PRODUCT VARIATIONS, QUALITY, AND PRODUCTIVITY: A COST-BENEFIT ANALYSIS

by

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ABSTRACT

The availability of options on an automobile can manifest itself in essentially two ways: through the availability of "fundamental varieties," namely body-styles and engine/transmission combinations - items of "fundamental" importance to an auto-buyer, and through the availability of "peripheral varieties," representing those stand-alone options and option packages which further tailor a vehicle to the customer's needs.

This thesis examines the relationship between the availability of fundamental and peripheral varieties and the manufacturability of the vehicle, and also in consumer decisionmaking. Essentially, are there extra costs associated with the presence of many vehicle options, and if so, are there benefits to be gained through additional sales which exceed the costs?

The statistical analysis of a database comprising 43 platforms reveals the following:

- There is a quality penalty (i.e. more defects) associated with the availability of additional "fundamental varieties", although there is no penalty involving the availability of "peripheral varieties".

- The availability of "fundamental varieties" or "peripheral varieties" has no discernible impact on assembly plant productivity (assembly hours/vehicle).

- The sale of a particular platform is benefitted through the availability of greater "fundamental variety", and to a lesser extent through the availability of "peripheral variety".

In sum, the benefits derived through the increased sales revenues associated with greater options availability surpasses the costs associated with such availability.

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Chapter I

Introduction

When making purchasing decisions, automobile buyers consider numerous factors - such as the reputation of the automaker, the size and price of the vehicle, the cost of operating the vehicle, and what features are offered on the vehicle. Different buyers want different things from their vehicles, factors which an automaker must accommodate if a sale is to be made. Many believe that the future of the auto industry will involve giving every buyer **exactly** what they want - from engine size, to trim features. This scenario appears possible since the advent of flexible manufacturing technologies. However, providing consumers with many options may come with some costs during the manufacture of the vehicle. The conventional wisdom suggests that there is a penalty in terms of vehicle quality and productivity.

Proponents of "lean production" - an approach to manufacturing which permits the flexibility of craft production while avoiding its related high costs[1] - have heralded many of the Japanese automobile manufacturers for their achievements in this area. In Japan, a vast majority of the cars are produced to customer specifications, with delivery of the car often occurring within two weeks of the initial order.[2] Conversely, American consumers who wish to custom order a vehicle from one of the domestic automakers must wait far

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[1] Womack, Jones and Roos, The Machine That Changed the World, New York, Rawson Associates, 1990, p. 13.

[2] Ibid., p. 183.

more time. The time between the initial order and delivery of the vehicle to the dealership can range from between three and twelve weeks - with the caveat that there may be delays.[3]

Because the majority of Japanese consumers custom order their vehicle, and they typically have many options (i.e. engine type, paint colour, upholstery, convenience features) from which to choose for the vehicle which they are purchasing, the Japanese assembly facilities must be prepared to deal with these specific orders. The production facilities do so by preparing and revising their forecasts and build schedules frequently. This flexibility, the relatively high productivity of the Japanese assembly plants, and the high quality associated with the Japanese-made automobiles have made these plants models of "lean production."

When these same Japanese manufacturers first began to export to North America, because of the distance between the assembly plants and the vehicles' final destination, the manufacturers were unable to offer special orders. Instead, many of the options which were available in Japan were offered as standard equipment. The different trim levels for any given model would usually not offer the same items as standard equipment, so consumers were given some limited choice in which items they would find on their car.

Given the distances involved, and therefore the lengthy shipping times, it was a reasonable decision for the Japanese automakers not to accept customer orders from North America. However, now many Japanese automakers have assembly plants in the United States and

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[3] This was obtained through interviews of sales managers at dealerships in the Boston area, representing the three U.S. automakers. Through these interviews one advantage of having few fundamental or peripheral varieties available of a given vehicle became apparent. I was told that it would be possible to custom order a Ford Festiva and have it delivered in only four days since the inventory of Festivas was large enough that essentially every combination of options had already been manufactured.

Canada. In this group we find, among others, Honda - with final assembly plants in Marysville, Ohio and Alliston, Ontario; Toyota - with plants in Georgetown, Kentucky and Cambridge, Ontario; Nissan - with a plant in Smyrna, Tennessee; Mazda - with a plant in Flat Rock, Michigan. These automakers now have assembly plants which are within a distance conducive to accepting special orders.

Despite their proximity to their North American consumers, these "transplants" do not offer the broad range of options which they offer on Japanese manufactured vehicles for their Japanese purchasers. Most vehicles produced by the "Big Three" automakers offer a significant number of options, so the Japanese companies which have assembly plants in the United States and Canada have made a conscious decision not to follow suit.

It is possible that North American consumers have simply been trained not to expect options on the vehicles made by these Japanese manufacturers. However, it is more likely that these companies simply chose to direct the manufacturing and engineering energies of their North American assembly facilities towards producing more "fundamental product varieties"[4] (Clark and Fujimoto, 1991) rather than the more "peripheral" stand-alone options.[5] At first glance, one might think that it was by keeping a degree of simplicity in their assembly operations that these transplants have achieved such a high degree of quality in their final products, and considerable productivity in the assembly plants.

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[4] Fundamental variety is found in those options that are the most easily recognizable and identifiable by consumers. These options would consist primarily of body styles and engine combinations.

[5] Clark and Fujimoto describe peripheral variety as the availability of options such as paint colour, upholstery, or any other feature which does not affect basic vehicle design

