THE DYNAMICS OF AUTOMOBILE DEMAND

Statement of the Problem.................. S. L. Horner

Factors Governing Changes in Domestic Automobile Demand............... C. F. Roos and Victor von Szeliski

Hedonic Price Indexes with Automotive Examples.................... A. T. Court

Significance of the Findings.................. S. M. DuBrul
General Motors Corporation
New York, N. Y.
1939
FOREWORD

Because of the great interest which has been evidenced during the past few years in the subject of prices and price phenomena, especially in the field of manufactured products, General Motors Corporation undertook to have a general study made of the effect of price and price changes upon the demand for automobiles. The study developed into a broad analysis of the many factors affecting automobile demand, and was presented at two sessions of a joint meeting of the American Statistical Association and the Econometric Society in Detroit on December 27, 1938, under the title of "The Dynamics of Automobile Demand." In addition, on the same program Mr. Court presented a paper on automobile prices and values.*

Most of the previous statistical studies of this kind have been outside the durable goods field. The present study has attempted to apply in the field of consumers durable goods some of the mathematical techniques which have been used, for the most part, in the field of perishable or semi-perishable goods. The study therefore represents, to a considerable degree, the breaking of new ground. Because of this fact and the interest expressed in the program as presented in Detroit, General Motors Corporation has published these papers in order to make the results of this study generally available.

*Permission of the Automobile Manufacturers Association to include in this pamphlet Mr. Court's paper "Hedonic Price Indexes" is gratefully acknowledged.
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOREWORD</td>
<td>iii</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>TABLE OF CHARTS</td>
<td>ix</td>
</tr>
<tr>
<td><strong>STATEMENT OF THE PROBLEM</strong></td>
<td></td>
</tr>
<tr>
<td>Price Problems and the Individual Automobile Manufacturer</td>
<td>3</td>
</tr>
<tr>
<td>Factors Which Might Be Expected to Influence the Demand for Automobiles</td>
<td>6</td>
</tr>
<tr>
<td>Meaning of Demand for Automobiles in Present Study</td>
<td>7</td>
</tr>
<tr>
<td>Important Factors Influencing Year-to-Year Changes in Sales</td>
<td>9</td>
</tr>
<tr>
<td>Important Factors Influencing Monthly Changes in Sales</td>
<td>16</td>
</tr>
<tr>
<td><strong>FACTORS GOVERNING CHANGES IN DOMESTIC AUTOMOBILE DEMAND</strong></td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>21</td>
</tr>
<tr>
<td>Section I—The Notions of Demand Function and of Elasticity</td>
<td>24</td>
</tr>
<tr>
<td>Section II—Recent Studies of Automobile Demand</td>
<td>26</td>
</tr>
<tr>
<td>A Time Trend Analysis</td>
<td>26</td>
</tr>
<tr>
<td>The P. de Wolff Study</td>
<td>29</td>
</tr>
<tr>
<td>Section III—Formulation of the Problem</td>
<td>31</td>
</tr>
<tr>
<td>1. New Owner Sales and Replacement Sales</td>
<td>32</td>
</tr>
<tr>
<td>2. Combined Sales</td>
<td>33</td>
</tr>
<tr>
<td>3. Dependence of Sales on Rate of Change of Income</td>
<td>35</td>
</tr>
<tr>
<td>4. The Concept of a Variable Maximum Ownership Level</td>
<td>36</td>
</tr>
<tr>
<td>Section IV—Definition and Measurement of the Factors</td>
<td>38</td>
</tr>
<tr>
<td>1. National Income</td>
<td>39</td>
</tr>
<tr>
<td>2. Cost of Living</td>
<td>41</td>
</tr>
<tr>
<td>3. Price</td>
<td>42</td>
</tr>
<tr>
<td>4. Used Car Prices and Stocks</td>
<td>44</td>
</tr>
<tr>
<td>5. Cars in Operation or Consumers' Car Stocks</td>
<td>45</td>
</tr>
<tr>
<td>Section V—Age Distribution of Car Inventory and the Pressure for</td>
<td>47</td>
</tr>
<tr>
<td>Replacement</td>
<td></td>
</tr>
<tr>
<td>Car Survival and Scrapping Curves</td>
<td>47</td>
</tr>
<tr>
<td>Age Distribution</td>
<td>50</td>
</tr>
<tr>
<td>Formulas for Replacement Sales</td>
<td>51</td>
</tr>
<tr>
<td>Section VI—New Owner Sales</td>
<td>54</td>
</tr>
<tr>
<td>Section VII—Retail Sales Demand Functions</td>
<td>58</td>
</tr>
<tr>
<td>Partial Relationships</td>
<td>61</td>
</tr>
<tr>
<td>The Residuals</td>
<td>64</td>
</tr>
</tbody>
</table>
CONTENTS

FACTORS GOVERNING CHANGES IN DOMESTIC AUTOMOBILE DEMAND—Continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIII</td>
<td>Other Factors Affecting Retail Sales</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>1. The Relation of Used Car Allowances to Automobile Sales</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>2. Financing Terms</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>3. Neglected Factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a. Highway Carrying Capacity and Car Servicing Facilities</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>b. Operating Costs</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>c. Purchasing Power Sources Other Than Income</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>d. Dealers' Used Car Stocks</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>e. The Price of Goods Competitive with Automobiles</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>f. The Style Factor</td>
<td>72</td>
</tr>
<tr>
<td>IX</td>
<td>Month-to-Month Fluctuations in Automobile Sales</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>1. Seasonal Variation, and New Model Stimulus</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Method of Analysis</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>2. Price Change Anticipation</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>3. Field Stocks and Production</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>4. Combination of Short-Term and Long-Term Factors</td>
<td>84</td>
</tr>
<tr>
<td>X</td>
<td>Discussion and Summary of the Results</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>1. The Concept of Demand</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>2. Formulation of a Hypothesis</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>3. Statistical Results</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>a. The Maximum Ownership Level</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>b. The Income Factor</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>c. Replacement Sales</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>d. New Owner Sales</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>e. Retail Sales</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>f. Price Elasticity</td>
<td>90</td>
</tr>
</tbody>
</table>

HEDONIC PRICE INDEXES

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance of Problem</td>
<td>99</td>
</tr>
<tr>
<td>Price Index Essentials</td>
<td>100</td>
</tr>
<tr>
<td>A Few Errors</td>
<td>100</td>
</tr>
<tr>
<td>Establishing Price Comparisons</td>
<td></td>
</tr>
<tr>
<td>Overlapping Series</td>
<td>103</td>
</tr>
<tr>
<td>Broad Definitions</td>
<td>103</td>
</tr>
<tr>
<td>Prices in Terms of Specifications</td>
<td>107</td>
</tr>
<tr>
<td>Significant Specifications</td>
<td>114</td>
</tr>
<tr>
<td>Summary</td>
<td>115</td>
</tr>
<tr>
<td>Discussion by Louis H. Bean of Hedonic Price Indexes</td>
<td>118</td>
</tr>
</tbody>
</table>
## CONTENTS

### SIGNIFICANCE OF THE FINDINGS

<table>
<thead>
<tr>
<th>The Supply Problem: Illustrations of Effects of Price and Cost Changes</th>
<th>124</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Demand Problem: Effectiveness of Price Changes Limited by Demand Conditions</td>
<td>131</td>
</tr>
<tr>
<td>Prices Controlled by Costs, Not by Concentration: Demand Controls Production</td>
<td>133</td>
</tr>
<tr>
<td>The Narrow Range of Feasible Price Adjustments</td>
<td>134</td>
</tr>
<tr>
<td>Other Weaknesses of Flexible Price Theory</td>
<td>136</td>
</tr>
<tr>
<td>The Limitations of Price Elasticity Analysis</td>
<td>137</td>
</tr>
<tr>
<td>No Measure of Quality Elements in Price Indexes</td>
<td>138</td>
</tr>
<tr>
<td>Other Significant Factors</td>
<td>138</td>
</tr>
</tbody>
</table>
# TABLE OF CHARTS

## STATEMENT OF THE PROBLEM

<table>
<thead>
<tr>
<th>Number</th>
<th>Chart Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Passenger Car Price Indexes 1925-1937</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Cars in Operation and Number of New Cars Sold in United States 1919-1938</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Total Car Sales in Domestic Market and Federal Reserve Board Index of Industrial Production 1919-1938</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Total Car Sales in Domestic Market and National Income Paid Out 1919-1938</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Total Car Sales—Domestic Market—Actual and Calculated—Based on National Income and Change in National Income 1921-1938</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>National Income 1919-1938</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>Total Car Sales in Domestic Market and Federal Reserve Board Index of Industrial Production 1929-1938 by Months</td>
<td>17</td>
</tr>
</tbody>
</table>

## FACTORS GOVERNING CHANGES IN DOMESTIC AUTOMOBILE DEMAND

<table>
<thead>
<tr>
<th>Number</th>
<th>Chart Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Time Trend Analysis—U. S. Passenger Car Sales 1919-1938</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>P. de Wolff Study 1921-1934</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Consumers' Car Stocks and Changing Maximum Ownership Level</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>Maximum Ownership Compared with Cars in Operation 1919-1938</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>Retail Sales of Passenger Cars and Related Factors 1919-1938</td>
<td>38</td>
</tr>
<tr>
<td>6</td>
<td>Annual Sales of Passenger Cars by Occupational Groups 1928-1935</td>
<td>41</td>
</tr>
<tr>
<td>7</td>
<td>National Income 1919-1938</td>
<td>41</td>
</tr>
<tr>
<td>8</td>
<td>Automobile Price Indexes</td>
<td>42</td>
</tr>
<tr>
<td>9</td>
<td>Cars in Operation 1919-1937</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>Passenger Car Survival Curves</td>
<td>48</td>
</tr>
<tr>
<td>11</td>
<td>Passenger Cars Scrapping Curves—Per Cent of Original Group Scrapped at Given Age</td>
<td>48</td>
</tr>
<tr>
<td>12</td>
<td>Passenger Cars—Scrapping—Theoretical Scrapping Derived by Applying Scrapping Curve to Retail Sales of Previous Years 1919-1938</td>
<td>49</td>
</tr>
<tr>
<td>13</td>
<td>Scrapping Rate by Age</td>
<td>52</td>
</tr>
<tr>
<td>14</td>
<td>Passenger Cars—Scrapping—Theoretical Scrapping Derived by Applying Scrapping Ratios to Age Distribution 1919-1938</td>
<td>52</td>
</tr>
<tr>
<td>15</td>
<td>Age Distribution of Consumers' Car Stocks 1919-1938</td>
<td>53</td>
</tr>
<tr>
<td>16</td>
<td>Replacement Sales—Actual and Calculated 1919-1938</td>
<td>55</td>
</tr>
<tr>
<td>17</td>
<td>New Owner Sales—Actual and Calculated 1919-1938</td>
<td>55</td>
</tr>
<tr>
<td>18</td>
<td>Percentage Increase in Car Population Related to Car Population 1919-1938</td>
<td>56</td>
</tr>
<tr>
<td>19</td>
<td>Maximum Ownership Level per Family, Formula M_2 1919-1938</td>
<td>58</td>
</tr>
<tr>
<td>20</td>
<td>Actual Sales Compared with Sum of Calculated New Owner and Replacement Sales 1919-1938</td>
<td>59</td>
</tr>
<tr>
<td>21</td>
<td>Passenger Car Sales—Actual and Calculated 1919-1938</td>
<td>60</td>
</tr>
<tr>
<td>22-29</td>
<td>Formula 16 for Retail Sales and Component Terms 1919-1938</td>
<td>62</td>
</tr>
</tbody>
</table>
TABLE OF CHARTS

