
Stochastic Frontier								
Time	μ	0.0398 (10.19)	0.0409 (10.64)	0.0402 (10.50)	0.0407 (10.52)	0.0411 (10.74)	0.0414 (10.60)	0.0431 (11.20)
Capital/Labor Ratio	θ	0.1417 (1.89)	0.1759 (2.34)	0.1377 (1.88)	0.1782 (2.38)	0.1584 (2.14)	0.1239 (1.66)	0.1334 (1.81)
Employees	γ	0.1274 (7.88)	0.1209 (7.39)	0.1293 (8.17)	0.1184 (7.28)	0.1225 (7.62)	0.1326 (8.25)	0.1260 (7.85)
Inefficiency Model								
Constant	δ_0	1.496 (4.08)	0.4822 (1.39)	2.182 (5.54)	0.8163 (4.35)	1.843 (4.26)	1.218 (9.61)	1.925 (4.53)
WIP/Sales Ratio (lagged)	δ_1	0.1779 (3.85)	0.2381 (5.45)	0.1356 (3.41)	0.2220 (5.26)	0.1575 (3.69)	0.2218 (5.60)	0.1889 (4.18)
Number of Vehicles Produced	δ_2	-0.0359 (-1.12)						
Cumulative Production	δ_3		0.0524 (1.91)					
Volume per Plant	δ_4			-0.1060 (-2.95)		-0.0951 (-2.65)		-0.0955 (-2.72)
Value-Added/Sales Ratio (lagged)	δ_5				-0.2348 (-2.08)	-0.1722 (-1.57)		-0.1941 (-1.78)
Design Quality	δ_6						0.0618 (2.44)	0.0661 (2.66)
Variance Parameters								
	σ^2_S	0.0462 (7.09)	0.0478 (6.30)	0.0451 (6.69)	0.0470 (6.71)	0.0448 (6.83)	0.0454 (6.96)	0.0432 (7.10)
	γ	0.7387 (5.81)	0.6480 (3.67)	0.6618 (4.14)	0.7110 (4.86)	0.6842 (4.41)	0.6852 (4.37)	0.6819 (4.36)
Loglikelihood Function		50.37	49.20	53.18	50.78	54.45	51.39	58.08

*All the explanatory variables in the stochastic frontier and in the inefficiency model are in logarithms, except for the design quality measure. Numbers in parentheses are t-statistics, which may be biased upward due to correlated errors.

Table 5. GM-Toyota Comparison Calculation

	Average Data Values (1965-1997)				Impact of Factor on log(Y/L)*	
	GM	Toyota	GM/Toyota	log(GM/Toyota)	Based on Reg. 3	Based on Reg. 5
Dependent Variable:						
Output per worker (Y/L)**	43.8	70.7	0.62	-0.48	(=differential to be explained)	
Explanatory Factors:						
Resource Levels						
Capital per worker (K/L)**	74.5	94.5	0.79	-0.24	-0.09	-0.06
Number of employees (L)	754,327	54,846	13.8	2.62	0.24	0.30
Capability Measures						
WIP/Sales	0.071	0.007	10.4	2.35	-0.29	-0.15
VA/sales	0.461	0.182	2.5	0.93		-0.18
Vehicles/Plant	170,687	607,418	0.28	-1.27	-0.23	-0.25
				Total:	-0.37	-0.34

*Impact of Factor = log(GM/Toyota) x regression coefficient.

**Thousands of 1982 dollars.

Table 6. Operating Profit Regressions

Dependent Variable: Net Operating Profit / Value Added

	6.1	6.2	6.3
Constant	-1.035 (-2.87)	-0.915 (-3.65)	-1.240 (-3.85)
US Dummy	0.225 (2.17)	0.116 (1.42)	0.169 (2.07)
Industry Growth	0.147 (3.65)	0.162 (4.08)	0.152 (3.80)
Firm Sales Growth	0.263 (5.45)	0.283 (5.96)	0.278 (5.91)
Capital to Labor Ratio	-0.083 (-1.89)	-0.081 (-1.88)	-0.066 (-1.65)
Employees	-0.064 (-1.19)		
Number of Vehicles Produced	0.080 (1.27)	0.058 (2.36)	
Volume per Plant	0.035 (0.72)		0.081 (2.79)
WIP/Sales Ratio (lagged)	-0.059 (-2.41)	-0.059 (-2.41)	-0.062 (-2.66)
Value-Added/Sales Ratio (lagged)	-0.104 (-0.26)	-0.373 (-0.99)	-0.084 (-0.25)
Design Quality	0.015 (0.99)	0.012 (0.84)	0.012 (0.81)
R-squared	.333	.330	.326

* Regression estimates based on AR1 procedure to adjust for serial correlation of the error. R-squared values are based on transformed data; t-values in parentheses.