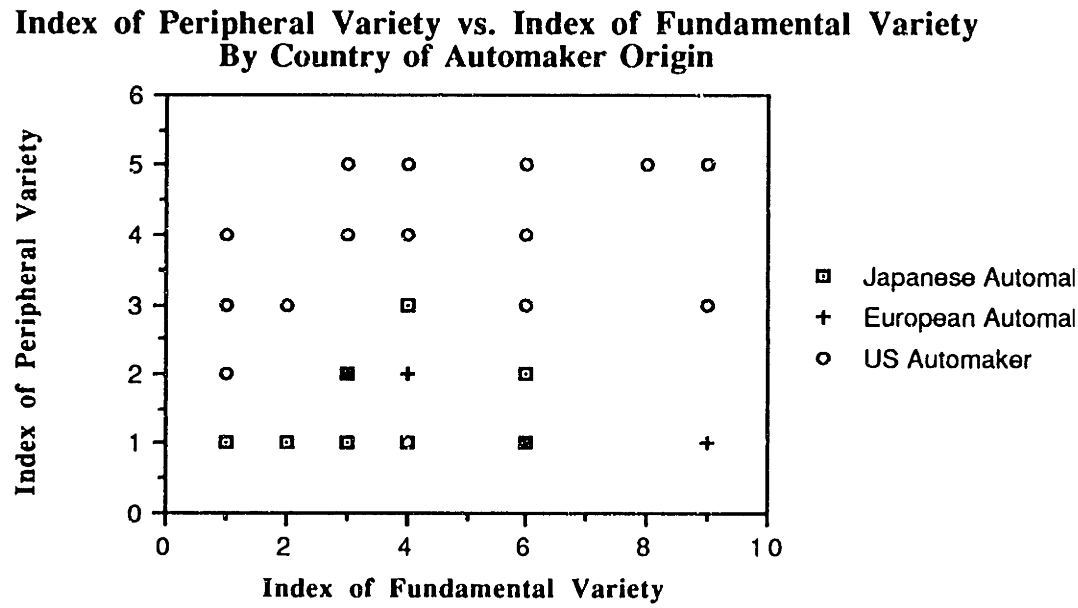

Figure 1

As is evidenced in Figure 1, the North American automakers persist in offering a considerable number of options, contributing to a huge number of "peripheral varieties" of their vehicles (each additional unit in the "index of peripheral variety" represents an additional order of magnitude of the number of distinct vehicles available for a platform if all of the combinations of options are counted). This is true in virtually every market segment. Even in the luxury segment, where vehicles are typically equipped with considerable standard equipment, there can be numerous stand-alone options available. For instance, the Cadillac Eldorado offers seven distinct options packages, incorporating some of the eighteen different stand-alone options available for the customer's selection; incorporating everything from heated windshields to wood appliques. However, when one buys an Eldorado, there is only a single body-style available (a two-door coupe), and no choice in engines. There are numerous examples of this approach in lower-end market segments as well.

This approach contrasts sharply with that of the Japanese manufacturers in the North American market. A case in point would be the Honda Civic. The Civic offers three different body styles from which to choose: a three-door hatchback, a four-door sedan, and a five-door station wagon. There are also three different engines. To permit some degree of customization, there are four different trim-levels one can order, with each level determining what features will be incorporated in the vehicle. Any other desired options - such as upgraded radios and luggage racks - are installed at the dealership.

Figure 2 displays the differing approaches which the various automakers employ with regards to "fundamental variety".[6] It is interesting to note that the American vehicles in the database have an average Fundamental Variety Index (FVX) which is slightly greater than that of the Japanese Vehicles.[7] The more telling indicator of the differing approaches to vehicle variety can be seen in Figure 3 which displays the average Peripheral Variety Index[8] (PVX) for the vehicles present in the database, broken down by country of automaker origin. Vehicles built by the U.S. automakers have by far the greatest PVX, almost tripling the average PVX of the vehicles manufactured by their Japanese counterparts.[9]

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[6] Fundamental Variety is represented in the database as an index comprised of the number of body styles multiplied by the number of engines available.

[7] Average FVX: US = 4.52, Japan = 3.27, Europe = 4.67, Other = 2.0

[8] Peripheral Variety is represented in the database as an index which roughly corresponds to the order of magnitude of the number of possible combinations of options available for a specific platform.

[9] Average PVX: US = 3.71, Japan = 1.33, Europe = 1.67, Other = 2.0

Average Fundamental Variety Index of Vehicles in Database
By Country of Automaker Origin

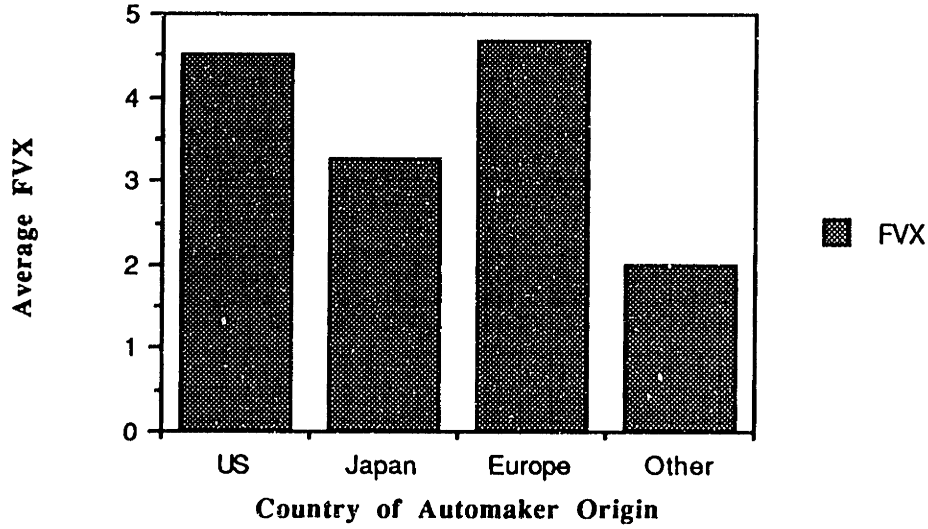

Figure 2

Average Peripheral Variety Index of Vehicles in Database
By Country of Automaker Origin

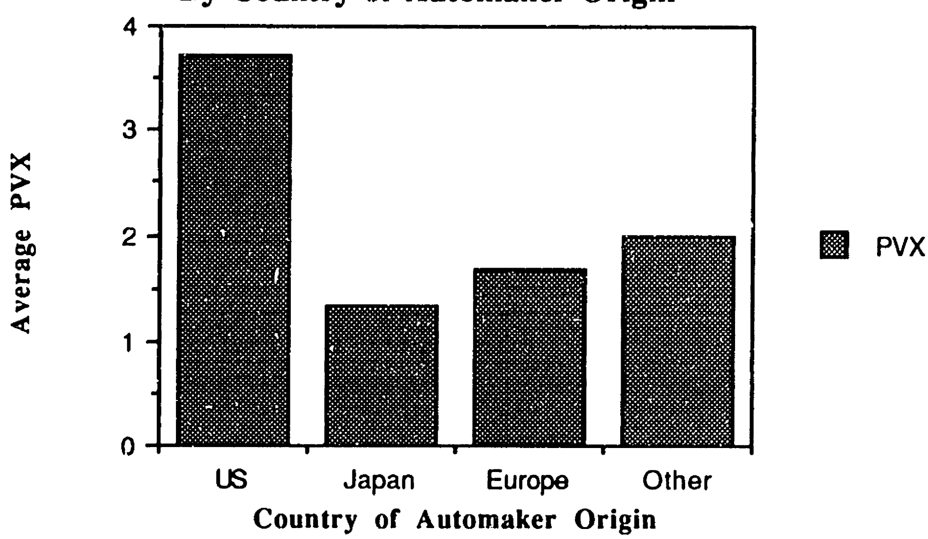

Figure 3

We appear to be at a cross-roads when it comes to product options policies. The advocates of "lean production" believe that the automobile assembly plants that will succeed will be those plants equipped to offer consumers whatever they desire. The more traditional automobile manufactures believe that the availability of this variety will come with very high costs such as decreased quality and productivity, and increased vehicle price.

Chapter II

Options Trends

When Henry Ford introduced the Model T, he was asked in what colours his customers could purchase the car. His infamous statement, "any colour - as long as it's black" represented the extent of his concern for such things as peripheral variety. However, the Model T was offered in nine different body styles - ranging from trucks, to sedans, to roadsters.[10] It was in this manner that Ford was able to satisfy the varied needs of his customers. The same chassis was used for each of these body styles, as were the same mechanical parts; and by offering considerable fundamental variety, Henry Ford was able to satisfy millions of purchasers.