FACTORs GOVERNING CHANGES IN DOMESTIC AUTOMOBILE DEMAND—Continued

<table>
<thead>
<tr>
<th>Chart</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Residuals from Equation 16 and Instalment Financing</td>
<td>66</td>
</tr>
<tr>
<td>31</td>
<td>Sales Adjustment Factor for Trade-in Ratio 1928-1938</td>
<td>67</td>
</tr>
<tr>
<td>32</td>
<td>Retail Sales Graduated for Seasonal Analysis 1926-1938</td>
<td>74</td>
</tr>
<tr>
<td>33</td>
<td>Retail Sales—Seasonal and New Model Factors 1926-1938</td>
<td>75</td>
</tr>
<tr>
<td>34</td>
<td>Passenger Car Retail Sales—Seasonal Variation and New Model Stimulus</td>
<td>76</td>
</tr>
<tr>
<td>35</td>
<td>Price and Seasonally Adjusted Sales of Passenger Cars—Monthly 1926-1938</td>
<td>81</td>
</tr>
<tr>
<td>36</td>
<td>Approximate Retardation of Sales During a Month Due to Deficient Field Stocks and Production</td>
<td>83</td>
</tr>
<tr>
<td>37</td>
<td>Monthly Sales, Adjusted for Seasonal—Actual and Calculated 1926-1938</td>
<td>84</td>
</tr>
<tr>
<td>38</td>
<td>Monthly Sales—Actual and Calculated 1926-1938</td>
<td>84</td>
</tr>
</tbody>
</table>

HEDONIC PRICE INDEXES

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Passenger Automobile—Weight vs. Price 1925 and 1935</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>Passenger Car Prices 1920-1939</td>
<td>112</td>
</tr>
<tr>
<td>3</td>
<td>Comfort—Average All New Passenger Cars 1925-1938</td>
<td>114</td>
</tr>
<tr>
<td>4</td>
<td>Performance—Average All New Passenger Cars 1925-1938</td>
<td>115</td>
</tr>
<tr>
<td>5</td>
<td>Durability and Dependability—Average All New Passenger Cars 1925-1938</td>
<td>116</td>
</tr>
<tr>
<td>6</td>
<td>Operating Cost Indexes 1925-1937</td>
<td>117</td>
</tr>
</tbody>
</table>

SIGNIFICANCE OF THE FINDINGS

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net Earnings vs. Dollar Sales—1924-1938—Four Automobile Companies</td>
<td>125</td>
</tr>
</tbody>
</table>

Analysis of Effect of Price and Cost Changes on the Profit of a Motor Company—1937

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Actual Results</td>
<td>126</td>
</tr>
<tr>
<td>3</td>
<td>Reflecting 5 Per Cent Increase in Variable Costs</td>
<td>128</td>
</tr>
<tr>
<td>4</td>
<td>Reflecting 5 Per Cent Decrease in Selling Prices</td>
<td>129</td>
</tr>
<tr>
<td>5</td>
<td>Reflecting 10 Per Cent Decrease in Selling Prices</td>
<td>130</td>
</tr>
</tbody>
</table>

Analysis of the Changes in Price Necessary to Maintain Volume with Changes in Intensity of Demand

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>With an Elasticity of 2 to 1</td>
<td>132</td>
</tr>
<tr>
<td>7</td>
<td>With an Elasticity of 1 to 1</td>
<td>132</td>
</tr>
</tbody>
</table>
STATEMENT OF THE PROBLEM

By the demand for automobiles in these studies is meant the sales of new passenger cars to consumers in the United States. This is a derived demand. The primary demand is for individual transportation service. But transportation service may be obtained for longer or shorter periods without purchasing a new car, since the automobile is a durable good. The two types of demand should be clearly distinguished. Some of the factors which have influenced the demand for transportation service, and thus the long-time trend of new car sales, are the improvement in the product and the lowering of real price, the decrease in the cost of operation, the increased mileage of good roads, the greater availability of service, the increase in population and improved standards of living.

In these studies, however, major attention is directed to factors operating over a shorter period. The more important factors influencing the year-to-year fluctuations in new car sales are believed to be general business activity and national income (considering both the level and direction of change), the cost of living in relation to national income, new car prices, used car prices and trade-in allowances, the number of cars in operation and the age of cars. Factors which influence more particularly the month-to-month changes in sales are seasonal variation, new model stimulus and date of announcement, the trend of general business activity and national income during the year, field stocks of new cars and used car stocks.

While it is necessary to consider these various factors, a fairly good statistical explanation of the fluctuations in sales may be obtained without using price as a variable. However, the primary purpose of these studies is to attempt to isolate and measure the effect of price and price changes upon the demand for automobiles.
STATEMENT OF THE PROBLEM

S. L. HORNER
General Motors Corporation

The papers at this morning’s session and those at the session this afternoon represent the results of a cooperative study. This study was undertaken to determine the effect of price upon the sales of automobiles, or, in other words, the elasticity of the demand for automobiles with respect to price. As the study progressed, it developed into a general analysis of the various factors which influence the demand for automobiles and it was thought that the results would be of interest to the Statistical Association and the Econometric Society.

*Price Problems and the Individual Automobile Manufacturer*

It is perhaps needless to say that we who are associated with the automobile industry have been working for a great many years on the problem of determining the factors which influence the demand for our product, including the price factor. However, most of the work done on this problem by people connected with the industry has been for the purpose of helping a particular manufacturer to decide the questions which confronted him in running his business. Thus, with respect to the effect of price upon sales, such studies as have been made have usually been undertaken for the purpose of determining the probable effect of a change in the price of a particular car upon the manufacturer’s volume and competitive position, as against its effect upon his profit margin. Or, they have been undertaken in order to determine the desirability of bringing out a lower or higher priced line of cars, in which case not only the problem of price, but also the
problem of a change in engineering specifications has to be considered. The automobile, like most manufactured products, has certain minimum acceptable specifications and a change in specifications may have more influence upon volume than a change in price. These are the kinds of price problems with which people connected with the automobile industry have been chiefly concerned. And until recently, the problem of determining for the industry as a whole the effect of price changes upon total sales of all makes has been of relatively little concern to individual automobile manufacturers. There are several reasons for this:

*First,* there is the difficulty of measuring price changes for the industry as a whole, in the case of a non-standardized product like the automobile. Changes in manufacturing specifications usually accompany price changes and frequently are made when no price change takes place. These changes in specifications, together with the shifting of volume to lower priced cars, which has accompanied the improvement in the product, are the principal reasons for the difficulty. Various indexes of automobile prices are available. Three of them are shown on the first chart (Chart 1). But, as Mr. Court will explain, none of them is entirely satisfactory.

*Second,* such studies as have been made over the years have indicated that, since the middle twenties when the growth factor became less important, the volume of automobile sales has been largely governed by such factors as the trend and level of consumers' incomes and price changes appear to have had a relatively unimportant influence.

*Third,* the problem has seemed to have little practical significance, since in a competitive industry like the automobile industry, it would be impossible to get the manufacturers to act together to move prices up and down in order to try to stabilize volume. It might be argued that one manufacturer could adopt such a policy and force his competitors to follow him. But while competitors might be forced to follow when he
STATEMENT OF THE PROBLEM

cut prices, there would be no such compulsion when an individual manufacturer raised prices and the manufacturer who followed this policy would lose competitive position and probably could not stay in business long.

However, even though it would be unrealistic to assume that an individual manufacturer could do anything about the matter, as long as the industry remains on the present competitive basis, the proposal that industry should vary its prices for the purpose of attempting to stabilize volume has received such wide currency in the past few years that General Motors decided to have a study made of the effect of price changes in general upon the total volume of automobile sales.

Accordingly, about six months ago, Mr. Roos, whose reputation as a mathematical economist is known to all of you, and his associates in the Institute of Applied Econometrics were asked to work out a statistical demand curve for automobiles and determine the price elasticity of automobile demand. This study has been a cooperative one, with Mr. Roos, Mr. Von Szeliski and Mr. Frank Alt providing the mathematical technique and objective viewpoint and various people connected with General Motors and the industry supplying figures and background information. The several automobile price indexes which are used have been chosen with the advice of Mr. Court of the Automobile Manufacturers Association, who has done a great deal of work over a period of years on the problem of measuring automobile prices.

Another reason for undertaking this study at the present time is that certain recent studies arrive at conclusions that we have been unable to accept. These studies develop mathematical expressions for automobile demand and one of them works out coefficients of price elasticity. The first of these is by P. de Wolff and was published in the April 1938 issue of Econometrica. However, de Wolff’s formula, which was based on data through 1934, when extrapolated gives a maximum number of cars in operation which has already been exceeded. Also, we think his conclusion that the price elasticity of demand for automobiles was more than 3.0 in the depression years 1932 and 1921, as compared with 1.0 in 1929, is unreasonable. The second of the studies referred to was made in 1937 and, although unpublished, it has been widely discussed. This study fails to account for actual sales by a rather wide margin when the demand formula is extrapolated a few years beyond the period of fit. Moreover, it sheds no light on the problem of price elasticity, since price was not one of the variables used. I will merely mention these studies in passing since Messrs. Roos and Von Szeliski will discuss them in detail.
THE DYNAMICS OF AUTOMOBILE DEMAND

Factors Which Might Be Expected to Influence the Demand for Automobiles

In order to arrive at a measure of the elasticity of demand for automobiles with respect to price, it is, of course, necessary to take account of the factors other than price which influence the intensity of demand in order that the influence of these factors may be held constant and the net regression of demand on price may be determined. It has long been recognized that the gross correlation of automobile sales with price is very low. Thus, early in the course of the present study, the question was raised of what factors other than price might be expected to govern demand fluctuations.

Without attempting to make a complete list one might mention as long-term factors:

1. The improvement in the product and the lowering of real price,
2. The decrease in the cost of operation,
3. The increased mileage of good roads,
4. Increasing length of car life,
5. The greater availability of service,
6. The increase in instalment buying,
7. The increase in population, and
8. Improved standards of living.

All of these have contributed to increasing car usage and the number of car owners. Since the middle twenties, the demand for new cars has been in large part for replacement, and a decreasing number of new owners has been coming into the market. In fact, during the depression there was an actual decline in the number of cars in use.

Apart from these long-term factors are the factors other than new car price which might be expected to influence the year-to-year changes in demand, among which are the following:

1. General business activity and national income (considering both the level and direction of change),
2. The distribution of national income,
3. The cost of living,
4. The psychological atmosphere—whether optimistic or pessimistic,
5. The extent and character of model changes,
6. The age of cars in the hands of new car buyers,
7. The number of cars scrapped,
8. The used car stocks in dealers' hands and the dealers' working capital position,
9. Financing terms—both the required down-payment and the length of time over which monthly instalments may be spread, and
10. Used car prices and trade-in allowance.
STATEMENT OF THE PROBLEM

Superimposed upon these factors influencing year-to-year changes in the level of automobile demand are the factors which influence the distribution of sales within a particular year, among which are:

1. Seasonal variation,
2. The dates of new model announcements and new model stimulus,
3. The trend of general business activity and national income,
4. New car stocks,
5. Used car stocks and deliveries,
6. Price change anticipation,
7. Weather conditions,
8. Abnormal interruptions in production,
9. Sales campaigns for both new and used cars, and
10. The relative prosperity of different geographical regions and different sections of the population.

Meaning of Demand for Automobiles in Present Study

Before attempting to suggest which of these factors are the more important, it is desirable to define more precisely just what we shall mean by the "demand for automobiles" in the present study. By the "demand for automobiles," as we shall use the term, is meant the sales of new passenger cars to consumers in the United States. Sales in a given year, of course, represent a point at the intersection of a demand curve and a supply curve, at the quoted price, but they constitute the only quantitative measure of demand which is available. Our justification for confining our attention to new passenger car sales in the United States is that these passenger cars constituted 73 per cent of the entire unit sales of the industry, domestic and export, in 1938 and over the past ten years they have accounted for 76 per cent of such sales. Moreover, the demand for commercial cars and trucks is subject to a somewhat different set of influences. This is also true with respect to the demand in foreign countries for American-made automobiles.

