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The Relative Efficacy of Distribution System Inventory Management Across Auto Manufacturers

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Wharton Undergraduate Research Scholars
WH-299-301

April 2004

Area of Research

Given the size of the automobile industry, and the high per-unit cost of a car in inventory, it would seem that inventory management is an important issue in the automotive industry. Indeed, there has been tremendous anecdotal coverage in the business press regarding automakers' consistent efforts to reduce inventory. Most research on automotive inventory management has focused on the impact of just-in-time (JIT) techniques on automotive inventory. The research showed that just-in-time has been remarkably successful in reducing the level of inventories held by most manufacturing companies, including the automobile industry

While a great deal of attention has been focused on JIT, comparatively little empirical research has been done on the impact of changing distribution systems on inventory levels in the auto industry. Anecdotally, some manufacturers, such as Toyota, are noted for their efficiency in distribution and other areas ("JIT: When ASAP isn't good enough). This paper will seek to test this hypothesis and ascertain the relative efficiency of different auto manufacturers in managing inventory in their distribution systems, both at the factory and dealer levels.

Industry Structure

Before conducting any research on the automobile industry, it is important to understand how automobile distribution systems are structured. Parts of these systems are fairly similar across different manufacturers, and are discussed in their 10-K forms, filed with the SEC. However, there are important and obvious distinctions between the final distribution systems used by import and domestic manufacturers.

The distribution system for domestic manufacturers first involves the manufacturing of the car. Most manufacturers attempt to correctly guess the colors and options that will be most popular for a particular model, as well as overall demand for the model. Once manufactured, cars are generally delivered from the factory to regional distribution facilities, and then are delivered to dealers. This is also true of vehicles manufactured domestically by foreign companies.

For cars that are manufactured abroad and imported, US subsidiaries recognize them as inventory as soon as they leave the ship that transported them. These cars are then transported by truck to regional distribution facilities, and then on to dealers.

Once a car has arrived at a dealership, it is stored on the dealership's lot until it is sold. Generally speaking, dealers are given strong financial incentives by manufacturers to sell cars quickly. Thus, total distribution system inventory includes both inventory held by the manufacturer and inventory held in dealers' lots. This metric is discussed in greater detail later in this paper.

Literature Review

Inventory management is a major area of operations research. There is a significant amount of theoretical research on optimal inventory management systems for distribution networks. There is also some empirical research on overall inventory levels in the United States. However, there has been little empirical research focusing specifically on the auto industry. Indeed, most auto

industry specific empirical research is from the management literature and deals primarily with case studies of how various manufacturers interact on a personal level with their dealers.

The theoretical literature dealing with inventory management is quite voluminous. By and large, this literature presents mathematical models that can be used to understand and predict inventory levels. An example of such work includes Ernst and Cohen (1993) who attempt to derive a model of inventory management for dealers that sell and service manufactured goods. However, Ernst and Cohen do not conduct empirical tests of their model, but rather test for its numerical reasonability.

While the theoretical literature argues that inventory levels should decline markedly as a result of the implementation of improved inventory management systems such as JIT, it is only recently that empirical studies of this have been conducted. A paper by Rajagopalan and Malhotra (2001) indicates that while it appears that the general level of inventories has decreased across all industries since the 1960's, it does not appear that the trend accelerated in the 1980's or thereafter, as JIT's proponents might suggest. However, a more recent study by Chen, Frank, and Wu (2003) indicates that, when studying inventories on a firm level instead of on an industry level, there appears to be a significant decrease in inventories since 1980. However, Chen, Frank, and Wu focus on the economy as a whole. They do not focus on a particular industry, nor do they focus on distribution, as opposed to production systems.

Data Set Definition

To answer the questions posed earlier, it is first necessary to define the set of companies to be evaluated. Three screening criteria were chosen: US GAAP compliant financial statements, total light vehicle sales of more than 500,000 units in the United States and Canada, and at least one North American production facility. For the purposes of this research, North America refers to the United States, Canada, and Mexico. Each of the aforementioned criteria are necessary to insure that the data collected are both meaningful and consistent for the reasons discussed below.