However, the industry changed considerably in the 1920s, when customers were able to find greater comfort, performance and variety in the vehicles of General Motors. Alfred Sloan modified the formula which had served Henry Ford so well with the Model T, and added variety in body styles and colour. By offering a "better" product with a somewhat higher price and a far greater number of peripheral varieties, GM was thereby able to compete with Ford, despite the fact that Ford had the lower priced vehicles.[11]

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[10] Womack, Jones and Roos, The Machine That Changed the World, New York, Rawson Associates, 1990, p. 37.

[11] Clark and Fujimoto, Product Development Performance, Boston, Harvard Business School Press, 1991, p. 44.

Among U.S. automobile manufacturers, there traditionally has been the thought that extremely high production volumes were necessary to keep costs low. This led to the strategy of using the availability of optional equipment and many colours as a means of vehicle customization. This offset the fact that there was considerable standardization of parts and components, and satisfied the demands of American consumers for distinctive vehicles. This approach was pursued until the 1970s, whereby U.S. car designs, through the emphasis of a "body on frame" construction, were such that body development could be separated from power-train and chassis development. Frequent styling changes and considerable choice regarding optional equipment were therefore possible.[12]

Only recently in the United States has there been any tendency to attempt to reduce the number of stand-alone options. There has been greater use of options packages, whereby complementary options are bundled. These packages are useful because they can lead to a reduction in the number of stand-alone options ordered, thereby simplifying the ordering and the manufacturing of vehicles. Often, these packages are targeted to specific customer groups. One example is the frequently offered "performance package" - which can include such things as a more powerful engine, special tires, and racing trim - permitting a vehicle to be tailored towards those consumers wanting a sportier vehicle. Another example would be the "convenience package", possibly incorporating such things as power door locks and windows, cruise control and tilt-steering. Special packages may even permit these customer groups to enjoy savings on options which they would probably otherwise order as stand-alone ("discount packages"). Conversely, some manufacturers appear to offer packages as a means of gaining additional profits - by bundling commonly ordered options with other, less favored options.

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[12] Ibid., p. 46.

In Japan, the majority of customers order their vehicles directly from the factory, meaning that, within the Japanese market, there are still many stand-alone options and option packages, in addition to a broad range of fundamental varieties from which customers may choose. This is possible since the Japanese manufacturers, who by using just-in-time production techniques, total quality control, and by maintaining close relationships with their suppliers, are able to have more flexible factories.

Toyota was a case in point in the 1970s, whereby the production system which was "born of the need to make many types of automobiles, in small quantities with the same manufacturing process"[13] gave the company a distinct competitive advantage. Because their workers had acquired rapid die changing expertise, lot sizes of only a few hundred parts could be stamped successfully, permitting considerable flexibility in the number of products which could be manufactured in the relatively small production facilities available.[14]

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[13] George Stalk, "Time - the Next Source of Competitive Advantage", *Harvard Business Review*, July-August 1988, p. 44.

[14] Krafcik, "Triumph of the Lean Production System", Sloan Management Review, Fall 1988.

Chapter III

Thesis Scope

A complexity database has been compiled consisting of some 43 different vehicle platforms sold in the United States. The vehicles contained therein are manufactured by 13 different automakers, representing four different geographical regions: North America, Europe, Japan and Korea. Figure 4 displays the breakdown of the vehicles by country of automaker origin. In Figure 5 there is a further breakdown of the platforms, showing not only the country of automaker origin, but the region in which the platforms were assembled.

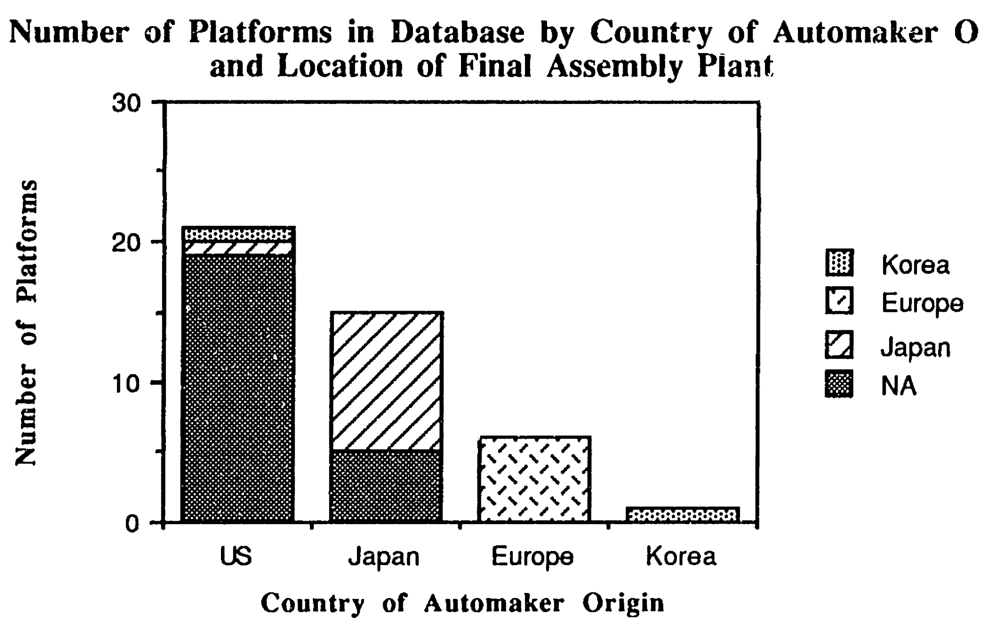

Figure 4

The vehicles represent several different market segments, comprising over 63% of all of the cars sold in the United States in 1989. The market segments present in the database run the gamut from sub-compacts to full-size vehicles. The breakdown of the database by vehicle price (which serves as a proxy for market segment) can be seen in Figure 5, as well as the country of origin of the manufacturers of the platforms present in each price range.