Furthermore, it should be emphasized that our attention will be directed to the demand for new passenger cars, as opposed to the demand for individual transportation service or car usage. This distinction is an important one, since the automobile is a durable good and the demand for transportation service, as provided by an automobile, may be satisfied in a particular year by merely running the old cars another year. Moreover, the demand for new cars is only part of the demand for car usage, since the latter may also be satisfied by the purchase of a used car. Prior to the middle twenties about the only way in which the demand for the use of an automobile could be satisfied was by purchasing a new car. But with something like 23,000,000 passenger cars in operation at the present time, and with a large supply of used cars available, the demand for car usage in recent years has come to be something much different from the demand for new cars.
THE DYNAMICS OF AUTOMOBILE DEMAND

The different character of these two types of demand is illustrated by the next chart (Chart 2), which compares the fluctuations in annual sales of new cars with the fluctuations in the number of cars in use. The number of new cars sold is plotted against the left-hand scale and the number of cars in use is plotted against the right-hand scale. It will be noted that the number of cars in use held up relatively well during the depression while new car sales fell sharply.

Chart 2

Over the longer term, the extent to which automobile usage is maintained or increased is an important influence upon the level of annual sales of new cars. But from the standpoint of year-to-year fluctuations in new car sales, the total demand for car usage is not believed to be an important influence.1

1The demand for transportation service or car usage is of course the primary demand, while the demand for new cars is the derived demand. Accordingly, the factors which influence the demand for and the level of car usage are extremely important to the automobile manufacturers. Relatively small changes in total car usage, because of the magnitude of the car population, exert a very much greater relative effect upon the level of annual new car sales. Moreover, the level of car usage together with the average length of car life determines the number of new cars that are required over a period to maintain the car population. But average car life, which is a function of both physical and economic factors, is capable of rather wide changes. Hence, changes in the level of car usage, by themselves, are of little assistance in trying to explain the year-to-year fluctuations in new car sales.
STATEMENT OF THE PROBLEM

A failure to distinguish between the demand for car usage and the demand for new cars is responsible for statements frequently made which attribute an important influence upon the short-term fluctuations in new car sales to such factors as the cost of operating and maintaining cars, the extent of congestion in metropolitan areas, and the mileage of good roads. Such factors as these exert an important influence upon car usage but have only a long-term, indirect effect upon annual sales of new cars. Of course, this is not to say that, if costs of operation should suddenly jump in a particular year, the sales of new cars would not be importantly affected. But within the limits in which these costs have varied in the past, no direct relationships with year-to-year changes in new car sales can be ascertained. In the present study, therefore, attention has been directed to the demand for new passenger cars as opposed to the demand for car usage, except in so far as the latter explains the long-term trend of new passenger car demand.

Important Factors Influencing Year-to-Year Changes in Sales

From our experience over a period of years, the factors which appear to have been most influential in affecting the year-to-year changes in the sales of new passenger cars are as follows:

2. Cost of living in relation to national income.
3. Price. This must be considered in connection with extent and character of the model changes. Price change anticipation must also be considered with the price factor.
4. Used car price and trade-in allowance, together with used car stocks.
5. Number of cars in operation and age of cars.
6. Maximum car ownership, which is dependent upon population, real national income and price.

It should be emphasized that these factors are intended only as a partial list of the influences upon year-to-year changes in new passenger car demand. Factors governing monthly changes in new car sales will be dealt with later. While it is impossible to draw a hard and fast line between the factors influencing yearly changes and those influencing monthly changes, it is desirable to attempt to make the distinction.

It has long been recognized that automobile sales show a high degree of correlation with general business activity. This is, of course, to be expected, since the level of business activity governs to a large extent the incomes of automobile buyers. The trend of business activity is also believed to exert an important psychological influence upon automobile sales, as it does upon the sales of all durable consumers' goods, the replacement of which may be postponed. When general business is improving, people, of course, have more confidence and are more willing to make the necessary outlay for the purchase of a new car, or to undertake the commitment in the case
of a time sale. When business is declining, the reverse influence is felt, as was shown dramatically in late 1937 and early 1938. This in turn affects business activity and incomes in the same direction with the usual cumulative effect.

It is probable that a number of different statistical series could be found, all of which would show a high gross correlation with automobile sales, since they would all reflect, more or less accurately, the change in incomes and buying psychology which are probably the most important influences on automobile sales. I will illustrate three of these relationships.

On the next chart (Chart 3) the number of passenger cars sold in the United States are shown plotted against the left-hand scale by years from 1919 to date, in comparison with the average of the Federal Reserve Board Index of Industrial Production for each year, plotted against the right-hand scale. The close correlation between these two series, with the scales adjusted, is strikingly evident, especially from 1925 to date when the automobile industry has been in the stage where most of its sales are for replacement, with relatively few new owners coming into the market. It will be noted from the chart that the timing of the movements of the two series has
been extremely close. The Federal Reserve Board series, of course, represents production, while the automobile series is retail sales, so one would naturally expect that the production series might move somewhat earlier, as it appears to do in the case of the monthly figures which will be shown later.

In attempting to appraise the significance of such a relationship as this, one must, of course, be extremely cautious in assigning causal relationships. Automobile production figures are included in the Federal Reserve Board Index, and while they have a direct weight of only 5.5 per cent of the total Index, they nevertheless have a greater indirect weight than this through steel production and other products which enter into the manufacture of automobiles. Accordingly, whether the fluctuations in automobile sales influence those in the Federal Reserve Board Index, whether the causation is the other way around, or whether the two series are affected by common causes, is a question I shall not attempt to answer.

The next chart (Chart 4) shows the same passenger car sales series, by years, in comparison with national income paid out from 1919 to date. Passenger car sales in units are plotted on the vertical logarithmic scale and national income paid out in dollars, on the horizontal scale. It will be noted that the relationship between automobile sales and national income payments is not as close as that previously shown between automobile sales and industrial production. The regression is circular with the automobile series tending to go up faster when national income is rising and to come down more rapidly when national income falls. There are believed to be two principal explanations of this circularity.

First, in the total income payments to individuals there are certain types of incomes, such as interest, dividends, salaries and certain classes of wages, which remain relatively stable for a longer or shorter period of time after there has been a change in general production. This tends to make the total national income move much more slowly and show narrower fluctuations than general production. But the individual recipients of incomes of this slowly changing type do not purchase products like the automobile entirely on the basis of their current incomes. They are more likely to be governed in their new car purchases in times of changing business conditions by the psychological factor, previously mentioned, which is based in large part on the trend of general business activity. Thus, when business activity is declining, that part of the national income which declines more slowly is not used for the purchase of automobiles to the usual extent because of the belief or fear that future income will be lower; and, when business activity is increasing, the opposite phenomenon takes place.

In the regression of automobile sales on national income most of the circularity can be eliminated and a fairly good fit obtained if the rate of change of national income is introduced into the equation as a second independent variable. On the next chart (Chart 5) actual passenger car sales
are shown in comparison with calculated sales, based upon national income and the change in national income from the preceding year. The regression equation used in obtaining the calculated figures (for the entire period) is as follows:

\[
\log\left(\frac{\text{Car Sales}_{Year_1}}{\text{Sales}_{Year_1}}\right) = -3.016 + 1.464 \log\left(\frac{\text{National Income}_{Year_1}}{\text{Income}_{Year_1}}\right) + 1.887 \log\left(\frac{\text{Nat'l Inc'y}_{Year_1}}{\text{Nat'l Inc'y}_{Year_0}}\times 100\right)
\]
with car sales in thousands of units and national income in billions of dollars.²

It will be noted from Chart 5 that while the fit constitutes a decided improvement over that of car sales on national income alone (see Chart 4) it is not very good in some of the later years, for example, 1933, 1934, 1935 and 1938. It was believed that the failure to fit the sales for these later years might possibly be due to a greater sensitivity of automobile sales to changes in the national income, which could not be measured by the year-to-year changes in national income. Accordingly, for the period 1930 to date, a second equation has been fitted using the same national income factor as before, but computing the change in income for each year as the ratio of the total in that year to the annual rate reported for the last six months of the previous year.³ It will be noted that this second equation tightens up the fit, except in the years 1930 and 1931. The large deviation in 1934 can probably be accounted for by the influence of the

² The formulation of a regression of automobile sales on national income and the change in national income, all in terms of logarithms, was first suggested to the writer by Dr. Alexander Sachs, Vice-President of the Lehman Corporation.
³ This could be carried back only to 1930, since monthly income payments to individuals are available only from 1929 to date.
THE DYNAMICS OF AUTOMOBILE DEMAND

Automobile Dealer Code which, by restricting used car trading, undoubtedly caused some curtailment of new car sales. The deviation in 1938 can probably be explained, in large part, by the price change anticipation factor, *i.e.*, many people, anticipating that an increase in automobile prices would be made when the 1938 models were announced, purchased cars in the 1937 model year which they otherwise would have purchased in 1938. (See page 15.)

A second explanation of the circularity in the regression of car sales on national income is based on the fact that not all of the total national income payments to individuals is available for the purchase of automobiles. Taxes constitute a prior lien upon the income of individuals. Furthermore, while the use of an automobile is definitely in the class of necessities for a great many people, nevertheless, the purchase of a new car constitutes a claim on the individual's income which is subsidiary to that of ordinary living expenses. Accordingly, only that part of the national income after taxes and above living costs is available for purchase of durable goods such as automobiles.

On the next chart (Chart 6) a breakdown of the national income is shown after individual federal taxes* and an estimated allowance for cost of living. It is a well-known fact that changes in the cost of living lag behind changes in the national income, both on the down side and on the up side. When national income is declining, therefore, the fact that cost of living declines more slowly tends to pinch that part of the national income which is available for the purchase of automobiles. Automobile sales then fall more rapidly than does total national income. On the other hand, when national income is rising, the slower rise in living costs tends to allow that part of the national income available for the purchase of automobiles to rise more rapidly than the rise in total income. Automobile sales then expand more rapidly than does total income. The national income after these deductions, and certain others which will be pointed out later, has been called Supernumerary Income and is used in the demand formula which Messrs. Roos and Von Szeliiski will

*State and local taxes paid by individuals should also be deducted but the figures are difficult to estimate.
STATEMENT OF THE PROBLEM

explain. The use of this Supernumerary Income factor enables them to eliminate the circularity in the regression.

The price factor will be dealt with in considerable detail by the speakers who follow. It is sufficient at this time merely to point out that price changes cannot be considered apart from changes in manufacturing specifications. It is, I think, safe to say that such changes in specifications have at times exerted an important influence upon fluctuations in sales, although this is an influence which is difficult to express in quantitative terms. There have been times when it has been felt in the industry that models had not been changed sufficiently and that if more radical changes had been made, more cars would have been sold in a particular year. On the other hand, numerous examples could be cited of individual manufacturers who changed models too radically and whose sales suffered thereby.

Closely allied with the price factor is the factor of price change anticipation. During periods of rising costs, such as that which took place in 1937 when labor costs were rising so rapidly, prospective automobile purchasers tend to anticipate an increase in the price of automobiles. This is particularly apt to be the case when the advance in costs continues over a considerable period of time without an increase in automobile prices. Automobile buyers are sufficiently well informed to realize that any such increase in costs must, in time, cause an increase in automobile prices. And, if they do not arrive at this conclusion themselves, they are almost certain to have it impressed upon them by dealers and salesmen within the industry. Thus, during the spring and summer of 1937, dealers and salesmen were urging people to buy their new cars, before prices were increased. This tends to cause a bulge in sales which is followed, after prices are increased, by a decline in sales.

Also closely tied up with the new car price factor is the price of used cars, which has a direct bearing upon the trade-in allowance that a new car buyer is able to obtain. Used car prices are, of course, influenced by national income and the general level of business activity. They are also influenced importantly by the stocks of used cars in dealers’ hands. The effective new car price is the difference between the full new car price and the trade-in allowance. Figures on trade-in allowances obtained for a representative group of dealers for the period from 1928 to date have been used in the demand formula which subsequent speakers will explain.