US GAAP compliant financial statements were a critical first step in winnowing the field of companies. US GAAP requires that manufacturers report raw materials, work-in-process (WIP), and finished goods inventories. Furthermore, while this distinction is made under other accounting systems, there are subtle differences between US GAAP and these foreign systems that can lead to substantially different inventory results. Thus, since the big three US auto manufacturers report their results in GAAP format and cannot reasonably be excluded from any sample of auto manufacturers, all manufacturers in the sample must have GAAP compliant financial statements.

The requirement for more than 500,000 units stems from a desire to evaluate only the practices of "mass market" manufacturers. This is designed to exclude such manufacturers as BMW and Porsche, which tend to make luxury vehicles that are known in the industry (reference to BMW distributor conversation) to sell at much different rates than "typical" light vehicles.
Finally, the manufacturers included in the sample set all needed at least one North American production facility. This was needed to avoid comparing all-import manufacturers to those with

North American capacity. It was also necessary to insure that production data was actually available for the company in question.

After applying the above criteria, a list of six companies was generated: Daimler-Chrysler, Ford, General Motors, Honda, Nissan, and Toyota. In addition to being suitable for comparison to one another, the companies in this list accounted for 85% of all light vehicle sales in 2001. Thus, while they do not comprise the entire US auto industry, these six companies unquestionably control the vast majority of it.

One important note before continuing is the handling of the 1998 Daimler-Chrysler merger in the data. For all data from 1998 onward, all of Daimler-Benz's effects on Chrysler's variables were removed. Since Daimler-Benz did not meet the criteria for inclusion in the data set as a standalone company, it did not make sense to include it as a part of Chrysler.

A final step in defining the data set was choosing the timeframe for data collection. Ideally, this would extend into the 1970's, so that differences between manufacturers would be more readily apparent. However, data on potential explanatory variables from that long ago is not nearly as extensive at is now. Furthermore, Nissan did not begin to provide GAAP-compliant financial statements until 1992. As such, 1992 was chosen as the starting point for data collection.

Data Collection and First Impressions

As a first step in data collection, final inventory and cost of goods sold (COGS) data was collected from the COMPUSTAT North America database for each of the companies in the data

set. In order to avoid exchange rate issues and adjust for the size of each company, inventory levels were measured in inventory days. This is defined as COGS/final inventory. All firms report balance sheet and income data on a standard quarter-end basis. Thus, even though firms may have different fiscal years, all firms report data quarterly as of 3/31, 6/30, 9/30, and 12/31.

Final inventory was used in the denominator for the obvious reason that it best represents the number of actual vehicles held by manufacturer. However, using this number also has an ancillary benefit, which is that final inventory numbers do not include intermediate goods that might be held off-balance-sheet by suppliers and non-final consumer related good held by parts subsidiaries of the major auto manufacturers such as Visteon and Delphi. Also important to note is that the final inventory number for US subsidiaries includes only those vehicles that have either been produced in the US or that have successfully passed customs if they were imported.