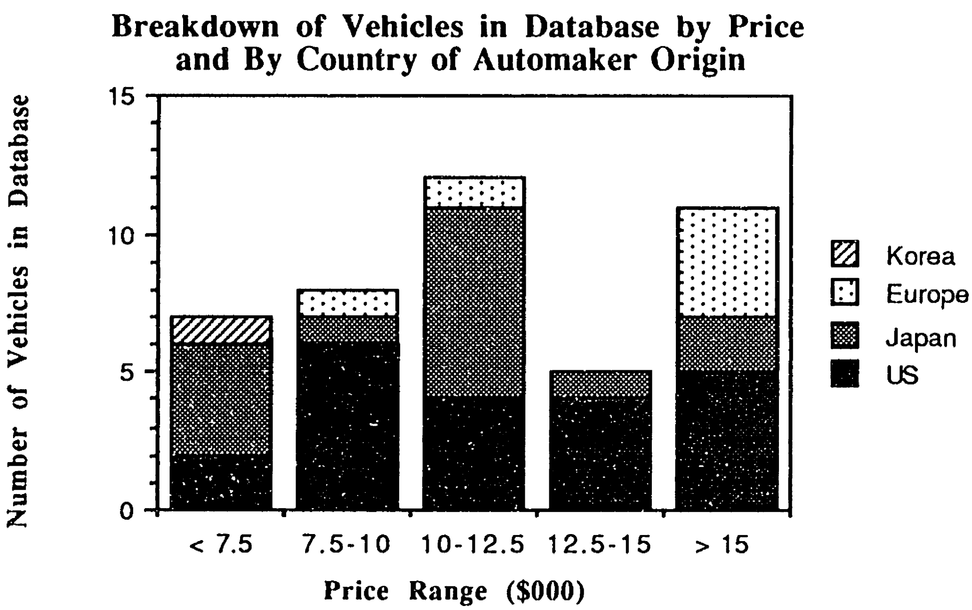

Figure 5

Chapter IV

Method

i Dependent Variables

Quality

The dependent variable in the quality regression analyses were the total number of defects per hundred vehicles. This data was obtained from the "J.D. Power - Initial Quality Survey, 1989." J.D. Power and Associates is a market research company in Agoura Hills California which surveys a significant number of American new car buyers 90 days after they have received delivery of their vehicles. Because the J.D. Power data only includes vehicles sold in North America, for the purpose of data consistency, it was decided to concentrate on the U.S. market specifically. Because the availability of fundamental and peripheral varieties would likely affect both the design and the manufacture of vehicles, no attempt was made to distinguish between types of defects. Instead, the total number of defects/100 vehicles reported by buyers during the first 3 months of ownership was used as the indicator of vehicle quality.[15]

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[15] Krafcik and MacDuffie in their 1989 study of assembly plants used an index which comprised only "those defects that an assembly plant can affect, ignoring such areas as engine performance and reliability." By choosing to use all defects reported by J.D. Powers, I made an assumption that the availability of fundamental and peripheral varieties has an impact well beyond the final assembly plant.

Productivity

The productivity data was obtained from the study by John Krafcik and John Paul MacDuffie of assembly plants - for the nineteen vehicles present in both the assembly plant study and the options policy database. The productivity numbers utilized represented a relative measure of the number of hours required to assemble a vehicle on a scale of 0-100. To facilitate the comparison of this model's results to the results of similar models, equivalent assumptions neglecting corrections for option content and worker absenteeism were made. Because the productivity data was assembled at the plant level, additional assumptions had to be made. In the event that more than one platform was being assembled at the same facility, the number of hours per vehicle specified in the Krafcik-MacDuffie database was applied to all of the platforms being investigated. In only one instance was the same platform being manufactured at more than one facility present in the database - on that occasion, it was the facility producing the greater proportion of that vehicle whose productivity (and Management Index) data was used.

Sales

The sales data used in these regression analyses was from the Ward's Automotive Yearbook, representing sales of vehicles in the United States - in terms of both sales revenue and unit sales. For simplicity of data gathering, the U.S. market was the one focussed on, and although this limits the scope of this investigation, it does permit a certain degree of consistency in data availability, and greater insights into the domestic market.

ii Independent Variables

Fundamental Variety Index (FVX)

The Fundamental Variety Index (FVX) is an indication to what extent the most basic and visible options are available to the consumer. The FVX consists of the number of body-styles available multiplied by the number of engines available for a given platform. For instance, the Ford Topaz platform has available two body styles - a two- and a four- door sedan. The platform also has two engines available, leading to a FVX of 4.

Within the database there is a range of FVX values from 1 to 12, representing numerous approaches towards the availability of fundamental variety. The average value of the FVX of the 43 vehicles in the database is 4.70.

Peripheral Variety Index (PVX)

The Peripheral Variety Index (PVX) represents to what extent stand-alone options and option packages are available for a given platform. The index essentially represents the total number of different combinations of all options available to a consumer, which is then transformed into a scale from 1 to 5. The transformations can be seen in Table 1. The average value of the PVX within the database is 2.56.

Table 1

Transformations of # of Peripheral Varieties into the PVX

Number of Peripheral Varieties	PVX	# in Database
1 - 100	1	15
101 - 1,000	2	7
1,001 - 10,000	3	9
10,001 - 100,000	4	6
Greater than 100,001	5	6

Dummy Variables

Because there was the possibility that other factors, beyond the options policies in effect on the vehicle which might affect vehicle quality and assembly productivity, several dummy variables were introduced. The two factors identified as having the greatest potential effect in the analyses were: the country of origin, and the market segment of the vehicle. The country of origin of the automaker was included in the regression through the use of variables which distinguished between automakers from the U.S., Japan, Europe, and elsewhere.

The market segment of the vehicle - i.e. mid-size, luxury, compact - was incorporated into the regressions through the use of several different variables. These included the ratio of vehicle curb-weight to its wheelbase. More luxurious cars are generally more "dense" than their less costly counterparts, leading to a higher weight to wheelbase ratio for luxury vehicles, and a relatively low ratio for compacts. The vehicle weight was also used as a proxy for market segment, as were average price and engine horsepower. This data was obtained from several sources, such as *Consumer Guide*, vehicle sales brochures, and Ward's Yearbook.

While performing the regression analyses for vehicle quality, the number of units sold was used to see if there was any significant relationship between the number of defects present on a vehicle and its sales numbers - in the event that institutional learning occurred which might cause fewer defects to be present when many cars are manufactured. Conversely, defect data was used in the regression analyses of vehicle sales in the event that consumers used vehicle quality as a determinant in their purchasing decisions.

In place of the country of automaker origin, the Management Index developed by Krafcik and MacDuffie for their World Assembly Plant Survey was used in a number of regression analyses. This measure places an assembly plant on a continuum between mass production and lean production philosophies, policies, and practices. It comprises four components: "the degree to which teamwork is employed in the plant; the level of 'visual control,' a proxy for worker span of control, employed in the plant; the level of unscheduled absenteeism, an indicator of worker participation and management expectations; and the percentage of floorspace dedicated to repair facilities, an indication of management expectations about process capabilities."[16] This variable would indicate whether it was the "leanness" of the manufacturing facility, rather than the nationality of the automaker, which contributed to vehicle quality and assembly plant productivity.[17]

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[16] J. Krafcik, "The Effect of Design Manufacturability of Productivity and Quality: An Update of the IMVP Assembly Plant Study", MIT International Motor Vehicle Program Working Paper, January 1990, p. 2.

[17] In previous studies, the Management Index was found to be an excellent predictor of assembly plant productivity and a good predictor of plant quality. "Lean" assembly plants (those with the highest Management Index scores) were those plants with the best productivity and quality.

Chapter V

Regression Results

i Quality

Classic thinking concerning the manufacturing environment suggests that the more complexity encountered in the workplace, the greater the cost in terms of product quality and assembly productivity. This is the main reason that the Design for Manufacture approach has concentrated on reducing the number of parts involved in product manufacture.