The practice of accepting trade-ins on the sale of new cars means, in effect, that several different persons, including the ones who buy used cars, are advancing part of the cash to cover the purchase price of a new car. If, in addition, during a particular year, dealers’ used car stocks increase, the dealers are also advancing part of the money to help the new car purchasers buy their cars, advances which the dealers get back when they subsequently sell the used cars. Thus, during periods of increasing dealers’ used
THE DYNAMICS OF AUTOMOBILE DEMAND

car stocks the amount of national income required to purchase a given quantity of new cars is less than otherwise would be the case. On the other hand, during periods when dealers' used car stocks are being liquidated, a somewhat larger portion of the national income is required to purchase a given number of new cars. Thus, the building up and liquidation of dealers' stocks of used cars constitutes another factor which tends to cause new car sales to rise and fall more widely than national income. It has not been possible to obtain a quantitative expression of this factor and hence it could not be used in the demand formula except indirectly through the trade-in allowance.

Of the other factors believed to be important in influencing changes in automobile demand, I have not yet touched upon the number of cars in operation and the age of cars or the maximum car ownership level. This concept of a maximum car ownership level, which is variable with real national income, population and price, is quite different from the usual concept of "saturation" which means a fixed level of ownership, as Messrs. Roos and Von Szelski will explain. These factors are long-term ones, and have been introduced into the demand formula for the purpose of measuring the long-time trend of passenger car sales.

Important Factors Influencing Monthly Changes in Sales

Let us now turn from the factors which influence the year-to-year changes in automobile demand to those which influence more particularly the month-to-month changes in sales. These are the factors which have received more attention from people associated with the industry than the longer-term factors. It is not possible, of course, to make a clear-cut distinction between these two types of factors. However, the additional factors, which are more closely tied up with the month-to-month changes, might be listed as follows:

Seasonal variation.
New model stimulus and date of announcement.
Trend of general business activity and national income during the year.
New cars available—field stocks and rate of production.
Price change anticipation.
Used car factor.

Among these various influences upon monthly changes in automobile sales, the most important is usually the seasonal influence. This is, of course, much more important in the northern part of the country than it is in the South. In some of the southern states, practically no seasonal influence can be discerned. However, the importance of the North as a market for automobiles is such that the figures for retail sales for the entire United States exhibit a rather wide seasonal variation during the year. The seasonal percentages which have been used, based on industry figures,
fluctuate from a high of around 11 per cent or 12 per cent of the year’s business in the months of April and May to a low of from 4 per cent to 5 per cent in the month of October. These percentages are based upon the assumption of November 1st announcements of new models by the industry. Moreover, they reflect not only the true seasonal influences, but also the influence of new model stimulus, which tends to increase sales during the first few months after the new model is announced and to decrease sales in the last few months during which the model is on sale. Thus, it represents a positive stimulus to sales in the early months of a model run and a retarding influence in the later months. This stimulus is also influenced, of course, by the extent of the model changes.

The trend of general business activity and national income during the year also constitutes an important influence upon the month-to-month changes in new car sales. The relationship between new passenger car sales, on a seasonally adjusted basis, and the Federal Reserve Board Index of Industrial Production is shown from 1929 to date on the next chart (Chart 7). Each series has been smoothed by a three-months moving average and expressed in terms of its own standard deviations from the nine-year average, 1929 through 1937. It will be noted that the general trend
of the two series has been rather close during this period and that the Reserve Board Index has tended to lead the automobile series at the turning points. During periods when business activity is trending downward, it will be noted that a very close correspondence is shown by the two series, but in the period of improving business from 1932 through the middle of 1937, the correspondence was not as close.

The supply of new cars available also constitutes an important influence on the month-to-month changes in sales. This factor is significant chiefly when stocks and the rate of production are low. At the beginning of a new model year, if production is slow in getting under way and dealers' stocks are low, the monthly trend of sales will, of course, be governed by the rate of production. This may modify the new model stimulus by shifting the effective date of new model announcement. After new car stocks in dealers' hands have been built up to an adequate level, this factor loses its importance as an influence upon sales.

It will be recognized that some of the factors which were discussed in connection with the year-to-year fluctuations in automobile sales might also exert an influence upon the monthly changes and vice versa. This is particularly true of such factors as price change anticipation, trade-in allowances and used car stocks.

In conclusion, I would like again to emphasize the great importance of general business activity and national income upon both the yearly and monthly changes in automobile sales. These factors, as has been noted, show a close correlation with automobile sales and appear to leave little to be explained by such factors as price. Of course, as the subsequent speakers will explain, there is some intercorrelation between automobile prices and national income. Nevertheless it would appear to be highly significant that fluctuations in automobile sales should show as close a correspondence as they do with the fluctuations in general business and national income.
FACTORS GOVERNING CHANGES IN
DOMESTIC AUTOMOBILE DEMAND

From the demand standpoint, the outstanding characteristic of passenger automobiles and other durable goods is their durability. In consequence, consumption of these goods is dissociated from purchase and ordinarily extends five to fifteen years beyond the date of acquisition. Consumers' car stocks thus take a prominent part in determining new car purchases. The demand situation is quite unlike that for perishable goods, in which the part played by consumers' stocks is negligible. Additions to consumers' stocks of automobiles, or new owner sales, depend chiefly on the difference between the actual car stock and the maximum stock or ownership level attainable under current conditions of income, price, operating costs and car life.

The concept of a variable maximum ownership level is of primary importance in the automobile industry because when car ownership is near the level of maximum ownership and a decrease in national income occurs, the effect is to make the market suddenly saturated. A consequence is the elimination of new owner sales, and even the forcing of liquidation of part of the consumers' car stock. It is found by statistical analysis that a 1 per cent increase in supernumerary income (national income less direct taxes and necessary living cost) would raise the maximum ownership level by about .1 per cent. Income changes also affect replacement sales, and a 1 per cent increase in supernumerary income would increase replacement sales by about 1.2 per cent. The over-all effect of income on total new car sales, new owners as well as replacement, appears to be that a 1 per cent change in income causes a 2.5 per cent change in sales. When consumer car stocks approach the maximum ownership level and the quality of these stocks is high, new car sales can be drastically lowered by moderate declines in income.

The influence of price on replacement sales is such that with each 1 per cent increase in price, replacement sales tend to decrease by .74 per cent (without allowance for possible correlation of price with operating costs). The over-all effect of price on combined new owners and replacement sales (after allowance for inter-correlation of price with operating costs) appears to be that a 1 per cent decrease in price increases sales by between 1 and 2 per cent, depending upon the degree of saturation of the market. A figure of .5 can be accepted as a fair average value of the elasticity of demand with respect to price under current conditions.

Automobile sales can be explained with an average error of 4.17 per cent for the period 1919-1937 with the above factors and without taking into account such factors as changes in financing plans, dealers' used car stocks, highway carrying capacity and style.

The two principal additional factors determining the monthly distribution of sales are the new model stimulus which depends upon the date on which new models are introduced, and the "pure" seasonal which depends chiefly upon the weather. The new model stimulus may deduct approximately 38 per cent from total industry sales in the month immediately before introduction and add almost 28 per cent to sales in the first month of the new model year. The "pure" seasonal reaches a low point in January at about 40 per cent under the average monthly level and rises as high as 37 per cent above the average in May. At times consumers anticipate price changes by buying early before a price advance, or by postponing purchase in anticipation of a lower price.

A combination of the short-term seasonal and new model stimulus with the long-term factors of cars in operation, national income and price, results in an almost complete explanation of monthly retail sales.
FACTORS GOVERNING CHANGES IN DOMESTIC AUTOMOBILE DEMAND

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Introduction

The purpose of the present study is to analyze the data measuring the principal factors affecting automobile demand by modern statistical methods with a view to showing, as accurately as may be, how the separate factors have combined to bring about the sales which have actually taken place.

Here "automobile demand" is taken as synonymous with sales which are defined as retail sales of new passenger cars within the United States. Thus in this study "demand" is taken to denote actual purchases. Demand is used in the widest possible sense, as comprising the relation of the amount sold to the complex factors which determine it. The first topic is the notion of demand in general, covered in Section I.

In recent years, several studies of automobile demand have been made. Two of these are discussed in Section II. The first study employs the classical methods of correlating national income and other factors with sales, and the second, that of P. de Wolff, published in Econometrica in April 1938, involves the notions of growth toward an upper limit and scrapping of old cars. Formulas are developed in these studies which give good representations of automobile demand over short periods, but do not explain sales history of other years very well. Furthermore, they appear to be defective in some respects particularly as to satisfactory formulation of the theoretical aspects.

The apparent difficulty of the subject seems to call for a careful reconsideration of the demand factors, and especially of how they interact to

*Dr. Frank Alt of the Institute assisted materially in this study.
bring about automobile purchases. This is undertaken in Section III. This study leads to a theory of automobile demand in outline as follows:

1. The central point is that the demand for new automobiles is a derived demand, since the primary demand is for transportation service. This is furnished by the total car population, only a part of which consists of cars sold during any given year. New car demand may thus be considered as dependent upon consumers' decisions regarding the number and quality of the cars to be maintained in operation.

2. Consumers are thought of as continuously adjusting the number of cars in operation toward some particular car population called "the maximum ownership level." This concept of a maximum ownership level appears to be of major importance in durable goods studies.

3. The maximum ownership level is regarded as changing continually in response to the economic status of consumers and such other factors as car durability and price.

4. Consumers are likewise thought of as continuously adjusting the quality of the car population toward an optimum level by replacements.

5. The rate at which consumers adjust the car population toward the maximum ownership level and the optimum quality level depends upon both general and specific economic conditions.

A theory of demand based on these concepts is then translated into mathematical terms; that is, a precise working hypothesis is set up which can be tested against the data.

Section IV surveys the available data to which the hypothesis can be applied and against which it can be tested, and describes briefly some new statistical series that seem to be required.

Section V presents a study of replacement sales, or "scraping." Studies of passenger car survival data show that there has been considerable variation in car life. A "theoretical scrapping" figure can be derived for each year by applying scrapping ratios to the number of cars in each age group at the beginning of each year. Actual scrapping is found to differ considerably from theoretical scrapping. Actual scrapping tends to be above theoretical scrapping when national income is high, and vice versa.

In Section VI the concepts of a maximum ownership level and of new owner sales are analyzed. The former is found to depend principally on the income factor but also on price, durability, and operating costs. Increased durability in recent years has decreased the new car purchases required for maintaining a given car population.

Section VII presents a formula for calculating new car sales by annual periods. New car sales are shown to be represented satisfactorily by a mathematical combination of the following factors:
FACTORS GOVERNING CHANGES IN DEMAND

(a) an income term, based on supernumerary income per capita, or income in excess of necessitous living costs and direct taxes,

(b) a price term,

(c) number of cars now in use,

(d) potential new car market—maximum ownership level, less (c),

(e) the pressure for replacement.

Such a formula accounts very well for the annual sales that have actually taken place during 1919-1938. Its advantages and disadvantages compared to other formulas are discussed. The contributions of the various factors are briefly explained.

Section VIII gives consideration to some secondary factors, i.e., used car allowances, volume of automobile instalment credit, dealer used car stocks, and financing terms. Brief discussion is made of some of the neglected factors and their possible influence.

Month-to-month fluctuations in car sales, as distinguished from cyclical and long-term variations, are analyzed briefly in Section IX. It is found that most of the short-term variation can be explained on the basis of a constant “pure seasonal” mainly dependent on weather factors, plus a new model stimulus effect varying with the percentage of the industry introducing new models in each month. Less important sources of fluctuations are price changes and deficient production or field stocks.

Section X presents a discussion of the statistical results, especially those bearing on elasticity of new car demand with respect to both price and income. Sometimes sales are very sensitive to changes in price and in income; at other times they are less sensitive. In brief, the sensitivity depends partly on the degree of saturation of the market. It is a false abstraction to speak of the effect of one factor such as price by itself; the factors always act in combination, and it is the combination which produces the sales effect.