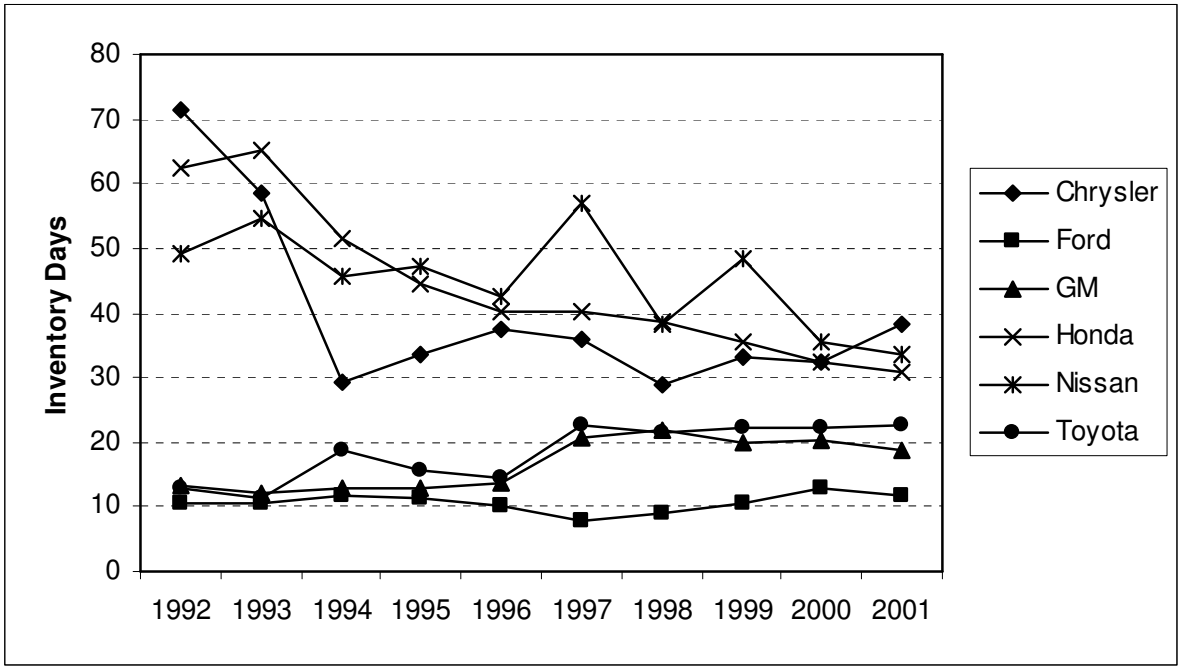
However, there was another issue that needed to be dealt with for final inventory data: seasonal fluctuations. Thus, using quarterly data without some sort of adjustment was not possible, as these would reflect seasonality. One method for dealing with this might have been to select financial statements from a particular date (12/31, for example) and compare final inventories on an annual basis. However, it was ultimately decided to average the quarterly data across each year from 1992-2001, and then perform inventory comparisons on annual basis.

This approach held significant advantages over the other methods. First, it enabled the inventory day ratios to capture a more "overall" picture of auto inventories, including those from busy as well as slow months. Selecting one date would have reflected only inventory levels in a

particular season, without reflecting overall levels. Also, adjusting for seasonality is an imperfect process and, without a longer time series of data, would likely have been impossible. Thus, averaging annual data allows for the best possible analysis of trends and variations in inventory levels.

To get an initial impression of the final inventory days by manufacturer, Figure 1 was constructed. A cursory inspection indicates that the average level of inventory days held by most manufacturers has indeed been falling. Furthermore, there do appear to be significant differences in inventory levels between different companies. For example, in 2001, Chrysler held 39 days in inventory, while Ford only held 12. In fact, both GM and Ford actually held fewer inventories on their balance sheet than Toyota, which is recognized in the industry as an inventory management leader. While these observations, if proven after controlling for explanatory variables, would have been most interesting, they excluded a critical component of distribution system inventory: car dealerships.

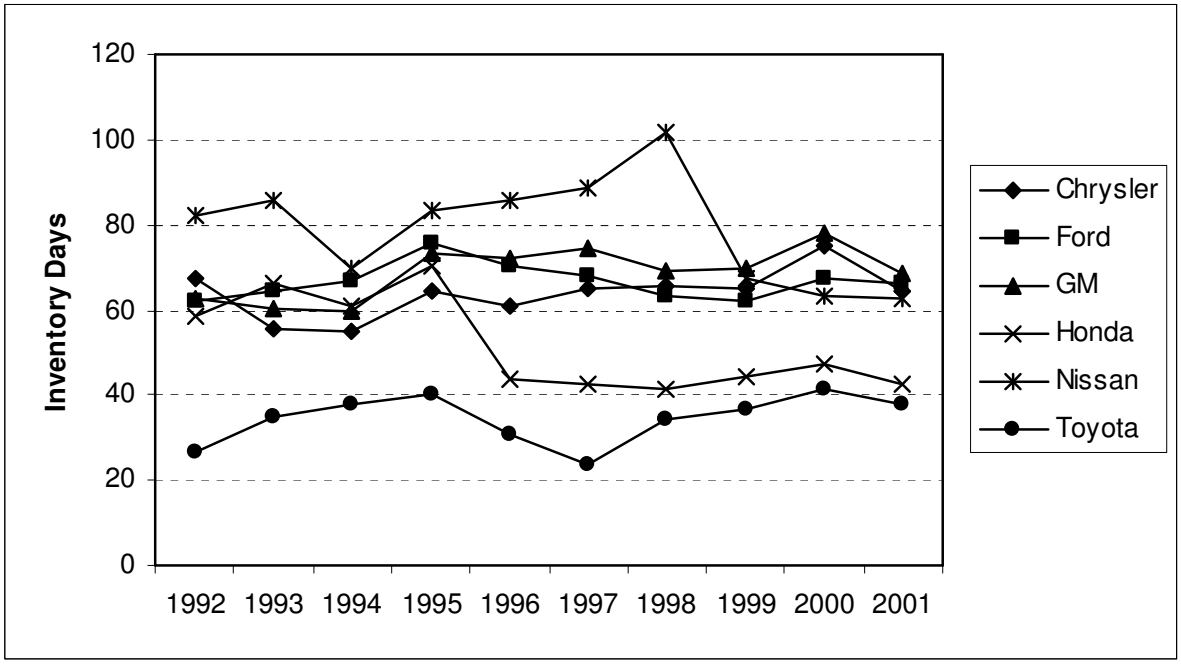
Figure 1. Manufacturer Final Inventory Days Over Time