Table 2 shows the results of the regression analysis for the number of defects. The Fundamental Variety Index (FVX) was one of the most significant variables present in the regression, with a significance level of 0.01. The only variables of greater significance, were two of the dummy variables: the one with the greatest significance was the variable which indicated if the automaker is a Japanese company (t-ratio = -5.336). The other dummy variable having considerable significance was the variable which constituted the average vehicle price (this variable served in part as a proxy for the vehicle class). These dummy variables indicate that the Japanese automakers continue to have a quality advantage over their counterparts elsewhere. Also, more expensive vehicles tend to have slightly fewer defects. This last finding may be due to consumer expectation surrounding luxury vehicles. Having paid considerable amounts of money for their vehicle, these consumers expect to have defect-free vehicles, forcing the manufacturers to pay greater attention during the manufacture of luxury vehicles, thereby contributing to fewer defects.

Table 2: Regression Analysis for Vehicle Quality [Defects/100 Vehicles[18]]

Number of platforms: 43 Overall predictive power: Adjusted $R^2 = 0.636$

Variable	Coefficient (effect of variable)	Standard Error (variation in variable)	Interpretation
Fundamental Variety Index (FVX)	8.306+	2.826	For every unit increase in the number of body-style-engine combinations there is a small, but very significant increase in the number of defects
Peripheral Variety Index (PVX)	-9.566#	5.575	For every unit increase in the PVX, there is a corresponding decrease in the number of defects
Dummy Variables:			
Japanese Company	-76.90+	14.41	
Ratio of curb weight to wheelbase	14.836*	7.153	
Average Price	-0.004+	0.0012 (t-ratio = -3.101)	
Sales (Units sold)	-0.000#	(t-ratio = -1.880)	
No other variables were statistically significant predictors of quality.[19]			Statistical Significance: + = 0.01; * = 0.05; # = 0.10

[18] See Table 1a in the Appendix to view the regression results with defects as the dependent variable.

[19] The other variable that was included was vehicle weight (as a further proxy for the vehicles' class). For the full results of this regression analysis, see Table 1 a (Column 1) in the Appendix.

At a 5% level of statistical significance we find other variables. The Peripheral Variety Index (PVX) was significant at this level, as were the dummy variables comprising the number of models available for a given platform and the ratio of curb weight to wheel base.

This regression model suggests that the availability of additional fundamental varieties comes with some quality penalties, whereas the availability of additional peripheral varieties has no adverse effect on vehicle quality (the model even suggests that there might be a quality benefit). If taken literally, the model indicates that the availability of an additional fundamental variety (i.e. an additional body-engine combination) can result in an additional 8.3 defects/100 vehicles.

This result supports the notion that vehicle complexity will come at some cost, however it runs somewhat contrary to the results obtained by Krafcik and MacDuffie,[20] and Klatten.[21] However, the extent of peripheral variety available for a given platform supports the findings of the aforementioned researchers.

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[20] In their 1989 paper "Flexible Production Systems and Manufacturing Performance: The Role of Human Resources and Technology", Krafcik and MacDuffie found that the relationship between "Underskin Complexity" and vehicle quality ran contrary to the conventional wisdom. There was the finding that those assembly plants where the highest levels of Underskin Complexity (complexity in this study indicated the number of parts and part combinations) occurred also had the best overall quality. These plants were primarily Japanese, and had a strong tradition of being able to manage considerable complexity.

[21] In his 1991 Sloan School Master's thesis, Jan Klatten found that there was no significant association between the number of parts used in automotive assembly and the level of quality, and even with the specific cases of parts related specifically to fundamental and peripheral variety. However, Klatten's work was based on a very small sample, consisting only of vehicles in the compact market segment.

The model indicates a positive effect on vehicle quality from the availability of peripheral varieties. Perhaps what's most telling from the result is that there is essentially no penalty in the number of defects when additional peripheral varieties are available on a vehicle. Although this result may be somewhat suspect, if taken literally the model suggests that when there is a unit increase in the index of peripheral variety (a unit increase in the index roughly corresponds to an order of magnitude increase in the number of combinations of options available for the platform in question), there is a decrease of 9.6 defects/100 vehicles. One possible explanation for this result is that greater care is taken during the assembly of those vehicles in which there is considerable peripheral variety. Perhaps having the potential of many "different" vehicles being assembled necessitates the use of better production methods. Or conversely, perhaps better production methods are used out of necessity when there are many peripheral varieties available for a specific platform.

The number of vehicles sold was significantly correlated with fewer defects per vehicle (but only at the 10% level). This suggests that there is probably some quality advantage to be gained by manufacturing large numbers of vehicles. However, due to the negligible size of the coefficient obtained in the regression, it is not possible to support in any meaningful sense the belief that large production volumes are a significant factor in keeping manufacturing costs low.

Management Index

The regression analyses were repeated, with the Krafcik and MacDuffie Management Index used instead of the dummy variables representing country of origin of the automaker. In Table 3 we find the results of these analyses, with a rather strong Adjusted R^2 of 0.617.

It is important to note that the sample size of the analyses changes when the Krafcik and MacDuffie Management Index is used. When the original database of 43 platforms was augmented through the inclusion of the Management Index, there were only 19 platforms common to both studies. As a result, the analyses which include the Management Index have a sample size of only 19, thereby limiting the number of variables which can be tested for significance simultaneously, due to "degrees of freedom" concerns.

Table 3: Regression Analysis for Vehicle Quality [Defects/100 Vehicles[22]]

Number of platforms: 19 Overall predictive power: Adjusted $R^2 = 0.617$

Variable	Coefficient (effect of variable)	Standard Error (variation in variable)	Interpretation
Fundamental Variety inIndex (FVX)	7.448#	3.914	For every unit increase the number of body-style-engine combinations there is a significant increase in the number of defects
Dummy Variables:			
Management Index	-1.210*	0.534	The more "lean" an assembly facility is, the fewer defects found in its vehicles.
Engine Horsepower	1.323#	0.614	

No other variables were statistically significant predictors of quality.[23]

Statistical Significance:
+ = 0.01
* = 0.05
# = 0.10

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22 See Table 1c in the Appendix to view the regression results with defects as the dependent variable - and the Management Index being utilized as a dummy variable.

23 The other variables included were the Index of Peripheral Variety and vehicle weight (as a further proxy for the vehicles' class). For the full results of this regression analysis, see Table 1 c (Column 1) in the Appendix.

In this analysis, the statistically most significant contributor to vehicle quality was the Management Index (5%) - and therefore the "leanness" of the final assembly facility, confirming the findings of MacDuffie and Krafcik. For every ten-point increase to the Management Index, there is a corresponding decrease by 12.1 in the number of defects found per 100 vehicles.[24]

Also very interesting is the finding the the Fundamental Variety Index is significant (at the 10% level). The significance of this variable echoes the MacDuffie and Krafcik finding that Underskin Complexity was an important predictor of vehicle quality. However, this study contradicts their finding that the greater the complexity, the fewer the defects.[25] The regression suggests that with every additional body-style/engine combination available, there is a quality penalty of 7.5 defects/100 vehicles.