The results of the study seem to call for a revision of the idea of price elasticity, at least in so far as durable goods are concerned. The classical concept which placed price at the focus of attention was formulated at a time when economic analysis of price phenomena was largely in terms of perishable or semi-perishable goods. The inadequacy of this view is due to the fact that, for durable goods, purchase is dissociated from, or at least does not run parallel to, consumption; the period of consumption in the case of automobiles extends over a period of several years after the purchase. Dissociation is possible because of consumers' car stocks, which at times may be more than ample relative to consumers' demand for automobile transportation. These stocks, which are negligible for perishable and semi-perishable goods, are a major factor in durable goods demand. Their effect is to accentuate the cyclical movements in retail sales independently of any price effect.

Price, though of some importance in explaining automobile sales, is clearly not a dominant factor. It appears, therefore, that the classical
THE DYNAMICS OF AUTOMOBILE DEMAND

theory that business stability can be accomplished by rapid price adjustment, applicable though it may be to a perishable and semi-durable goods economy, cannot validly be applied to the modern durable goods economy; for such a theory disregards the most characteristic mark of durable goods, their durability.

Section I—The Notions of Demand Function and of Elasticity

The principal aim of this investigation is to arrive at a demand function for passenger cars. The phrase "demand function" is used in contrast with "demand curve" to emphasize the broad, multi-factor meaning of demand as employed in this study. Thus a demand function is any formula or rule, mathematical or non-mathematical, which connects the amount of a commodity taken by consumers with the factors which determine it.

When attention was first directed toward demand phenomena many decades ago, demand was usually considered in relation to price alone. Other factors were neglected as unimportant or taken to be of a long-term, non-cyclical character, like population. The demand schedule and the demand curve were written: Demand = function of price. Or demand was plotted as ordinate in a graph, and price as abscissa. Various hypotheses with respect to the nature of the relationship were explored and the considerable body of economic theory was built upon the findings.

An early study of demand was tacitly assumed to be a study of "the" demand curve or of "the" elasticity of demand. In the first statistical studies, which were confined to agricultural commodities such as wheat, cattle, cotton, sugar, and oats, price was the principal independent variable and satisfactory results were obtained. Auxiliary variables such as the general price level or national income were also used in some cases. Other variables were lumped together in what has commonly been called a catch-all time trend.

Such procedure yielded satisfactory demand relationships and will probably continue to meet with reasonable success in analyses of staple perishable goods demand. But the notion is entirely inadequate for consideration of durable goods.

(2) H. L. Moore, Economic Cycles: Their Law and Cause, New York, 1914.
(3) H. L. Moore, Forecasting the Yield and the Price of Cotton, 1917.
(4) Henry Schultz, Statistical Laws of Demand and Supply with Special Application to Sugar, Chicago, 1928.
(5) For reference see Henry Schultz, The Theory and Measurement of Demand, Chicago, 1938. This excellent work contains exhaustive treatments of demand for various agricultural commodities.
(6) This was pointed out by G. C. Evans, The Dynamics of Monopoly, American Mathematical Monthly, July 1925, and by C. F. Roos, A Mathematical Theory of Competition, American Journal of Mathematics, July 1925. See also C. F. Roos, Dynamic Economics, Principia Press, Bloomington, Indiana, 1934, pp. 53-68, and C. F. Roos, Victor von Szeksil and Roy Wentzich in their study "Factors Influencing Residential Building" presented before the American Association for the Advancement of Science, December 1933 and published in Dynamic Economics.

24
Price is only one of many determining factors. Once regarded as the sole variable proper to a demand study, price need not, as a matter of fact, appear at all in the demand formula. Certain misleading ideas about the role of price must be cleared away. While price and price variation must play significant parts in accounting for actual variations in consumption of most agricultural products and of many other products, a broad economic area exists in which price and price changes can account for only a part of the actual variation in demand, at least over the medium term. For a great number of items, variation in price merely induces short-term speculation and does not appear to be the most significant factor in accounting for variation in consumption.\(^7\)

Elasticity is a characteristic of demand with respect to a particular demand factor. It is the percentage change in the amount demanded corresponding to a one per cent change in the factor.\(^8\) Thus a price elasticity of 1.5 means that a 1 per cent drop in price will increase sales by 1.5 per cent. The notion of elasticity should be broadened to include income elasticity,\(^9\) and elasticity with respect to other factors.

The purpose of the present study is, then, to determine a law or formula employing the more important variables affecting automobile sales and then to separate the formula into its component parts to show approximately the

\(^{(1)}\) Compare Schultz's analysis of the broadening of the notion of demand, *Theory*, pp. 5-12. He points out the inadequacy of a one-price demand theory, and argues for a general demand function containing the prices of all commodities. The present study suggests that demand functions be still further generalized to admit all types of variables which affect consumer purchases. Analyses of seasonal variation or of family expenditures by income groups are demand studies no less than determinations of "the" demand curve.

Note also in recent business cycle literature the emphasis on general attitudes of consumers toward goods and toward money—"propensity to spend," "liquidity preference," etc.


"Although general economic theory is accustomed to give the central place to prices and although I myself in an attempt to give business cycle schemes did so too, I do not consider . . . (that omitting price is) . . . a great disadvantage. In many cases, statistical investigation leads to the suggestion that the role of prices is not so important as we have been accustomed to think."

However, in reacting against the single-factor theory of demand fluctuations, one should not go too far. The national income and general consumer attitudes, the new factors invoked to explain consumer demand, may in their turn prove to be affected by prices and price relationships. Price relationships as a cause of the general level of income are not ruled out because they can be dispersed in many demand analyses, and partial stabilization of sales by adjustment of prices to the cost of the marginal producer is not to be decried because full stabilization cannot be maintained by changing this factor.

\(^{(2)}\) For discussion of definition, see Schultz, *Theory*, pp. 40-46.

\(^{(3)}\) For a definition of income elasticity, see C. F. Roos, *Dynamic Economics*, p. 22 and Schultz, *op. cit.*, p. 39. The notion of elasticity of demand with respect to price originated with Augustin Cournot, but was popularized and extended by Alfred Marshall. In the work of many contemporary writers it is common to assume that the demand curve is a hyperbola, \(y = ap^{-b}\), where \(a\) and \(b\) are constants. Then by definition price elasticity \(= -\frac{\partial y}{\partial p} = \frac{dy}{dp}\) where \(dy/dp\) is the derivative of \(y\) with respect to \(p\), or the slope of the demand curve. In such cases the elasticity \(b\), is constant or in a broader sense varies with the factors other than price that influence \(b\). In the broad sense \(y = f(p, t)\) where \(t\) is a parameter representing the factors other than price, and elasticity \(= -\frac{\partial y}{\partial p}\) where \(\partial y/\partial p\) is the partial derivative of \(y\) with respect to \(p\).
contribution of the individual factors. For this investigation adequate measures of each factor must be obtained, the problem must be translated into mathematical terms, and a statistical fit made to the data. To the results thus obtained, tests of significance or reasonableness of findings must be applied.

Section II—Recent Studies of Automobile Demand

Two studies of automobile demand have recently attracted attention among students of the industry. One uses methods of correlating sales with national income, cost of living, the number of cars over six years of age, and a time trend. The other is an attempt by P. de Wolff to apply the theory of growth to the automobile industry.

A Time Trend Analysis

The factors used in the first study,
(a) real income of wage earners in manufacturing, mining, transportation and construction,
(b) other real income,
(c) cars more than six years old,
(d) a time trend,

are shown in the first panel of Chart 1, page 28. They are combined by a product formula of the following type:

\[
\text{Passenger Car Sales} = \left[ \frac{\text{Real Income}}{\text{Wage Earners}} \right] \times \left[ \frac{\text{Real Income}}{\text{Other}} \right] \times \left[ \frac{\text{Cars more than six years old}}{\text{Trend}} \right]
\]

The square brackets in this and similar formulas denote “function of.” The relationship of sales to each factor is shown in the second, third, fourth, and fifth panels of Chart 1.

The effect measured by the wage-earner income part of the formula is shown in the second panel of Chart 1. The horizontal scale measures wage-earner real income in billions, and the vertical scale passenger car sales in millions. The curve, therefore, shows the passenger car sales corresponding to any wage-earner real income between 6 and 14 billion dollars, provided that the other factors are at their average values. Panels 3, 4, and 5 show the adjustments to be made to the curve values in panel two, for various values of other real income, number of cars more than six

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(10) Unpublished.
(12) For discussion of sum and product formulas, see p. 27.
FACTORS GOVERNING CHANGES IN DEMAND

years old, and time.\textsuperscript{13} The formula was fitted to data for 1921-32, so that 1919-20 and 1933-38 represent extrapolations.\textsuperscript{14} The fit is decidedly poor in 1919-20, presumably because price was not included as a factor, and again in 1937. The good fit for 1921-32 is not as significant as a glance at the charts might indicate because of the number of constants (nine) used in the formula.

Another important test is the reasonableness of the assumptions. In this respect the study seems to be at fault. First, the number of cars more than six years of age does not affect new car sales appreciably, in the belief of industry economists. The owners of 7-year-old jalopies are not prospects for new car sales. Such jalopies affect new car sales, if at all, only through their influence on the prices of other used cars. Furthermore, if the average life of cars and the age distribution is changing (as it is), choice of a fixed number of years is objectionable.\textsuperscript{15} The real income of wage earners appears as the most important single variable in the studies. The objection can be made that wage earners are not as important customers for new cars as those in the middle and higher income brackets, but this criticism is minor, since other real income was also used in the study. With these two income factors much of the past variation in automobile sales attributable to national income and the cost of living can be explained.

Strong exception can be taken to combining the two income factors by multiplication. One can see a basis for adding the two portions of the income stream with different weights A and B, on the theory that one type of income is more available for the purchase of new cars than another, thus

\[
\text{Retail Sales} = [A \times \text{Wage Income} + B \times \text{Other Income}] \times [\text{Other Factors}],
\]

but no rationale is offered for the product combination.

The large contribution of the time trend is a serious element of weakness in the formula. The trend has a downward slope of 4.4 per cent per year.

\textsuperscript{13} The calculation for 1929 is as follows:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Reading from Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wage-earner real income</td>
<td>13.9 billion</td>
<td>3,571,000</td>
</tr>
<tr>
<td>Other real income</td>
<td>51.4 billion</td>
<td>1,224</td>
</tr>
<tr>
<td>Cars more than six years old, units</td>
<td>3,130 thousand</td>
<td>.936</td>
</tr>
<tr>
<td>Time</td>
<td>1929</td>
<td>.914</td>
</tr>
</tbody>
</table>

Product—Calculated Passenger Car Sales | 3,739,000

Thus with wage-earner income = 13.9 billion dollars, panel 2 indicates passenger car sales of 3,571,000 cars; this figure is entered in the column “reading from curve” of the adjacent table. The values of the other factors in the table call for adjustments of 1.224 and .936, and the time trend value is .914 and these figures also appear in the column “reading from curve.” The product 3,571,000 $\times$ 1.224 $\times$ .936 $\times$ .914 = 3,739,000 cars is the calculated passenger car sales.

\textsuperscript{14} It is a well known statistical fact that the method of curve-fitting by least squares employed in this study generally gives the best fit in the center of the data. See Henry Schultz, The Standard Error of a Forecast from a Curve, Journal of the American Statistical Association, June 1930. Hence the test of extrapolation is not exactly conclusive. Nevertheless, a reasonably good fit should be obtained for several years.

\textsuperscript{15} The influence of age of cars is considered and the scrapping question is discussed at length on p. 47.
These charts summarize a demand study which uses a catch-all time trend. The factors used are shown in the first panel. The second panel shows sales related to the real income of wage earners. The adjusted sales are actual sales adjusted for the trend and divided by the adjustments indicated in panels three and four. Illustration of calculated sales is shown in footnote 13.

Chart 1
FACTORS GOVERNING CHANGES IN DEMAND

What omitted factors are working against automobile retail sales with any such cumulative force? None! It is obvious that the function of the time trend is to compensate for the sharp rise in the factor number of old cars, i.e., to set off one error by another.