Figure 1. Real Value-added per Employee

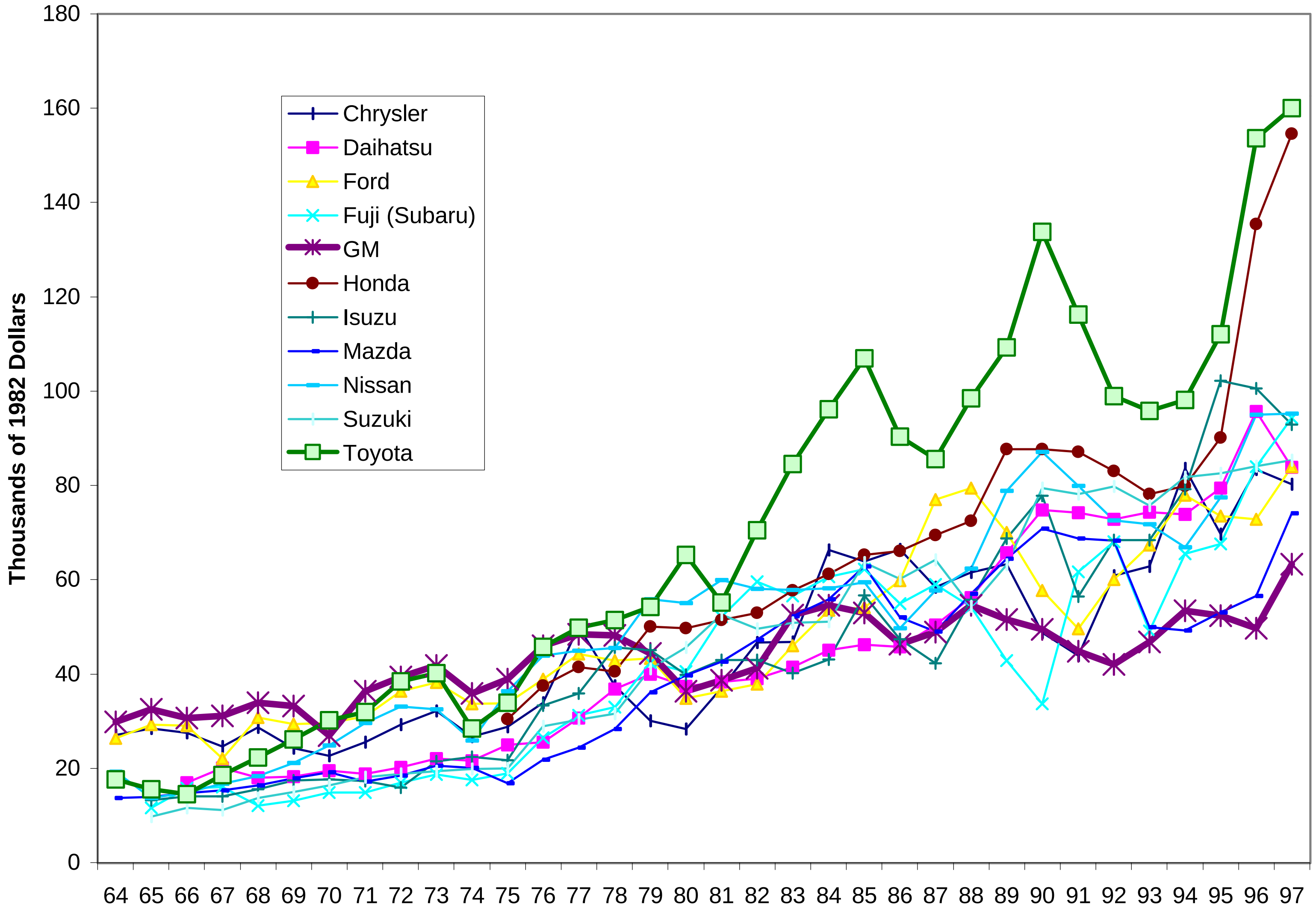

Figure 2a. Capital Stock per Worker (Japan)