Of note is the fact that, in this regression, the Peripheral Variety Index was not statistically significant. This contrasts with the significance of the variable (10%) in the regressions which incorporate the nationality of the automaker - and the decrease in defects associated

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[24] In their September 1989 paper "Flexible Production Systems and Manufacturing Performance: The Role of Human Resources and Technology", MacDuffie and Krafcik found that for every ten-point increase in their "Production System Management Index" there was a corresponding decrease by 6 defects/100 vehicles of those defects directly related to the final assembly of the vehicle - revealing a very similar result in terms of the effect of plant management on vehicle quality.

[25] It is important to note that in the MacDuffie and Krafcik study, Underskin Complexity was a plant-level variable which included the number of engine/transmission combinations, and other variations which are hidden from the consumer which the plant must contend with. The PVX, is instead a product-level variable, which may account for the difference in result.

with increased peripheral varieties. This suggests that the leaner assembly facilities are capable of accommodating peripheral variety, and it is this "leanness" that results in higher quality vehicles, and not something intrinsic to the availability of greater numbers of peripheral varieties.

ii Productivity

With the availability of many body-styles, engine-transmisison combinations, stand-alone options, it would seem likely that there would be some kind of productivity penalty in the assembly plant. With the very real possibility of never assembling the "same" car twice, it might seem difficult to implement the standardizing, mass-production techniques, which in past have been associated with increased productivity.

However, despite what the conventional wisdom might say concerning the relationship between the availability of product varieties and productivity, the regression analyses do not reveal any kind of relationship between either the availability of fundamental or peripheral varieties and the productivity of assembly plants. Therefore, there is considerable evidence that there is no productivity cost associated with the potential of many product varieties. Table 4 displays the results of the regression.[26]

The productivity measure represents 0 to 100 scale of the number of hours of effort required to assemble a vehicle, and was obtained from the Krafcik and MacDuffie World Assembly Plant Study. As can be seen from the regression model, the strongest predictor of plant productivity is if the plant is operated by a Japanese automaker (1% level of

[26] See Table 3 in the Appendix for the full results of the regressions with productivity as the dependent variable.

significance). If the assembly facility is Japanese, there is a large decrease in the time required to assemble each vehicle. The second most significant variable is if the plant is operated by a European automaker (5% level of significance), where there is an increase in assembly time. Together these two variables account for 70% of the variation in assembly productivity. Neither the FVX nor the PVX proved statistically significant, suggesting that neither the presence nor the absence of many fundamental or peripheral varieties had an effect on plant productivity.

Table 4: Regression Analysis for Assembly Plant Productivity

Number of platforms: 19 Overall predictive power: Adjusted $R^2 = 0.704$

Variable	**Coefficient** (effect of variable)	**Standard Error** (variation in variable)	**Interpretation**
Fundamental Variety Index (FVX)	-0.188	0.691	The number of body-style-engine combinations has no significant impact on productivity
Peripheral Variety Index (PVX)	-2.605	1.886	The number of peripheral varieties available has no effect on productivity
Dummy Variables:			
Japanese Company	-18.873^{+}	5.697	
European Company	14.282^{*}	6.772	

Statistical Significance:
$^{+}$ = 0.01
* = 0.05
$^{\#}$ = 0.10

In the recent work of MacDuffie and Sethuraman at the Wharton School, there has also been an investigation of the impact of complexity on labor productivity, using the same World Assembly Plant productivity and Management Index figures as used in this study.

In a draft of their 1992 paper "Impact of Product Variety on Manufacturing Operations: An Empirical Investigation in the Auto Industry" (not yet published), they found that "model mix complexity" (which is a variable representing the number of models and body styles being assembled at a given facility and therefore roughly akin to the FVX) was not a significant factor in explaining productivity differences between assembly facilities, which is essentially the same result as found in this study. However, they found that "option complexity" (a variable which represents the option content of the models produced in an assembly plant and therefore similar to the PVX) was statistically significant (at a 5% level) - and that greater option complexity had an adverse effect on total labor productivity. This represents a different result than found in this study, and may be due to differences in interpreting peripheral variety and option complexity.

Management Index

The regressions were repeated using the Management Index developed by MacDuffie and Krafcik.[27] The Management Index did not prove to be as effective a predictor of productivity as the nationality of the automaker; when used in place of any dummy variables representing nationality, the Management Index and the PVX and the FVX together accounted only for 42% of the variation in productivity (versus 70% when the Japan and Europe dummy variables were used). When the Management Index and the dummy variables representing nationality were used, the Management Index did not prove significant in predicting productivity. In none of these analyses did either of the PVX or the FVX prove to be of any statistical significance.

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[27] The results including the Management Index can be seen in Table 3, columns 3 - 5 in the Appendix.

iii Sales

American consumers have always been thought to prefer variety of choice in their automobile purchases, and two rather distinct philosophies of providing variety have been pursued in the American market. The availability of considerable fundamental variety, by offering several body styles and engines, has been the tactic primarily employed by the Japanese automakers in the North American market. Instead, the North American automakers have typically concentrated to a somewhat lesser extent on fundamental variety, preferring to offer considerable peripheral varieties to their customers.

Table 5 shows the regression analysis results for vehicle sales in the United States. The strongest predictor of vehicle sales in the statistical model was the FVX (with a significance level of 1%), for which there was a strong positive correlation. The PVX was next, followed by the dummy variable indicating if the vehicle was built by a European manufacturer.

The regression results suggest that both approaches concerning the availability of variety have their merits. By offering an additional fundamental variety, the model indicates that there will be additional revenue of as much as $50 million from further sales from that platform.[28] By increasing the number of peripheral varieties, the model also suggests that further sales will be made.[29] In effect, through the availability of greater numbers of peripheral and fundamental varieties of a given platform, automakers are thereby able to

[28] Δ Sales \$ = exp (19.389 + 0.176) - exp (19.389) = \$ 50,678,000

[29] The statistical model suggests a very significant increase in sales when there is a unit increase in the PVX:
Δ Sales \$ = exp (19.389 + 0.217) - exp (19.389) = \$ 63,822,000

obtain additional revenue, probably since they are better able to tailor their products to meet the needs of a greater number of purchasers.

Table 5: Regression Analysis for U.S. Vehicle Sales [ln(Yearly Sales of Platform - $)[30]]

Number of platforms: 43 Overall predictive power: Adjusted $R^2 = 0.513$

Variable	Coefficient (effect of variable)	Standard Error (variation in variable)	Interpretation
Fundamental Variety inIndex (FVX)	0.176^{+}	0.0512	For every unit increase the number of body-style-engine combinations there is a significant increase in sales revenue
Peripheral Variety Index (PVX)	0.217^{+}	0.0783	For every unit increase in the PVX, there is a corresponding increase in sales
Dummy Variables:			
European Company	-0.762*	0.286	
Weight	0.001*	(t-ratio 2.089)	
Defects	-0.006*	(t-ratio -2.604)	

Statistical Significance:
$^{+}$ = 0.01
* = 0.05
$^{\#}$ = 0.10

Another interesting finding which the regression reveals is the negative correlation between defects and sales revenues (significant at a 5% level). If taken literally, the model would

30 The natural logarithm of sales revenue was used for this model since it yielded a greater predictive power than did the regression analyses for sales untransformed. See Table 2 a in the Appendix to view the regression results with the untransformed sales as the dependent variable.

link a $1.6 million decrease in sales revenues with every additional defect/100 vehicles present on a given platform.[31]

In the event that the FVX was somehow serving as a proxy for the number of different models available for a given platform (i.e. the GM-J platform is available in two different models: as a Chevrolet Cavalier and as a Pontiac Sunbird), this number was substituted into the regression model for the FVX. There was an initial suspicion when performing these analyses that perhaps consumers were merely "fooled" by the automakers by the appearance of greater fundamental varieties through the use of several different models.