Still another test is whether the formula gives plausible car sales for extreme values of the variables. Thus, with a real national income of 88 billion dollars in 1936 prices (1937 real income was about 67 billion), the formula indicates annual sales of about 10,350,000 passenger cars and a similar formula shows truck sales of 2,642,000 trucks—13 million motor vehicles in all. Since modern motor vehicles have an average life of more than 8 years, this volume of sales indicates an eventual car population of about 104 million units, or four times as many as there are now. This is beyond reason.

Finally, because the study does not use price as a variable, it throws no light on the problem of the price elasticity for passenger cars.

The P. de Wolff Study

In a study published in *Econometrica*, April 1938, and summarized on Chart 2, P. de Wolff used (1) corporate profits and (2) price to explain new owner sales; he used (3) non-workers' income and (4) theoretical scrapping, as computed from data on car scrapping, to explain replacement sales. The time trend element in replacement sales is a straight line. The time trend element in new owner sales is represented by the derivative of a logistic growth curve with a fixed upper limit.18

De Wolff's formula for new owner sales is

\[
    \text{New Owner Sales} = \left( \frac{\text{Logistic Trend}}{\text{Corporate Profits}} \right) + 0.2 \left( \frac{\text{Corporate Profits}}{\text{Price}} \right) - 0.65 \text{ Price} + 3.36
\]

New owner sales are in millions of cars, corporate profits in billions, and price of cars is Scoville's average unit value in hundreds of dollars.

The trend is shown in panel 5 of Chart 2, and corporate profits in panel 2 and price in panel 3. The price used is the average unit value of all passenger cars produced.

The formula for replacement sales is

\[
    \text{Replacement Sales} = \left( \frac{\text{Theoretical Scrapping}}{\text{Income}} \right) \left\{ 1 + 0.034 \left( \frac{\text{Non-workers'}}{\text{Income}} \right) - 0.0985 - 0.0164t \right\}
\]

Theoretical scrapping (panel 4) is computed by applying a table, based on experience, showing the percentage of cars sold which are scrapped in the first, second, third, . . . year of life, to retail sales by years.

The fit to total sales is satisfactory for the period covered—1921-34.

---

Calculated shipments to domestic market, panel (5), is the sum of the four lines in the lower part of the panel which are: theoretical scrapping, calculated deviation of actual scrapping from theoretical (depending on non-workers' income), the trend of new owner sales, and the calculated deviation of new owner sales from trend (depending on corporation profits and prices).
FACTORS GOVERNING CHANGES IN DEMAND

Weak points of the study are: (1) the use of a fixed upper limit (de Wolff's upper limit of 22.8 million, based on Bureau of Public Roads registration figures, was already exceeded before the study was published); (2) the use of a constant survival curve for passenger cars, for this curve is changing drastically, as will be shown below; (3) the use of the average unit value for all cars which introduces a spurious price correlation (see footnote 22, page 43); and (4) separate treatment of new owner and replacement sales. New owner sales are probably not wholly independent of replacement requirements, and, what is more important, the actual new owner sales and replacement sales are not known accurately, whereas their sum is known accurately.

It is interesting to note that whereas the time trend formula places most emphasis on wage-earners' real income and combines the factors by multiplication, de Wolff uses non-workers' income and corporate profits and combines the data by addition. Yet both fit the data well. De Wolff found price non-significant for replacements, whereas the time trend study did not use price as a factor. If price is non-significant for replacement, this is important, because for the fully saturated market of 1937, i.e., saturated according to de Wolff's definition, the price elasticity was low. From a practical point of view this would mean, if correct, that little could be done to stimulate demand in 1937-38 by cutting prices.

Section III—Formulation of the Problem

The previous section shows that, as far as fitting data is concerned, studies employing different factors and different formulations of the relations among them fit the period 1921-34 equally well. The data themselves do not point to a particular demand function; they are neutral, and will obligingly "confirm" widely disparate analyses. The significance of any analysis therefore depends more on economic logic than on statistical techniques as such.

It seems desirable to make a careful re-appraisal from the standpoint of economic theory of the factors at work and their interrelationships. In the interests of precision, this reformulation of the problem will be in mathematical terms. As G. C. Evans has so aptly remarked: "When we find this feeling for hypotheses and definition and, in addition, become involved in chains of deductive reasoning, we are driven to a characteristic method of construction and analysis which we may call the mathematical method. It is not a question as to whether mathematics is desirable or not in such a subject. We are in fact forced to adopt the mathematical method as a condition of further progress."17

The task is to select an equation expressing the way in which passenger car sales depend upon these factors; that is, to select a hypothesis for testing. Let it be recognized at once that the economist has not much to guide

THE DYNAMICS OF AUTOMOBILE DEMAND

him in making this selection; he is not in the position of the physicist who
has a vast range of accurately verified theory to help him in his hypothesis-
making. Economic theory has no such precision in its concepts and no such
certainty in its deductions, as has physics; and, therefore, the mathematical
economist cannot declare a particular formula as uniquely appropriate for
describing a given economic phenomenon.

But this partial agnosticism which one must accept at this stage of de-
development in economic science does not justify one in selecting some simple
formula and plunging ahead with a least squares computation; careful
analysis will usually suggest, if not a particular functional form, at least the
general characteristics which would make a function appropriate.

1. New Owner Sales and Replacement Sales.

Consider first the new owner sales or net additions to cars in operation. New
owner sales can be taken as the product of (a) the number of potential
new owners, and (b) the probability that an individual selected at random
from this group will purchase a car.18

(a) Potential New Owners. Suppose that automobiles are being intro-
duced into a population consisting of \( f(t) \) families at the time \( t \) and that
the cars in operation at \( t \) are \( C(t) \). At any time there must be some upper
limit to the car-maintaining ability of the country. This can be represented
by \( f(t) \cdot m(t) \), where \( m(t) \) depends upon the carrying capacity of the
highways, the durability of cars, the price of cars and the per capita income
of the population.

Then if replacements are ignored, the number of prospective purchasers
is \( (f(t) \cdot m(t) - C) \). The probability of selling a car will clearly be
proportional to the number of prospects, i.e., new owner sales, \( S_N \), are
given by

\[
S_N = A_0 \left\{ f(t) m(t) - C \right\}
\]

where \( A_0 \) is the probability that an individual selected at random will buy
a car.

(b) The probability that an individual selected at random will buy a car.
The quantity \( A_0 \) will vary as the product becomes known and wanted and
facilities for use are built up. These factors can be considered propor-
tional to the cars in operation. Hence, to a first approximation, \( A_0 \) can be
replaced by \( A_1 C \), so that

\[
S_N = A_1 C \left\{ f(t) m(t) - C \right\}
\]

18 An excellent book which illustrates how hypotheses can be translated into mathematical terms
is A. J. Lotka's *Elements of Physical Biology*, Williams & Wilkins, Baltimore, 1925. See also Victor
von Stelinski and Louis J. Paradiso, "The Demand for Boots and Shoes," Econometrica, October
1936, pp. 341-2, for a brief discussion of curve selection, and C. F. Roos, *Dynamic Economics*,
pp. 13-68.
FACTORS GOVERNING CHANGES IN DEMAND

Another consideration tending to justify replacing \( A_0 \) by \( A_1 \), \( C \) is that capacity of sales outlets tends to expand parallel to the number of cars in operation.

Clearly the quantity \( A_1 \) \((t) \) must depend upon per capita income available for automobile purchases, \( I \), and upon the price of the product, \( p \). The quantity \( A_1 \) \((t) \) can be replaced by \( A_2 \) \( p^{-\alpha} I^\gamma \).

In addition there is the purchasing power available from cars traded for new ones. This can be measured in part by the ratio of used car allowance to price, although the proper variable is the change in the value of dealers' stocks of used cars. Thus, if \( T = \) the trade-in price ratio, the formulation for new owner sales becomes

\[
S_N = A_3 p^{-\alpha} T^\beta I^\gamma C \left\{ f(t) \left[ m(i) - C \right] \right\}
\]

The function \( A_3 \) \((t) \) is obviously a catch-all for neglected factors. In particular it contains the number of cars traded to dealers, credit terms and the like.

The quantity \( m \) \((t) \), which is the upper limit or maximum ownership level per family, depends at least upon the income factor, the price of cars and the durability of cars; that is

\[
m(t) = B(t) p^{-\delta} I^\epsilon d^b
\]

where \( d \) is an index of durability or the average car life, and \( B \) a catch-all for other factors. The factors \( p \) and \( d \) are given the same exponent because it appears likely that, from the standpoint of maintaining a car fleet, a one per cent increase in average car life has the same effect as a one per cent decrease in price. The ratio \( p/d \) is an index of replacement cost.

We are thus led to the formula

\[
S_N = A_3 \left( p^{-\alpha} T^\beta I^\gamma C \left\{ f \cdot B(t) \left( \frac{p}{d} \right)^{-\delta} I^\epsilon - C \right\} \right)
\]

where \( A_3 \) \((t) \) and \( B \) \((t) \) represent additional factors which are believed to be of minor influence. A good fit is obtained if \( A_3 \) \((t) \) and \( B \) \((t) \) are assumed to be constant except for random errors.

Replacement sales are assumed to be the product of theoretical scrapping, \( X \) (Chart 14, p. 52), and such other factors as price \( p \), trade-in price ratio \( T \), and per capita income \( I \); that is

\[
S_K = A_4 \left( p^{-\alpha} T^\beta I^\gamma X \right)
\]

2. Combined Sales.

New car sales, \( S \), then are given by

\[
S = S_N + S_K
\]

\[
S = A_4 \left( p^{-\alpha} T^\beta I^\gamma C \left\{ f \cdot B \left( \frac{p}{d} \right)^{-\delta} I^\epsilon - C \right\} + A_4 p^{-\alpha} T^\beta I^\gamma X \right)
\]
THE DYNAMICS OF AUTOMOBILE DEMAND

If we do not insist on different exponents for \( p \), \( T \) and \( I \) for new owner and replacement sales, we can write the simpler formula

\[
S = A_0 p^{-\alpha} T^\beta \Gamma^\gamma \left[ C \left\{ \int B \left( \frac{p}{d} \right)^{-\delta} t - C \right\} + A_0 X \right]
\]

Actually, the two formulas are almost identical and the second seems to give a satisfactory fit to the data.

The above formulation has proceeded on the assumption that new owner sales are independent of the amount of replacement required. This may not be quite true. New owner and replacement sales as measured are certainly not independent; an error of measurement in one of the quantities is necessarily accompanied by an equal and opposite error in the other. On statistical grounds, there is, therefore, reason for working with combined sales. Moreover, there are economic grounds for believing that new owner sales are slightly influenced by replacement requirements. If the latter are large, consumers will not add as many cars to their car stocks as they would if fewer replacements were needed. If replacement requirements are small, some car owners may be able to go on a two-car basis, or at any rate they may spend the money not needed for replacements in such a way that others can become new car owners. The new-owners term should therefore for statistical and also for economic reasons be decreased by some fraction of replacement sales. The improved formulation of new owner sales \( S_N \) would then be

\[
S_N = S_N - a(S_R - \bar{S}_R)
\]

where \( (S_R - \bar{S}_R) \) is the deviation of replacement sales from some constant value, \( \bar{S}_R \).

This change is readily allowed for by rearranging equation (6):

\[
S = A_0 p^{-\alpha} T^\beta \Gamma^\gamma \left\{ C \left[ \int B \left( \frac{p}{d} \right)^{-\delta} t - C \right] + A_0 X + G \right\}
\]

in which \( A_0 = A_0 (t - a) \) and \( G = a\bar{S}_R \). As the various constants, \( A_0, B, A_0 \) and \( G \) are to be determined by the data, it should be possible to put \( G = 0 \), at least in initial approximations. It should be noted that in this equation the separate parts no longer represent new owner and replacement sales as such; the equation represents total retail sales.\(^{19} \)

\( ^{19} \) Another formulation is:

Car owners now have a fleet of \( C(t) \) cars. Suppose that they do not make replacements during the interval \( t \) to \( t + \Delta t \), and that \( x \) cars are scrapped. The car fleet at \( t + \Delta t \) will number \( (C - x) \) cars. The potential market is \( M - (C - x) \) cars, and the development follows as for new owner sales.

\[
Sales = A_0 T^\beta p^{-\alpha} (C - x) \left[ M - (C - x) \right]
\]

\( M \) in the above formula is the maximum ownership level.
3. Dependence of Sales on Rate of Change of Income.