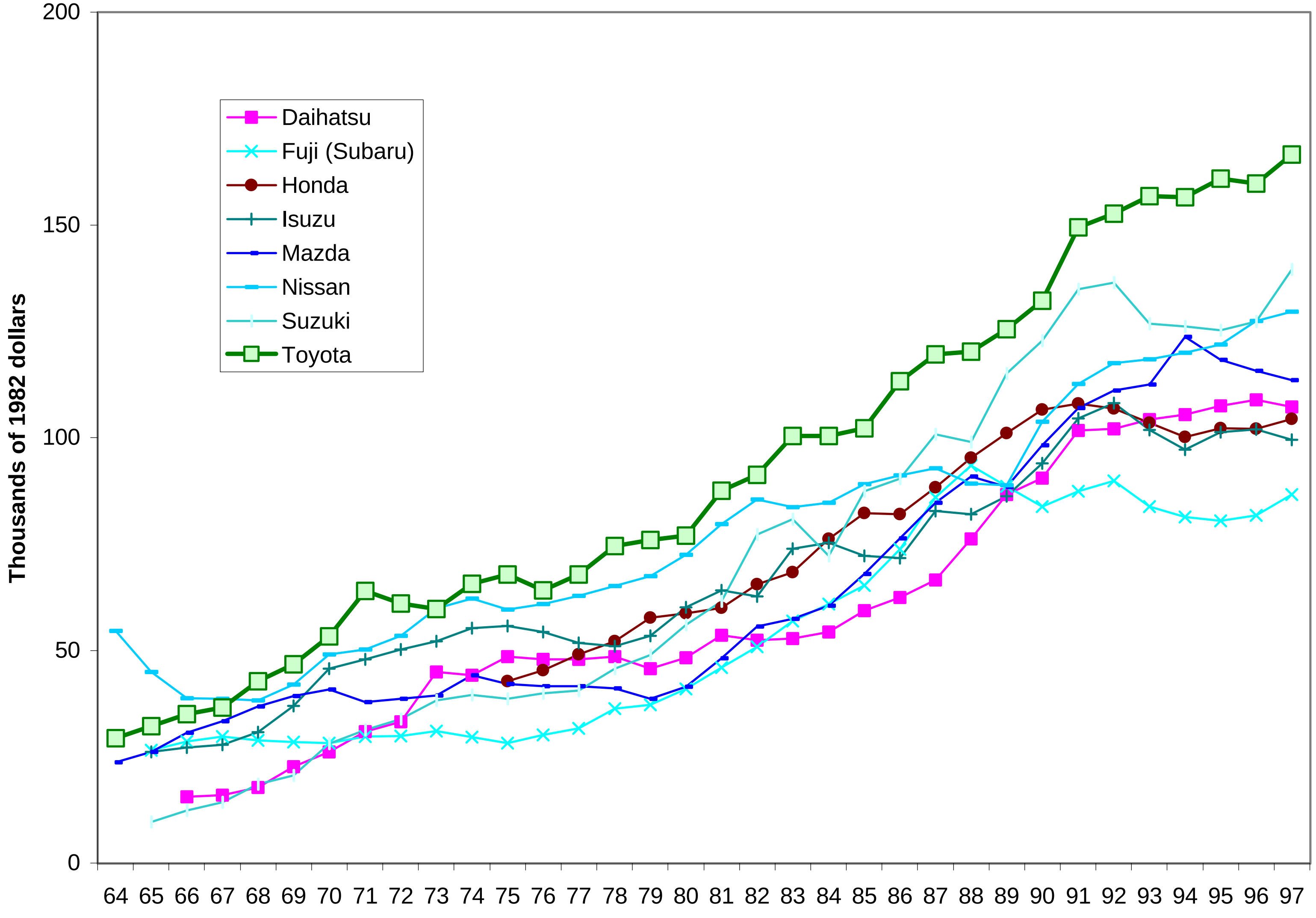

Figure 2b. Capital Stock per Worker (US)