The regression analyses indicated that the number of models available was not a statistically significant factor when predicting vehicle sales.[32] This suggests that American auto-buyers are less interested in which division manufactured a vehicle, but instead in the properties and merits of a given vehicle.

This technique is used frequently by the U.S. automakers who tend to market the same platform in the U.S. market under a variety of names and guises. For instance, by marketing a specific platform under the auspices of Pontiac, Buick and Oldsmobile, as GM does with the N-Platform, different customer groups can be targeted. Pontiac has traditionally positioned itself to appeal to younger, more performance-minded buyers, while Buick and Oldsmobile vie for a more mature and potentially wealthier market.

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[31] The model shows the following decrease in sales revenue with the presence of an additional defect/100 vehicles:
Δ Sales \$ = exp (19.389 - 0.006) - exp (19.389) = \$ 1,577,000

[32] The regression had an Adjusted R^2 of 0.39. Although the coefficient for the number of models was positive, its t-ratio of 1.31 strongly suggested that the variable was not statistically significant and therefore no conclusions could be drawn.

Particularly with General Motors, this approach has a strong historical tradition, when Alfred Sloan developed in the 1930s, a broad product line designed to appeal to every car-buyer - Chevrolets were directed at first-time buyers and those who preferred cheaper cars, to Cadillacs, for wealthier buyers and status seekers - buyers were supposed to graduate from Chevrolets to Pontiacs, and so on, until the GM buyer reached the automotive pinnacle, the Cadillac. It is possible that the availability of multiple models is similar to the availability of additional peripheral varieties. Consumers buying U.S. automobiles, in addition to choosing such options as power steering and vehicle colour, also have a choice in the name and "brand" of their vehicle, and therefore in the image which their car projects.

Unit Sales

To further examine the effect of option availability on vehicle sales in the United States, the relationship between the Fundamental and Peripheral Variety Indices and unit sales was examined statistically. The predictions made in the examinations of sales revenues were consistent with the regression results of the unit sales analyses.

In Table 6 we can see the results of the regression.[33] What is rather interesting is the comparison of the regressions for total sales revenue and units sold, and the similarity in the variables which proved to be significant, and the fact that the variables were significant at very similar levels. The FVX, closely followed by the PVX, were the two variables which proved the most significant predictors of units sold. With the ratio of vehicle curb-weight to wheelbase, a proxy for market segment, next in significance, followed by (at a significance level of 10%) the dummy variables for European manufactured vehicles, the

[33] See Table 2c in the Appendix for the results of all of the regression analyses involving unit sales.

number of defects and vehicle curb weight, the set of these six variables accounted for 54% of the variation in the number of units sold, revealing a meaningful relationship.

For every additional body style / engine combination, the model predicts that there would be the sale of an additional 30,000 vehicles. Also, as the number of peripheral varieties available for a platform increases ten-fold (which is approximately equivalent to the availability of an additional three stand-alone options for a given platform), there exists the possibility of as many as 37,000 units from a platform being sold.

Table 6: Regression Analysis for # U.S. Vehicles Sold

Number of platforms: 43   Overall predictive power: Adjusted $R^2 = 0.538$

Variable	Coefficient (effect of variable)	Standard Error (variation in variable)	Interpretation
Fundamental Variety Index (FVX)	30,714^{+}	7,934	For every unit increase in the number of body-style-engine combinations there is a significant increase in the number of units sold from a specific platform
Peripheral Variety Index (PVX)	37,144^{+}	12,075	For every unit increase in the PVX, there is a corresponding increase in units sold
Dummy Variables:			
European Company	-87,002$^{\#}$	44,344	
Weight	255.2$^{\#}$	127.6	
Weight/Wheel Base	-40,802*	19,021	
Defects	-666.5$^{\#}$	343.6	

Statistical Significance:
$^{+}$ = 0.01
* = 0.05
$^{\#}$ = 0.10

Of additional interest is the finding that there is a negative correlation between defects and the number of units sold in the United States. The model suggests that for every additional defect/100 vehicles present on a given platform, that sales of that platform would be decreased by 666 units. The statistical significance and negative correlation between the dummy variable representing European vehicles and sales revenues is probably reflective of generally lower unit sales of vehicles produced in Europe in the U.S. market.

Chapter VI

Conclusions

The product options policies which an automaker employs can have a genuine impact on the manufacturability of the company's vehicles and their eventual sale. The regression analyses revealed that the most significant effect which option availability has is in determining vehicle quality. The FVX and the PVX, and the dummy variables representing market segment, units sold, and whether the automaker was Japanese, together accounted for 64% of the variation in the number of defects present - thereby proving to be a very good model of vehicle quality.

The presence of many fundamental varieties proved particularly important in the analysis of vehicle quality. With a statistical significance level of 1%, the additional defects associated with additional fundamental varieties which the model predicts must be taken very seriously. There appears to be a significant quality penalty associated with higher numbers of fundamental varieties. No such penalty is associated with high peripheral variety, the model even suggests that there are decreasing numbers of defects associated with higher peripheral varieties (although no causal link should be implied).

A similar analysis was performed with regard to assembly plant productivity and the options policies in place on the vehicles assembled. The model was able to account for 70% of the variation in assembly plant productivity, suggesting that it was a very good predictor of productivity, however, neither the availability of fundamental varieties or peripheral varieties proved statistically significant. Far more useful predictors of plant productivity proved to be the country of automaker origin, or the "leanness" of the plant. In sum, the options policies present on a vehicle had no discernible effect on the hours necessary to assemble that vehicle.

Using the model developed to predict U.S. sales, it was possible to explain 51% of the variation in revenue per platform. The number of options available for a platform proved to be, statistically, the most significant variables, including the dummy variables representing vehicle quality, market segment and the nationality of the automaker. The presence either of additional peripheral or fundamental varieties had a positive effect on sales revenues.

When the quality cost, in terms of additional defects, associated with additional fundamental varieties (there appears to be no such cost associated with peripheral variety) is factored into the model of vehicle sales, the benefits of additional fundamental varieties appear to well outweigh the costs.[34]

If taken literally, the models suggest that the revenue to be gained in the U.S. market alone through the availability of an additional fundamental variety could be as much as $35 million. Of course this value does not reflect any other costs (i.e. capital or administrative) which might be associated with the availability of an extra fundamental variety, and it is a very rough estimate. However, its magnitude and the strong predictive values of the two models utilized suggest that there are considerable benefits to be gained by having many fundamental varieties available of the same platform, and likewise with peripheral varieties.