An important school of thought in the automobile industry holds that sales depend upon the rate of change of national income as well as upon the level. The explanation usually given is that when income is decreasing, jobs and earnings are uncertain and the preference for liquidity increases. Hence although income to purchase a car may exist, it is not used. Conversely, in a period of rising national income consumers tend to mortgage future income and at times overextend themselves.

The theory is plausible. Moreover, as Mr. Horner has said, a satisfactory statistical explanation of sales can be obtained by using national income and its rate of change but not by using income alone. How then, it may be asked, can a satisfactory explanation of sales be obtained by using formula (6) which does not explicitly involve the change in income? The answer is that (6) implicitly involves the rate of change of income. The demonstration follows:

The number of cars in operation, C, depends upon the national income of the preceding year and hence the term $fB \left( \frac{p}{d} \right)^d I^e - C$ contains a weighted difference of this year's and last year's national income.

If, to simplify notation, we write,

$$fB \left( \frac{p}{d} \right)^d I^e - C = KI^e - C$$

and

$$A \left( \frac{p}{d} \right)^a T^q I^r C = D I^r C,$$

then

$$C(t) = C(t-1) + DI^r (t) C(t-1) \left[ KI^e (t) - C(t-1) \right]$$

$$C(t+1) = C(t) + DI^r (t+1) C(t) \left[ KI^e (t+1) - C(t) \right]$$

$$= C(t) + DI^r (t+1) C(t) \left[ KI^e (t+1) - C(t) - DI^r (t) \right]$$

$$\times C(t-1) \left\{ KI^e (t) - C(t-1) \right\}$$

$$= C(t) \left\{ 1 + DI^r (t+1) \left[ KI^e (t+1) - KDI^r (t) C(t-1) I^e (t) \right] 
- C(t) + DI^r (t) C(t-1) \right\};$$

The term $KI^e (t+1) - KDI^r (t) C(t-1) I^e (t)$ is thus seen to be a weighted difference of income at time $(t + 1)$ and time $(t)$. It is therefore a measure of the rate of change of national income. Thus, the formula (6) implicitly expresses the relation of car sales to change in national income.
THE DYNAMICS OF AUTOMOBILE DEMAND

But it should be clearly understood that in the mathematical formulation presented here, cars in operation is regarded as the "principal" variable, the causal factor, for which last year's national income can stand as a "proxy" variable. The principal variable should be used whenever it can be identified and obtained. Moreover, much of the effect hitherto traceable to the rate of change of national income is explained by using the sensitive supernumerary income series to be discussed below rather than the sluggish income series employed in previous studies. This innovation has many theoretical advantages and moreover makes possible a more accurate representation of sales or demand.

Another reason why retail sales behave as if change in national income was a causal factor is variation in dealers' used car stocks. Thus when national income turns down, dealers usually have too many used cars in stock which have to be liquidated. The public buys used cars on balance, and consequently sharply decreases its purchases of new cars. And when national income turns up after a prolonged decline, consumers start selling used cars on balance, thus obtaining additional purchasing power for new cars. The net purchases of the public from the dealers, new and used cars combined, probably exhibit much less tendency to circular regression on national income than do new car sales alone. (See also Section VIII, item 2 and item 3-d and footnote 31.)

4. The Concept of a Variable Maximum Ownership Level.

The concept of a variable maximum ownership is sufficiently important to deserve additional consideration. Chart 3 shows schematically how sales are related to it. The car population in the first ten years is shown growing asymptotically along the curve $u_0 u_1$ toward a maximum ownership level of 40,000,000. Then an increase in income or other factors raises the asymptote to 59,000,000 and a new period of growth takes place between years 10 and 20. The car population shifts to a new curve $u_2 u_3$ as shown by the diagram. At the 20th year the asymptote drops sharply to 28,000,000, and the car population begins to drop along the new curve $u_3 u_4$; there is an actual excess of cars which has to be liquidated.

Chart 4 shows a maximum ownership level derived from the data. Its formula is

$$\text{Maximum Ownership} = \text{Number of Families} \times (0.378 + 0.00068 \times \text{Real Supernumerary Income per Capita}) \times \left(\frac{p}{d}\right)^{-3}$$

in which the ratio $p/d$ is an index of replacement cost. The quantity $d$ is a durability index based on average age of cars at retirement, and with 7.04 years as the base. Thus with age at retirement equal to 8 years, the durability of cars is represented by an index of 114 (i.e., $100 \times 8.0 / 7.04$) and if price were 90 the index of replacement cost would be $90 / 114$ or 80. With prices at 100 and durability at 100, the number of cars maintained per family is $0.378 + 0.00068 \times \text{real supernumerary income per capita}$. The
Chart 3

Chart 4

The chart shows cars in operation in 1919-21 well below the maximum ownership level, and growing rapidly toward it. In 1922 the level rose sharply, and the car population entered on a new cycle of growth; its rate of increase accelerated. The car population was built up rapidly toward the maximum ownership level, which it almost reached in 1929. The national income fell and the maximum ownership level dropped sharply below the actual cars in operation and a period of retrogression set in. The factor \( \left\{ \left( B + \frac{p}{d} \right)^{-S} - C \right\} \) of formula (3), potential new owners, suddenly became negative.

Although the recent maximum ownership level was not reached in 1937, a surplus of cars developed almost immediately with a drop in income; the market was in effect suddenly saturated. With falling national income and employment, payments on newly purchased cars were defaulted and dealers, who already had surplus stocks of used cars, had their stocks increased still further by repossessions. New car sales fell off very sharply.

In the above circumstances it is probable that price-cutting of new cars avails little, for prices of used cars are successively cut faster than the new. Price-cutting of new cars in such circumstances certainly accentuates dealer distress.
THE DYNAMICS OF AUTOMOBILE DEMAND

This illustration serves to emphasize Scoville's point that what automobile owners consume is not new cars but transportation service. This service at present comes from the 23 million cars already in existence. It can be maintained without buying new cars if the consumers will (a) purchase cars from dealers' stocks, or (b) run the old cars longer. If by magic all the 23 million passenger cars now in use should become indestructible, automobile owners could enjoy about 500 billion passenger miles of transportation per annum forever without buying a single new automobile. The demand for new cars is therefore secondary to and derived from the demand for personal transportation.

Discussion of the maximum ownership level will be resumed in Section V.

Section IV—Definition and Measurement of the Factors

The basic factors have been defined in broad terms and a hypothesis has been formulated as to how they are related to sales. The next step is to give the utmost precision to the formulation of the problem by defining

![Chart 5](image)

the factors as logically as possible, and to examine the data available for measuring them (Chart 5). After that, the hypothesis is made concrete by fitting it to the data.
FACTORS GOVERNING CHANGES IN DEMAND

1. National Income.

The appropriate concept of income for the present study seems to be the total money arriving in the hands of consumers, the disposal of which is at their choice, or the total money flow available for expenditure in the consumers' goods market. Curiously no such index of income appears to have been calculated. Although our knowledge of income in the United States has been greatly increased by studies of the National Bureau of Economic Research and the Department of Commerce, a close inspection of their definitions shows that they include certain items which do not arrive in the hands of the consumers and exclude certain items which do. Hence none of these indexes is appropriate for this study.

The national income, as defined at one time by the Department of Commerce, excluded farm benefit payments, direct relief payments and soldiers' bonuses. These items, which are clearly available for expenditure in the goods market, are carried in the series shown in the October 1938 Survey of Current Business, called "income payments." Both old and new series exclude the items of saving, corporate as well as entrepreneurial. In so far as the present problem is concerned, entrepreneurial savings and corporate savings differ in an essential respect. The former, calculated by subtracting a hypothetical and rather arbitrary "labor allowance" from entrepreneurs' income, are available for expenditure in the consumers' goods market, whereas the latter, calculated by subtracting actual dividend payments from corporate income, are not. Another reason for including entrepreneurial savings is that many cars are purchased for business purposes, and are bought out of business income. This would also justify including corporate savings to some extent.

The usual national income estimates, moreover, include as income certain items not at the disposal of consumers, on the ground that they have accrued to their credit. Interest on long-term debt is one such component. This interest is without doubt "paid out" by corporations and government, but only a part of it is paid directly to individuals. The largest portion is paid to banks, insurance companies, corporate sinking funds, pension funds, etc. How much actually reaches individuals as interest on deposits, pensions, etc., is an unanswered question. In 1937 national income paid out reported by the U. S. Department of Commerce reached a level of 69.34 billion dollars, partly because of the inclusion of an item of $934,000,000 representing employers' contribution of social security taxes. Actually, individuals did not receive social security benefits in 1937. Under existing federal practice, however, these social security funds do reach the goods market. This is because they are used for current operating expenses of the government, part of which is government salaries and interest, under which form they do get counted in the national income. Counting the funds

\[\text{Footnote:} \] In fact, not only entrepreneurial savings, but depreciation allowances are available, and have actually been used, for the purchase of consumers' goods.
again as payments of taxpayers is evidently duplication.

In fact, from the standpoint of the goods market, inclusion in the national income of any direct tax paid by consumers necessarily constitutes duplication. Direct taxes include income and inheritance taxes, gift taxes, dividend taxes and personal property taxes. For example, Robinson has an income of $10,000. He pays a tax of $1,000, which the government transfers to Jones as salary. The combined spendable income of the two is Robinson's $9,000 net after taxes plus Jones' $1,000, or only $10,000, not $11,000. Hence, direct taxes are merely transfers of income; in no way are they additional buying power, and they should be eliminated in studies of demand. The table below shows various definitions of income, including the series of the Institute of Applied Econometrics, which is called Disposable Income.

### Items Included In The Income Factor

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<tr>
<td>Corporate savings</td>
<td>Out</td>
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<tr>
<td>Entrepreneurial savings</td>
<td>In</td>
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<tr>
<td>Social security taxes</td>
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<tr>
<td>Other direct taxes</td>
<td>Out</td>
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<td>Direct relief</td>
<td>In</td>
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<td>Soldiers’ bonus</td>
<td>In</td>
<td>Out</td>
<td>Out</td>
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<tr>
<td>Wages, salaries, dividends, interest, entrepreneurial withdrawal, rents and royalties</td>
<td>In</td>
<td>In</td>
<td>In</td>
</tr>
<tr>
<td>Imputed income</td>
<td>Out</td>
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It will be seen that income payments of the Department of Commerce approaches closely to the desired concept. The disposable income series is income payments, plus entrepreneurial savings, less direct taxes other than social security taxes. Only federal direct taxes have been eliminated in calculating the preferred factor disposable income; state and local direct taxes should also be deducted but are quite difficult to estimate.

Other sources of purchasing power for new cars are the increase (or decrease) in consumer credit, or in loans on securities. These have not as yet been studied well enough to permit including them in a study of demand.

It is natural to inquire whether a gross variable such as disposable income alone can be used or whether the distribution of such income must also be considered. The latter is the correct view, but the refinement is not necessary. Sales to such groups as mercantile, professional, artisans, farmers, financial and miscellaneous have moved in the same direction, as has

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(21) The National Bureau of Economic Research and the Department of Commerce correctly regard privately financed relief payments as transfers of income, not as additional income. Union dues, particularly check-off dues, are in the same category as direct taxes.
been shown by J. W. Scoville. (See Chart 6.) Because the series all move so closely together, time series analysis would be inadequate to measure the effects of changes in the distribution of income.

2. Cost of Living.

Since the cost of living is a price that consumers consider in allocating their disposable income among the different channels of expenditure, it should have some influence on the sales of automobiles. But it is unrealistic to speak of consumers' choosing between meeting necessitous or subsistence living cost and buying an automobile. Such living cost is, in fact, on a par with taxes as a deduction from income. Only the balance after deduction of living cost and taxes is at the genuine choice of the consumer.