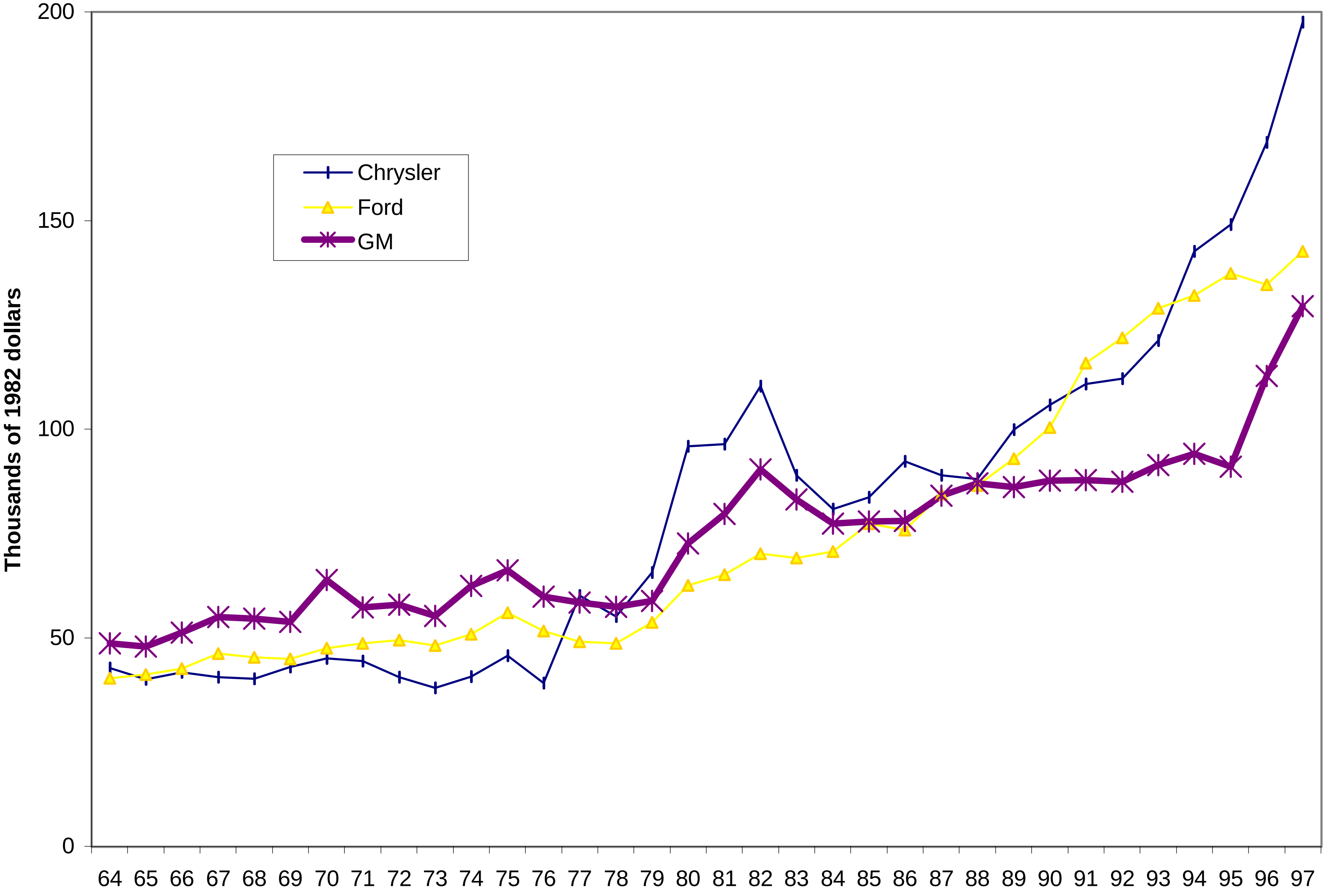

Figure 3. Number of Employees

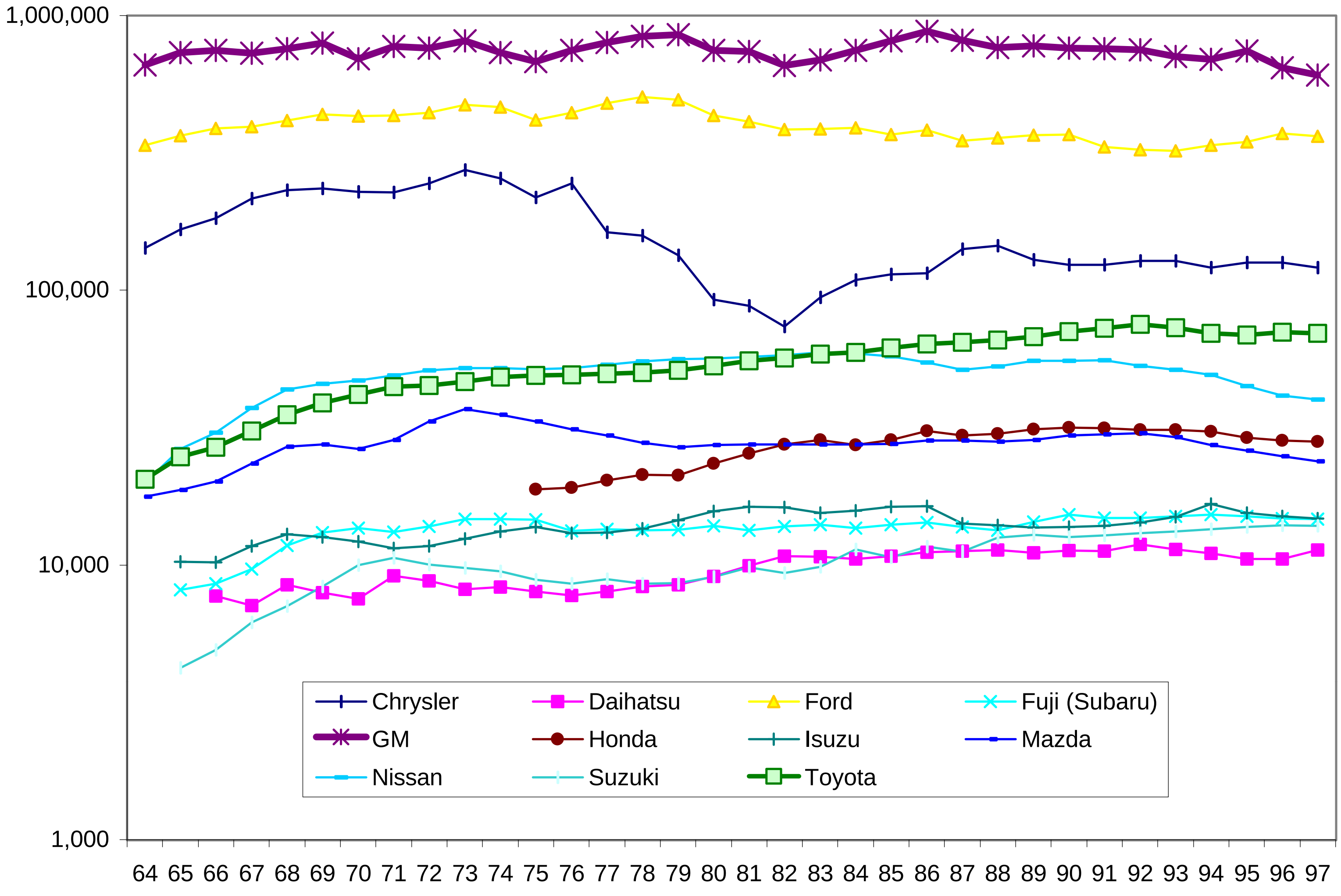