Clearly, in order to have any sense of the actual level of inventory in the automotive distribution chain, dealerships need to be included. By including dealerships, it is possible to more directly capture inventory fluctuations that occur as a result of "hot" model introductions. It also captures any efficiencies a manufacturer might realize in how it allocates models to dealers.

Data for dealer inventories were obtained from Ward's Automotive Yearbook (1993-2003 editions). In this case, the data were presented in a monthly format. For similar reasons to those discussed for manufacturer inventories, dealer inventories were averaged over the course of a year and then used for annual comparison. For purposes of illustration, dealer inventories are included in Figure 2.

Figure 2. Dealer Inventory Levels (1992-2001)



In figure 2, the overall inventory levels appear to be more stable. However, there are clear differences among manufacturers. Also, Ford is among the manufacturers with the highest levels of dealer inventory, whereas it had among the lowest factory inventory levels. Looking at this data, it appears that some manufacturers go to greater lengths to push inventory to dealers than others. Since the ability to push inventory to dealers says very little about the efficiency of a company's overall distribution *system* (the company and the dealer).

This problem augurs for the creation of a "system inventory" level. This number was obtained simply by adding dealer inventory levels to manufacturer inventory levels. By doing this, it was possible to capture system-wide effects, without needing to explicitly control for whether or not a particular manufacturer concentrated its inventories at the dealers or in its own lots. System inventories are summarized in figure 3.

Figure 3. System Inventory Levels (1992-2001)