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[34] Δ Sales \$ = exp (19.389 + 0.176 - 8.31defects*0.006) - exp (19.389) = \$35,412,000

All told, the automakers will have considerable impetus to react to consumer demands for greater selection. It appears that the "lean production" techniques described in the book The Machine that Changed the World will be the tools necessary to overcome some of the difficulties associated with increased customization of automobiles. However, this study reveals that the obstacles aren't as great as might initially have been perceived, and that there are many rewards to be gained by giving automobile buyers exactly what they want.

APPENDIX

Table 1 a.

Regression Parameters for Dependent Variable Total Defects

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	78.89	0.919	91.711	1.608	122.80	6.71
FVX	6.257	2.55	4.167	2.15	2.621	0.988
PVX	-11.68	-1.73	-10.64	-1.92	9.277	1.68
# Models	-30.05	-2.73	-32.218	-3.025		
USA	-2.447	-0.064				
Japan	-112.03	-2.98	-97.49	-6.53		
Europe	-38.88	-0.919				
Engine HP	0.321	0.858				
Weight	-0.067	-1.38				
Wt/WhlBs	15.69	1.90				
Price	-0.005	-3.34	-0.005	-3.691		
Sqr(Sales)	-0.077	-1.41				
R^2	0.707		0.628		0.106	
Adj R^2	0.603		0.565		0.061	
F	6.799		10.109		2.368	
P	0.000		0.000		0.107	
N	43		43		43	

Table 1 b.

Regression Parameters for Dependent Variable SQR(Total Defects)

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	7.54	2.67	5.21	1.72	8.04	2.53
FVX	0.215	2.76	0.131	1.78		
PVX	-0.464	-1.94	-0.536	-2.59	-0.472	-2.29
# Models	-1.09	-2.82				
USA	1.14	1.50				
Japan	-3.14	-4.98	-3.43	-6.11	-3.51	-6.09
Europe						
Engine HP						
Weight	-0.003	-1.57	-0.004	-2.06	0.018	1.27
Wt/WhlBs	0.674	2.61	0.803	2.88	0.602	1.93
Price	-0.000	-3.73	-0.000	-3.08	-0.000	-3.30
Sqr(Sales)	-0.002	-1.114				
R^2	0.718		0.618		0.603	
Adj R^2	0.642		0.555		0.537	
F	9.354		9.725		9.109	
P	0.000		0.000		0.000	
N	43		43		43	

Table 1 c.

Regression Parameters for Dependent Variable "Total Defects"

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	260.54	2.92	148.92	2.14	172.31	0.977
FVX	7.45	1.90	11.58	2.54	10.15	1.74
PVX	5.64	0.762	1.93	0.249	-1.81	-0.209
Mgt Index	-1.21	-2.27	-.963	-1.50	-1.33	-2.14
Engine HP	1.32	2.15	0.245	0.931		
Weight	-0.096	-1.80				
Wt/WhlBs					0.317	0.036
Price					0.001	0.226
Sqr(Prod)			-0.066	-0.933		
R^2	0.724		0.677		0.634	
Adj R^2	0.617		0.552		0.494	
F	6.811		5.441		4.510	
P	0.003		0.006		0.013	
N	19		19		19	

Table 2 a.

Regression Parameters for US SALES ($)

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	.404 E10	1.469	.234 E10	1.130	-.191 E9	-.437
FVX	.336 E9	3.312	.314 E9	3.480	.156 E9	1.905
PVX	.312 E9	1.447	.372 E9	2.709	.451 E9	3.408
USA	-.778 E9	-.625				
Japan	-.110 E10	-.876				
Europe	-.163 E10	-1.292	-.707 E9	-1.401		
Engine HP	.650 E7	.619				
Weight	.285 E7	1.803	.276 E7	1.900		
Wt/WhlBs	-.397 E9	-1.497	-.340 E9	-1.569		
Defects	-.104 E8	-2.007	-.861 E7	-2.201		
R^2	0.550		0.535		.342	
Adj R^2	0.427		0.458		.309	
F	4.481		6.909		10.407	
P	0.001		0.000		0.000	
N	43		43		43	

Table 2 b

Regression Parameters for Dependent Variable ln(US SALES $)

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	21.85	14.21	19.39	3.03	19.79	75.7
FVX	0.182	3.21	0.176	3.44	0.062	1.27
PVX	0.224	1.86	0.217	2.77	0.308	3.895
USA	-0.816	-1.17				
Japan	-0.827	-1.17				
Europe	-1.52	-2.15	-0.762	-2.66		
Engine HP	0.006	0.953				
Weight	0.002	1.72	0.000	2.09		
Wt/WhlBs	-0.205	-1.382				
Defects	-0.005	-1.891	-0.006	-2.60		
R^2	0.611		0.571		0.349	
Adj R^2	0.505		0.513		0.317	
F	5.756		9.861		10.745	
P	0.000		0.000		0.000	
N	43		43		43	

Table 2 c.

Regression Parameters for US SALES (vehicles)

Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	627,176	2.631	438,589	2.407	542,840	2.523
FVX	33,641	3.828	30,714	3.871		
PVX	31,611	1.693	37,144	3.076	43,856	2.904
USA	-114,580	-1.063				
Japan	-143,200	-1.312				
Europe	-213,027	-1.944	-87,002	-1.962	-60,525	-1.167
Engine HP	616.6	0.676				
Weight	268.1	1.961	255.2	2.000	213.7	1.423
Wt/WhlBs	-46,365	-2.016	-40,802	-2.145	-42,238	-1.887
Defects	-862.93	-1.914	-666.5	-1.940	-54.329	-0.152
# Models					40,444	1.256
R^2	0.627		0.604		0.463	
Adj R^2	0.525		0.538		0.373	
F	6.154		9.147		5.164	
P	0.000		0.000		0.001	
N	43		43		43	

Table 3

Regression Parameter for Dependent Variable **Productivity**

	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat
Const	39.52	4.83	41.98	6.15	27.76	1.79	36.06	2.83	69.78	5.88
FVX	-.237	-.331	-.188	-.272	0.143	0.171			-.804	-.828
PVX	-3.07	-1.47	-2.61	-1.38	-3.39	-1.58	-2.56	-1.46	-3.21	-1.95
MgtX					.188	.893	.110	.688	-.509	-3.86
USA	4.92	.580			8.05	.871				
Japan	-15.6	-1.94	-18.9	-3.37	-19.7	-2.11	-22.4	-3.14		
Europ	17.7	1.95	14.3	2.11	21.6	2.13	15.6	2.30		
R^2	0.776		0.770		0.790		0.776		0.514	
AdjR^2	0.690		0.704		0.685		0.713		0.416	
F	8.999		11.72		7.515		2.153		5.283	
P	.001		.000		.002		.000		.011	
N	19		19		19		19		19	