Figure 4. Average Vehicle Output per Plant

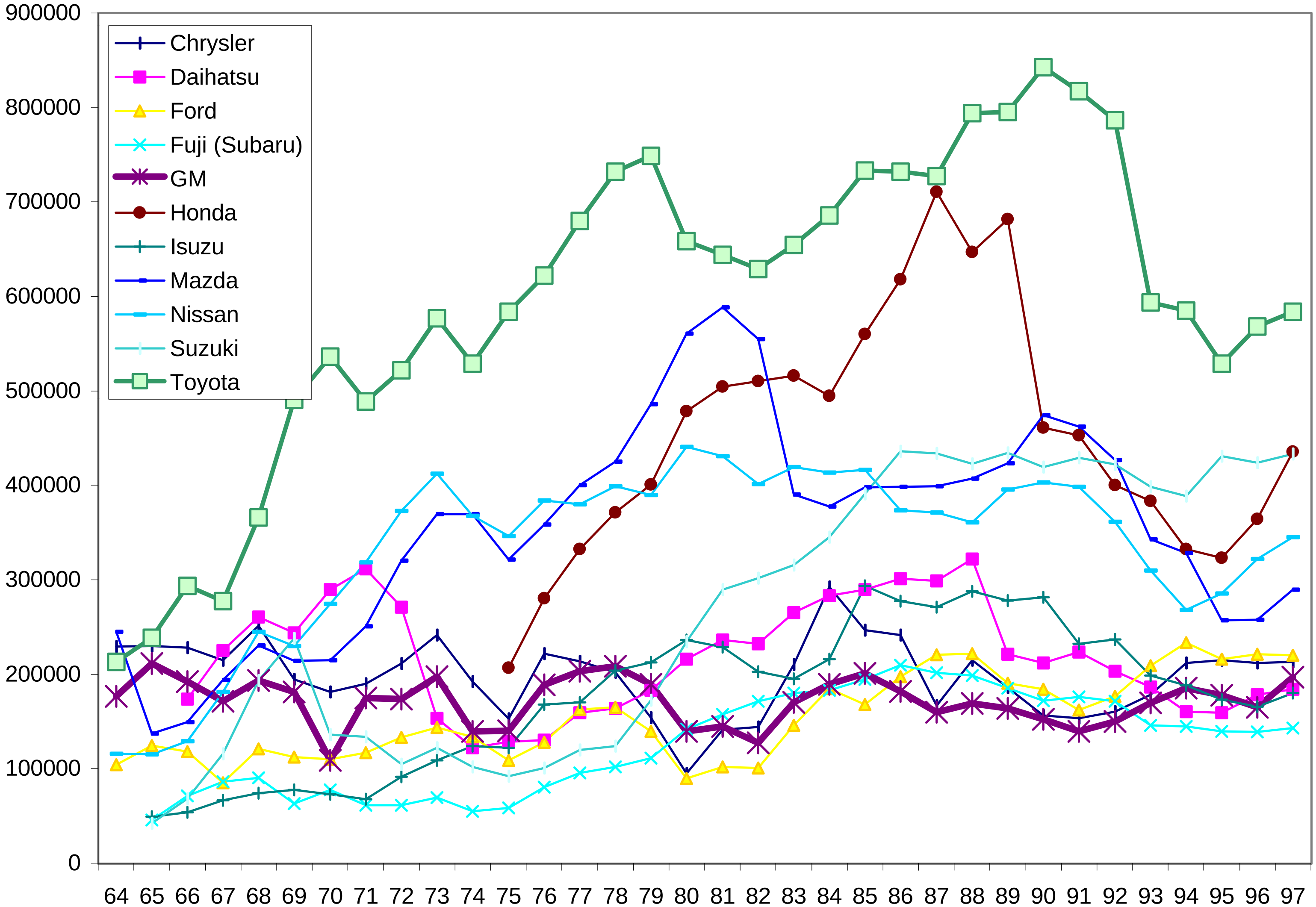

Figure 5. WIP/Sales Ratio