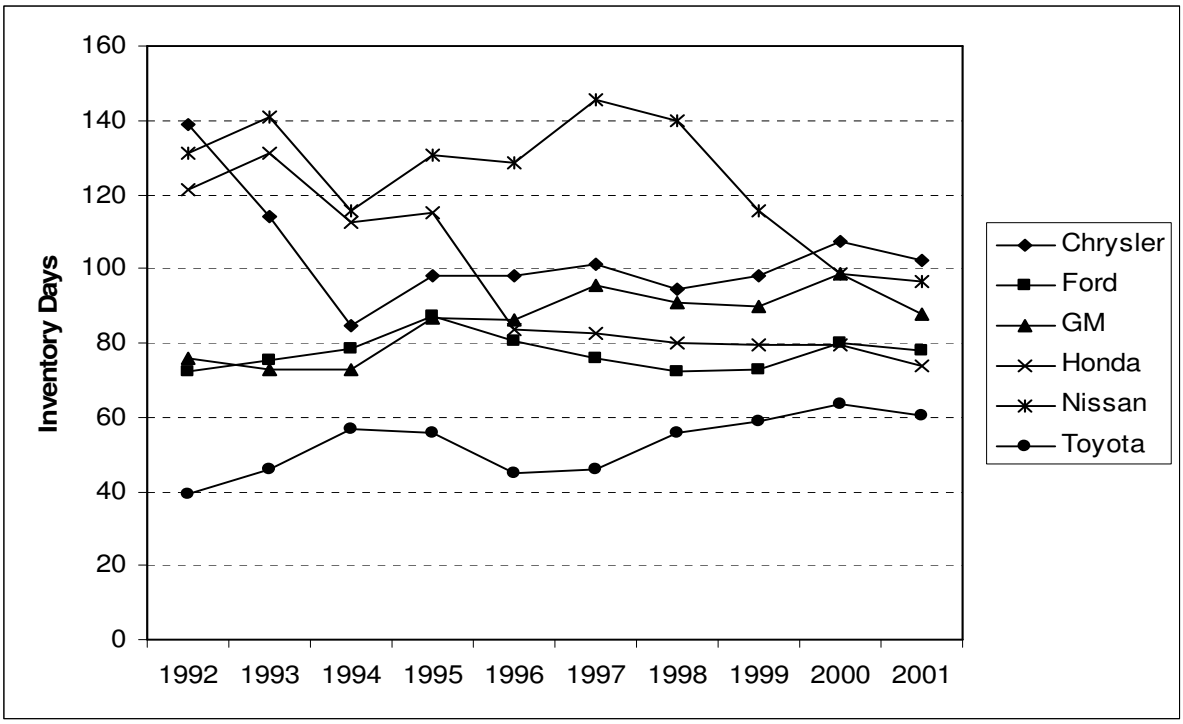


Figure 3 tells a much more interesting story than either of the previous two. Clearly, there is a great deal of variation in inventory levels from firm to firm. What is more, some firms have exhibited definite downward trends in their inventory levels. Also, and importantly, this graph squares with the widely accepted industry conventional wisdom; that Toyota has lower levels of inventory than every other auto manufacturer and has maintained those low levels for some time.

Of course, at this juncture, it is necessary to explore the drivers of inventory levels to see if there might be some explanation for the variances in inventory levels among manufacturers other than the overall quality of their distribution system. Consulting with trade publications, such as Ward's, led to a list of a number of factors. These can be subdivided into four categories: sales and production, market share, product mix (cars vs. trucks), and capacity.

Understanding a manufacturer's sales and production levels is clearly important to understanding inventory. A product that is not selling or is overproduced will clearly lead to an inventory buildup. At the same time, a hot-selling product can reduce inventory substantially- and do so independent of distribution system. Thus, this category initially led to four explanatory variables: car sales, car production, light truck sales, and light truck production. Data for these, provided on an annual basis, was obtained from Ward's automotive yearbook.

Related to sales, but also competitive dynamics, is market share. Market share had potential value as an explanatory variable because, in theory, a company with a high and increasing market share should have hot selling products and lower inventory. Market share was calculated, again on an annual basis, from sales data from Ward's. In the initial regression, both market share and sales were used. However, this was changed in subsequent regressions, and will be discussed further.

Product mix, with regard to the number of cars a manufacturer sells versus the number of light trucks, can also influence inventory. According to Ward's, light trucks sell more quickly than cars. Thus, if a manufacturer is lowering its inventory levels by selling more trucks than cars, it does not point to any efficiencies in distribution, but rather a change in products sold.

Finally, capacity is an important issue that needs to be controlled for, especially in the case of importers. Since, especially for an importer, increasing capacity reduces the number of vehicles that need to be imported, system inventory can decrease. One reason for this is that, due to the

long lead time required for imports to be transported from the factory, manufacturers maintain higher inventory levels to guard against shortages. On the other hand, it is also possible that, because of the long lead time required to receive imports, a manufacturer would be cautious in using import inventory, and thus carry less of it. Despite this caveat, it seems more plausible that higher capacity would lead to lower inventory. The impact of capacity holds true to some extent even for domestic manufacturers, but as with importers, its effects are not intuitive.

The discussion above thus implies certain hypotheses about the effects of the various explanatory variables. Explicitly stated, they are as follows:

1. There are significant brand effects. Using Toyota as a baseline, most manufacturers are expected to be worse at managing their inventories.
2. Increases in sales decrease inventory.
3. Increases in production increase inventory.
4. High market share decreases inventory.
5. Decreasing the proportion of cars in the product mix decreases inventory.
6. Increased capacity decreases inventory.

Of course, the focus of this research is on testing Hypothesis 1. As such, in order to test this hypothesis, it ultimately became necessary to change the construction of many explanatory variables and introduce new ones. Thus, of these original hypotheses, only H1 was ultimately tested. The reasons for this will be explained in greater detail later in this paper.

Initial Regression

In theory, the explanatory variables described above should account for most of the exogenous variance in auto manufacturers' inventory levels. In practice, there are a number of issues that must be addressed to make a meaningful statement about distribution practices. However, as a starting point, a regression can be constructed with system inventory levels as the dependent variable and the aforementioned explanatory variables, along with dummy variables representing the various manufacturing firms being studied.