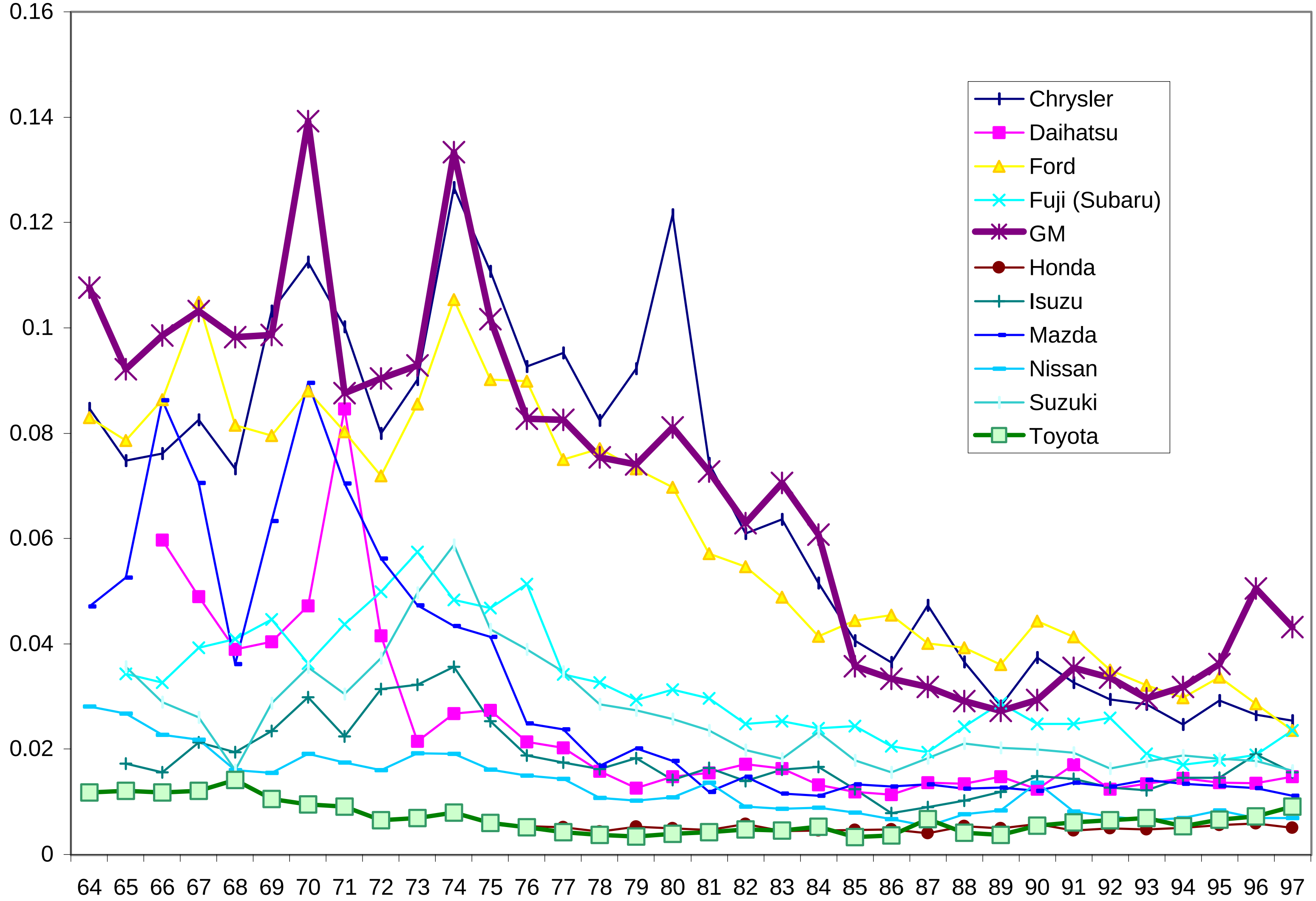

Figure 6. Value-added/Sales (Vertical Integration)

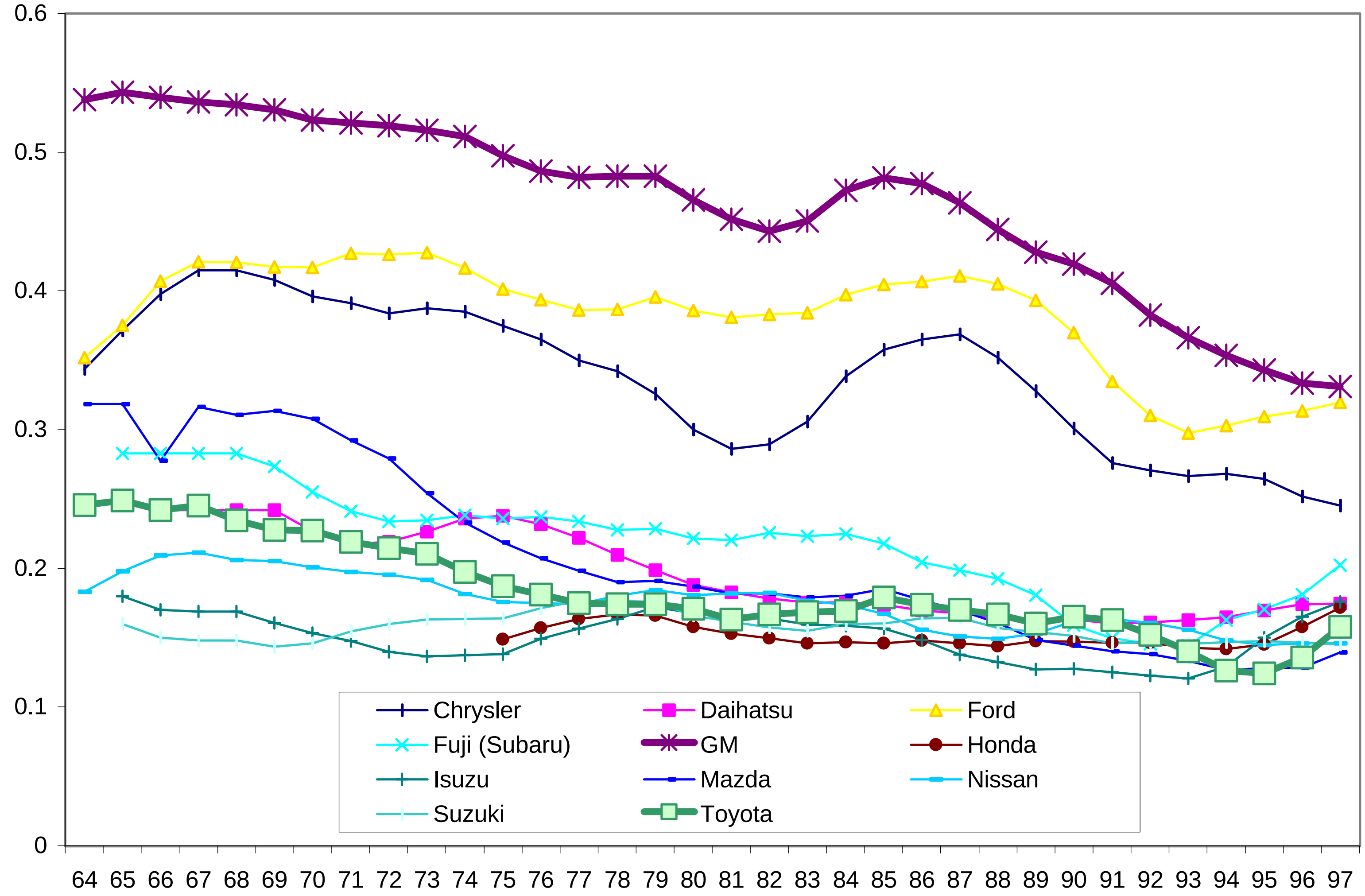

Figure 7. Cumulative Output of Vehicles

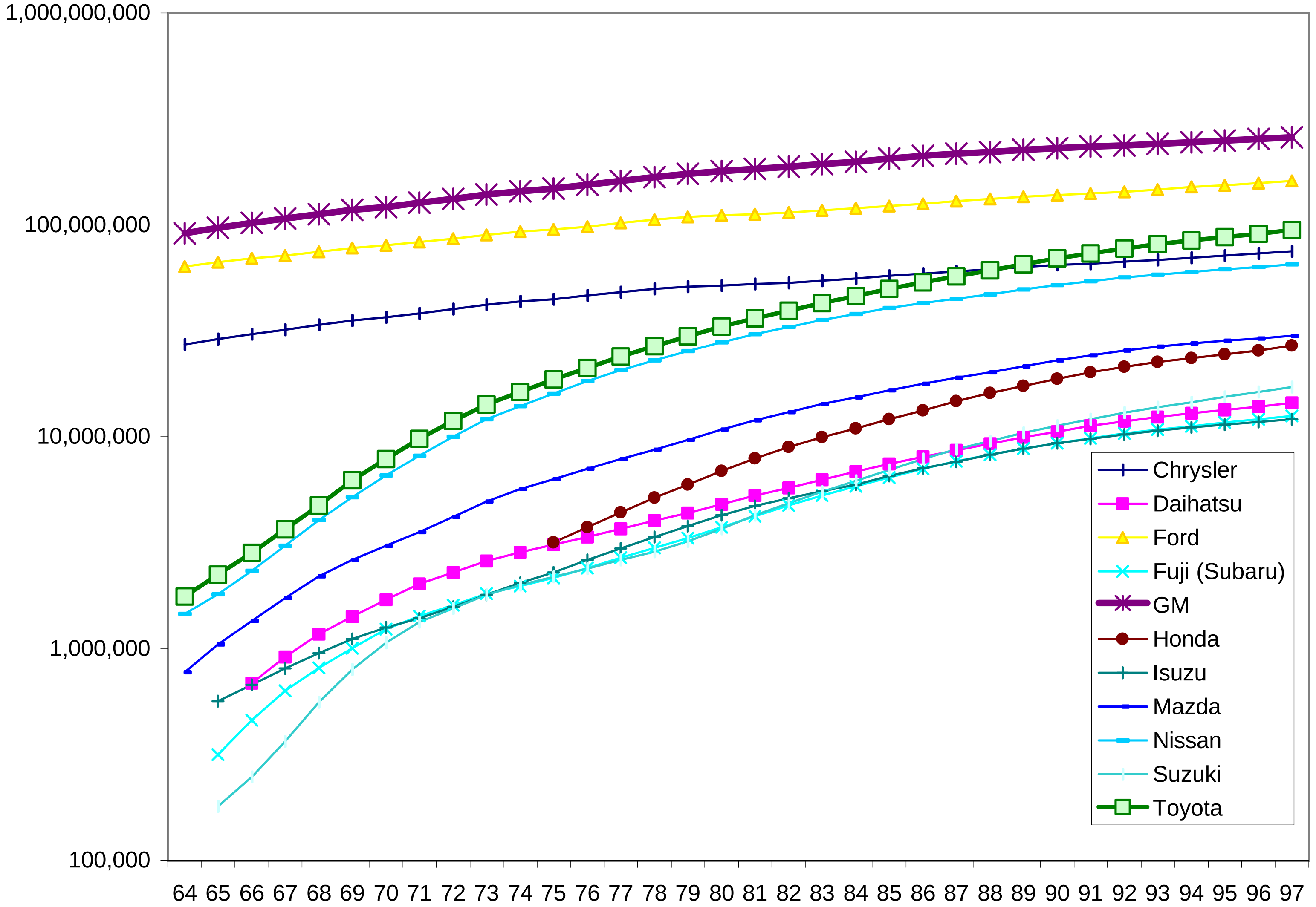

Figure 8. GM vs. Toyota Efficiency Plot