In choosing the dummy variables, it is important to be aware of several critical rules. First, since there are six qualitative possibilities (the six companies) only five dummy variables could be used. Additionally, no dummy variable could be added that correlated perfectly with a company dummy variable. This means that, for example, a dummy variable for Importer (as opposed to domestic producer) could not be added. However, a separate regression with only a domestic dummy variable can be run. This regression does not describe the data better than using separate brand variables.

The results of this initial regression are summarized below in figure 4.

Figure 4. Regression of system inventory levels against untransformed explanatory variables

R Square	0.817107	
	Coefficients	*Standard Error*
Intercept	-34.7234	51.22522
Capacity	6.83E-07	1.01E-05
Car Sales	-1E-05	5.28E-05

Truck Sales	1.39E-05	3.81E-05
Car Market Share	25.53065	463.5497
Truck Market Share	-48.3036	282.1535
Product Mix**	143.1087	54.78655
Car Production	-1.4E-05	3E-05
Truck Production	8.36E-06	3.45E-05
Chrysler	80.44127	50.23406
Ford	41.70159	64.71662
GM	53.50609	67.98627
Honda	16.19403	14.21279
Nissan***	69.0807	13.46288

***(significant at the .01 level. **significant at the .05 level. *significant at the .1 level.

While there are several problems with this regression, a first step is to focus on the obvious problems of multicollinearity, evidenced by the preponderance of low t-statistics in the presence of a large F-statistic. Furthermore, the presence of multicollinearity is confirmed by a number of extremely high correlations between variables in a variable correlation matrix.

While multicollinearity can be handled using several regression techniques, in this case, it is logical to transform some of the variables that are being used in order to multicollinearity. Thus, the sales and production variables are transformed into total sales/total production. This also leads the already insignificant market share to become even less significant, as changes in this ratio tend to be highly correlated with changes in market share. Thus market share (both car and truck) is dropped. All other variables are retained as they are. The previous regression can then be rerun with the transformed variables, and the results are summarized in figure 5.

Figure 5. System Inventory Regression against transformed variables

R Square	0.780346	
	Coefficients	*Standard Error*
Intercept	24.70384	35.3283
Chrysler***	86.48091	18.24869

Ford**	62.42026	29.39993
GM*	78.09725	44.19934
Honda***	26.79121	8.684555
Nissan***	70.61255	6.256775
Total Sales/Total Production	-3.92204	14.35665
Capacity	-7.6E-06	8.04E-06
Product Mix**	63.68118	28.82999

***(significant at the .01 level. **significant at the .05 level. *significant at the .1 level.

Here, the t-statistics are for the most part large, as was the F-statistic. Multicollinearity is effectively dealt with. However, a more important problem is embedded in this data: autocorrelation. This should not be surprising—the inventory data are in time-series form, and autocorrelation is known to be a typical problem with using time series data.

Another confirmation of the presence of autocorrelation here is the extremely low Durbin-Watson statistic. In this case, its value was .91. As such, it is possible to state with 95% confidence that there is positive autocorrelation. Especially since there are well-recognized weaknesses to the Durbin-Watson statistic in terms of being unable to detect autocorrelation, any positive reading is a very strong signal that there is a significant autocorrelation problem.

One frequently used method of dealing with autocorrelation involves the use of first differences to create non-correlated variables for regression. However, that relatively simple method is not applicable in this case. Because of the presence of dummy variables, taking first differences (a dummy variable is 1 in its first appearance and 0 thereafter) would make the dummy variables ineffectual. As such, it is necessary to use the quasi-first differences method, as suggested in (Maddala, 192).

The quasi-first differences method involves multiplying the previous year's variable by a correlation coefficient, and then subtracting that value from this year's variable. This is done for all variables, both dependent and independent. For dummy variables, the first in a particular series is divided by one minus the correlation coefficient.