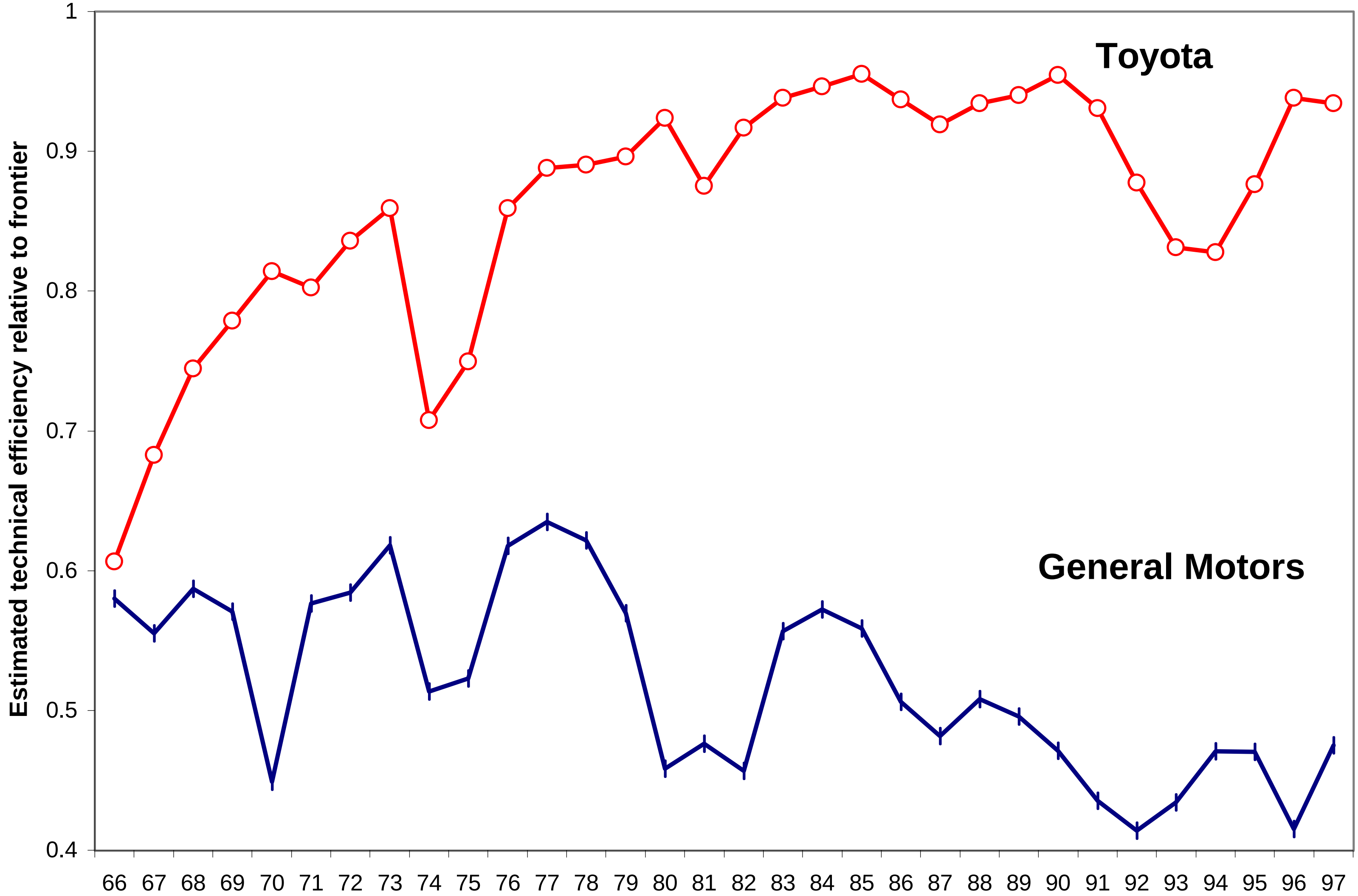

Figure 9. Estimated impact of factors on value-added per employee, relative to Toyota (Reg. 5 coefficients and 1965-97 avg. data values)