There is no generally agreed-upon procedure for finding the correlation coefficient to be used in quasi-first differencing. For simplicity, the Cochrane-Orcutt procedure is used here. The procedure sums the products of sequential residuals of the original regression (with gaps for dummy variable changes) and then divides that sum by the sum of the squared residuals. The equation follows: $\hat{\rho} = \frac{\sum \hat{\mu}_t \hat{\mu}_{t-1}}{\sum \hat{\mu}_t^2}$

As Cochrane-Orcutt is an iterative procedure, it is run once, quasi-first differences are taken, and the regression is rerun until the estimated correlation converges to zero. Also, capacity differences are removed. Capacity is highly serially correlated, making it difficult to run the Cochrane-Orcutt procedure and achieve convergence. As it was not a particularly significant variable to begin with, the problem of multicollinearity was further ameliorated. The regression results after the completion of the procedure are summarized in figure 6.

Figure 6. Regression results after correction for autocorrelation using Cochrane-Orcutt

R Square	0.401982	
	Coefficients	*Standard Error*
Intercept	2.042599	15.47156

Chrysler***	24.1673	7.922316
Ford**	15.19359	6.71591
GM***	15.90428	5.580887
Honda	5.028794	5.987746
Nissan***	23.73371	4.602659
Product Mix	72.06847	46.77127
Total Sales/Total Production	4.664307	12.39048

***(significant at the .01 level. **significant at the .05 level. *significant at the .1 level.

Clearly, there remain significant brand effects on inventory levels. However, it is quite disturbing that there do not appear to be any other effects on inventory levels. It is clear that a significant explanatory variable is neglected in this regression.

Looking at the system inventory graph in figure 3 for intuition, it seemed that inventory is very responsive to percent changes in capacity and percent changes in market share. A regression including these two variables produces a superior adjusted-r square to the previous regression, and finds that percentage changes in capacity are indeed significant. Furthermore, they have the largest impact of any statistically significant explanatory or dummy variable.

This seems incongruous. How could it be that market share growth, or at least sales/production has no effect on inventories? After comparing percentage changes in capacity to sales growth, it seems that they serve as (somewhat inefficient) predictors of future sales growth. Unsurprisingly, car companies seem able to forecast future demand and build capacity to meet it. Moreover, jumps in capacity seemed to coincide with what, anecdotally, were the introductions of hot new vehicles that tremendously increased sales. With that in mind, testing for the significance of sales growth, even while controlling for percent capacity changes is helpful.

However, before sales growth can be used in a regression, it is clear that using it and the sales/production independent variable can cause significant multicollinearity problems in the regression. The two variables, almost by definition, are highly correlated. Since sales to production did not prove significant in past regressions, it makes sense to drop the variable.

Dropping sales to production from the regression also has the benefit of making the model more logically consistent. While sales to production is clearly critical to inventory, it is so central that it is a variable companies with good distribution systems manage directly. By definition, inventory rises when sales to production falls, and falls when sales to production rises. As such, it is not a control variable, but rather an expression of how well the different companies manage inventory and should not be included separately from the brand variables in any case.

After re-running the regression, the final results are presented in figure 7:

Figure 7. Final regression

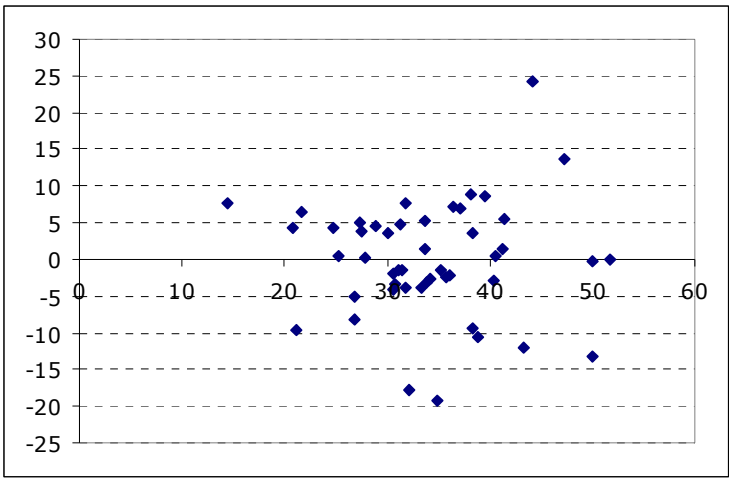
R Square	0.490001	
	Coefficients	*Standard Error*

Intercept	6.976352	11.42102
Chrysler***	22.9559	7.196392
Ford**	13.72607	5.933582
GM***	14.0729	5.000492
Honda	4.967555	5.59322
Nissan***	23.32667	4.53756
Product Mix	70.33227	43.31038
Sales Growth**	-45.168	19.09356
% Capacity Change	17.90124	18.19743

***(significant at the .01 level. **significant at the .05 level. *significant at the .1 level.

At this point, a test for heteroskedasticity in the residuals needs to be performed. While it seemed unlikely that, given the nature of the data set, this is being a problem, two tests were performed. One simple test was a visual inspection of the residual plot. There did not appear to be any significant heteroskedasticity. The plot is included in figure 8 below.

Figure 8. Final regression residual plot



However, a more exact test is needed to be sure. In this case, the RESET test (Maddala, 162), can be used. This test involves regressing the residuals on the predicted values of the dependent variable squared, to the third, power, and so forth to the n-th power. For this research, the significance of the regression coefficients is tested on a regression where the predicted values are

raised up to the fifth power. The coefficients generated by the regression are insignificant. With this in hand, we can conclude that the regression is non-heteroskedastic.

Discussion of Results

The basic hypothesis being tested by this experiment is that there is some sort of systemic difference in how various manufacturers manage their distribution systems. This hypothesis can be accepted for a particular manufacturer if the coefficient of that manufacturer's dummy variable is significant. In fact, all of the dummy variables except for Honda are significant at the .05 level.

More interesting than the actual value of the firm dummy variable coefficients is their rank order. The higher a firm's coefficient, the more the firm's distribution system may be said to add to its inventory days. Thus, Nissan is the most inefficient firm, followed closely by Chrysler. Toyota is the most efficient firm, as all dummy variable coefficients are positive. Thus, when all dummy variables are set to 0 (Toyota's value) inventory is at its lowest. Toyota is followed closely by Honda, although its coefficient is insignificant. Finally, Ford and GM follow the two leaders.

It is interesting that only Honda's distribution system does not have a statistically significant effect on inventories. However, this seeming insignificance can be explained by the inexplicable drop in Honda's inventory levels from 1994-1996. This does not appear to be the result of any of the explanatory variables. One possible explanation is that late 1994/ early 1995 marked the introduction of the Honda Odyssey in North America. This one car became extremely popular,

and cannibalized some sales from Honda's other models. Thus, while overall sales growth may not have risen, it seems that the Odyssey simply replaced slower moving vehicles.

The importance of sales growth is certainly interesting, but it is not the least bit surprising. Clearly, growing sales lead to lower inventories, as customers buy more and the manufacturer presumably has better products to sell. Such a situation ought to lead to low inventories.

Also, the high significance of most of the firm effects (except for Honda's) implies that the effect is at least reasonable stable throughout the entire time range. Thus, the IT investment spending of the 1990's did not appear to have filtered down into the automakers' distribution networks as of 2001. Again, Honda appears to be the exception as its final system inventory continued to decline. Nonetheless, further analysis needs to be done to confirm the lack of firm-specific trends in the 1990s.

It is important to note that several possible explanatory variables were not used. These include number of models offered, number of dealerships, and age of dealerships. Data could not be found for these variables. Had such data been available, it is possible that the inclusion of these variables would have made the brand effects insignificant. The inclusion of these and other variables is thus a potential area for future research.

In summation, it does seem that distribution systems make a difference in final system inventory. While the insignificance of Honda's distribution is certainly a puzzle, it does not detract from the fact that the five other manufacturers' distribution systems each play a significant role in their

system inventory levels, as opposed to the quality of their product, their product mix, and their North American capacity.

Further Research

There are two areas of future research in this direction that are worth pursuing. One is performing additional tests to verify that the firm effect is stable over time and that there is indeed no significant shift during the course of the 1990s.

Another possible area of future research is investigating the implications of good inventory management for financial performance of firms. In order to truly investigate this, relatively low-level cost accounting data would be needed, to assess the actual costs to the company arising from its inventory. Such a data requirement made such research impractical at this time, but in the future, better data might enable it. In the end, it is the financial implications of lowering inventories that are of most interest to profit-seeking firms. If it is Toyota's final system inventory management that is powering its profits, as opposed to only its cars, laggards such as Chrysler and Nissan might consider spending more time and effort improving their distribution systems and changing the current, stable status quo.

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