For the present study, subsistence or necessitous living cost has been determined as $200 per capita per year for 1923 and in other years varying with the National Industrial Conference Board index of the cost of living. This figure was obtained by measuring the influence of national income and living costs upon total expenditures for durable consumer goods, automobiles, furniture, new housing, and the like. Disposable income less such deductions for living costs is here defined as Supernumerary Income. The series presented on Chart 7 corresponds to this definition with the exception that entrepreneurial savings are not shown. It is interesting to note in passing that this determination of living cost gives a present value of $695 for a family of four and that this figure is only slightly under the corresponding WPA standard of $800.
THE DYNAMICS OF AUTOMOBILE DEMAND

Supernumerary Income is the income factor used in the demand function.


One major difficulty in determining the effect of price on car sales has always been the construction of a satisfactory price index. Possible definitions of price (see discussion by A. T. Court) are:

1. Price is the average delivered price of the lowest priced cars freely available in volume. Such an index for 1926-1938 is shown in Chart 8. This index, representing as it does the price of the marginal car, has much to commend it for demand studies. The theory is that this price determines the number of units sold, and that the prices of other cars merely determine the distribution of sales among the various price brackets.

2. Price is a weighted average of indexes, each of which represents the delivered price or average unit value of cars that are substantially comparable from an engineering point of view. This index is particularly useful for portraying short-time changes in price, but is not satisfactory for the type of demand problem considered here. It would be appropriate if automobile sales were adjusted in some way for the number of quality units per car.

Chart 8
FACTORS GOVERNING CHANGES IN DEMAND

3. Price is an average of prices of makes, on the theory that a Ford is a Ford, etc. This is the B.L.S. index.

4. Price is the ratio of total expenditures for new passenger cars to the number of cars purchased. This is the Scoville index. It is useful for measuring consumer expenditures on automobiles, but is unsatisfactory for measuring demand.

5. Price is the above ratio adjusted for variation in the number of units bought in various price classes.

6. Price is the average price per pound. This index is useful in measuring to some extent changes in value to the consumer.

7. Price is the average price per unit of quality. (See *Hedonic Price Indexes* by A. T. Court.)

Some previous studies of automobile demand have used the average value per unit, that is, Scoville's index. But this introduces a spurious correlation. Other studies have used the B.L.S. index which is so gravely in error since 1926 that it is unsuitable for any purpose.

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[(22) Scoville's price index, \( p \), is calculated by dividing the wholesale value of passenger cars \( V \) by factory sales, \( F \), that is, \( p = \frac{V}{F} \). If this were used to represent price in a demand study, as in de Wolff's investigation, the formula for sales, \( S \), would be

\[
S = Z \left( \frac{V}{F} \right) - a = Z \left( p - a \right) F \alpha
\]

in which \( Z \) represents other factors.

Since an extremely high correlation exists between \( S \) and \( F \), a good fit will almost inevitably be obtained. In other words, the formula may become, not a study of the correlation of sales with price, but of retail sales with factory sales. De Wolff used \( V/F \) as a measure of price, and what is more, used factory sales to domestic market (factory sales \( F \) less exports \( E \)) as his dependent variable. The correlation he examined is, therefore,

\[
F - E = g(Z, V/F),
\]

and it is not surprising that, with only 14 observations to fit, he obtained close agreement between actual and calculated values.

De Wolff's correlations are heavily influenced by the 1927 data. In this year Ford was practically out of production and consequently (1) total production was low and retail sales were retarded, and (2) the unit wholesale value was high. Price, on Chart 2, Panel 3, as a result, has a contour which fits 1927 factory sales "like a glove." And because it is the net additions to cars in operation rather than calculated replacements which were affected by the Ford shutdown, de Wolff's correlations show a price effect for new owner sales, but none for replacement sales.

The question of whether the use of \( V/F \) introduces spurious correlation depends in part on whether the changes in \( V/F \) are due to supply factors (reduced supply of a particular car, as in 1927) or to demand factors (shift of consumer choice from one price class to another). The former type of change would seem to be far more dangerous than the latter and fortunately it has influenced the \( V/F \) ratio considerably in only one year, that is, in 1927.

The \( V/F \) ratio obtained by using Scoville's price index may be written as follows:

\[
V/F = \sum \alpha p_i = \sum \alpha p_i \Delta + \sum \alpha p_i \Delta
\]

Here \( p_1 \ldots p_n \) are the prices of five makes of car. For convenience assume that \( p_1 < p_2 < p_3 < p_4 < p_5 \). The coefficients \( \alpha \) are the ratios of sales of the individual makes to total sales, so that \( \Sigma \alpha = 1 \).

Suppose now that the lowest priced car loses part of its market, and that the other cars share corresponding gain in proportion to their present volume. The new proportions will be denoted
THE DYNAMICS OF AUTOMOBILE DEMAND

The number of units sold, all models, without reference to the number of quality units embodied therein represents retail car sales. So the first definition of price, which excludes the prices of cars above the lowest priced group, seems to be the most satisfactory for the purposes of measuring elasticity of demand. From 1926 an index of the average unit value of Chevrolet, Plymouth, and Ford was used, and prior thereto, the B.L.S. index.

This index of unit value of Fords, Plymouths and Chevrolets is the same type of index as Scoville's, but, being confined to the lowest price bracket, is not much affected by inter-bracket shifts in sales volume. Its possible disadvantages are more than outweighed by the fact that it meets the required definition fairly well, and it was used as the price factor in the more detailed analyses. However, correlations have been worked out using other price indexes as well (see p. 91).

4. Used Car Prices and Stocks.

Used car prices and stocks should have an important influence on new car purchases. For instance, the more consumers are willing to pay for used cars, the less cash will be required of new car buyers who offer old cars as

by primes. Thus

\[ n_1 = n_1 - \Delta n_1 \]
\[ n_2 = n_2 + \left[ \frac{n_2}{(1 - n_1)} \right] \Delta n_1 \]
\[ n_3 = n_3 + \left[ \frac{n_3}{(1 - n_1)} \right] \Delta n_1 \]

By differentiating \( V/F \) partially with respect to \( n_1 \) and using the above equation, the influence of a shift \( \Delta n_1 \) on the proportion of the market enjoyed by the lowest priced car is found to be

\[ \frac{\delta V}{\delta n_1} = \frac{1}{1 - n_1} \left[ n_2 p_3 + n_3 p_3 + n_3 p_4 + n_3 p_5 \right] \]

From this relationship it follows that when \( p_1 \) differs widely from the other \( p \)'s, the ratio \( V/F \) can be considerably affected; when the \( p \)'s do not differ much, \( V/F \) cannot be affected materially by inter-price-class shifts.

Whether the spurious correlation due to using \( V/F \) is serious, depends on the amplitude of the change in \( V/F \) due to volume shifts, compared to the amplitude due to changes in the general level of the prices themselves. If the prices themselves undergo considerable fluctuations, small changes due to volume shifts are inconsequential. Because the prices of cars in the low-priced group are substantially equal, the unit value of these cars is not much affected by volume shifts and it chiefly reflects changes in the general level of prices. Its use as a measure of price is therefore unobjectionable.

The present study uses a unit value for price, but, being restricted to cars of one price class (Ford, Chevrolet, and Plymouth), it is not affected at all by volume shifts between this class and others, and only moderately by shifts between these three makes.

As a matter of fact, the price index used for the purpose of measuring demand elasticity should rise to some extent during 1927—but the amount of the rise should be governed by the unit value of the lowest priced cars available in volume, not by the unit value of all cars.

This conclusion follows from the concept of sales determination by the price of the lowest price car available in volume. It is reasonable to suppose that the prices of cars above the margin have no influence on the number of units sold—merely on the make of unit bought. On a general price rise, a prospective Buick purchaser need not abandon the idea of buying a car—he may merely shift his preference to Pontiac, or Dodge. The marginal price can change, even though price quotations do not change. Suppose that there are only two cars sold in the given market, the Brown at $800 a unit, and the Green at $1,000 a unit. As long as production is ample, the price of the Brown at $800 is the controlling factor in determining the total number of units sold, but if the plant producing it is destroyed by fire and no more can be produced, the price of the Green car becomes the controlling factor. The marginal price rises from $800 to $1,000, although there has been no change in price quotation.

44
FACTORS GOVERNING CHANGES IN DEMAND

trade-ins; an increase in the trade-in allowance, whether as a result of increased consumer incomes, direct inflation of the price level, or because a newer type of car is being traded, should be a positive factor in increasing sales. (See Statement of the Problem, S. L. Horner.)

There are no usable data on used car prices. The best available figure seems to be the ratio of trade-in allowance to the new car value. Thus, the trade-in ratio must be interpreted as measuring somewhat crudely two distinct effects, (1) increased allowance on new car purchases and (2) changes in consumer credit due to changes in dealer credit.

5. Cars in Operation or Consumers' Car Stocks.

The variables so far discussed might well enter into any study of price elasticity. Consumers' stocks, however, are peculiarly characteristic of durable consumers' goods, whether they be housing, furniture, or automobiles. The effect of large consumers' stocks is to loosen and diffuse the connection between the purchase of a good and the consumers' enjoyment of the service it affords. The consumer can continue to enjoy the services of the good for a considerable time without replacing the good; purchase is not synonymous with consumption. Thus, the actual purchases of durable goods need not be related in a simple fashion to the variables commonly used in demand studies.

On the other hand this complicating factor of consumers' stocks is non-existent or negligible for perishable and semi-perishable goods, purchase and consumption of which are closely related in time. Hence it is natural that the earliest successful demand studies were concerned with staple consumers' non-durable goods such as wheat, barley, sugar and cotton.

The number of cars in consumers' hands measures the consumers' stocks from a short-term viewpoint. From the consumers' long-term viewpoint, their stock is the unused car mileage, as John W. Scoville has pointed out. The unused service or quality aspect of the consumers' stock will be discussed in Section V below.

The consumers' stocks include all usable passenger cars. "Cars in operation" has been used as synonymous with consumers' stock, though strictly speaking it is not; a car stored in a garage or back lot is not in operation, but it is part of the stock. Neither one is a precise concept because there are so many borderline cases; cars gradually become less and less usable, lingering perhaps for years in an intermediate zone between living and dead, alternately resuscitated and abandoned, before they are irrevocably junked or scrapped. According to Scoville, "The death of a car is a nebulous affair—it is difficult to tell when the car made its last mile."

In practice, the car inventory is necessarily measured by registration figures (see footnote 25, pp. 49-51). Total registration figures include cars bought in previous years re-registered during the current year, plus new cars.

(25) John W. Scoville, Behavior of the Automobile Industry in Depression.
registered for the first time during the current year. By subtracting new car registrations from year-end registrations, year-beginning reregistrations are obtained. These are assumed to measure cars in operation, the consumers' car population. This assumption is probably justified in years of prosperity, but may be wide of the mark in a depression, when enforcement of registration laws in outlying districts may be lax, and when many usable cars may be in storage.

An additional difficulty is that registrations are not known accurately. The two sources of total registrations are the Bureau of Public Roads, and the R. H. Donnelley Corp. mid-year car count of all titles registered in state motor vehicle bureaus as of July 1st of each year from 1933. Chart 9 shows cars in operation calculated on the basis of each set of figures. The consumers' stocks calculated from the Bureau of Public Roads figures exceed that based on the mid-year car count by 500,000 cars and more. Those who place chief reliance on the mid-year car count assert that the Bureau of Public Roads figures contain duplications, for example, because in about half the states new license plates must be obtained when cars change ownership. On the other hand, the mid-year car count, which reports car registrations by model year and make, reveals very obvious internal inconsistencies, and it seems to be definitely off the track in 1933. For example, the detailed tabulation of makes by model years shows more 1934 model cars on the road in 1936 than in 1935. The registered cars in operation show a large decline in 1931 and 1932 and a sharp recovery in 1933 (Chart 9). New owner sales calculated from these figures show a sharp rise in 1933 and replacement sales a corresponding drop. It is easier to believe that the basic figures are wrong than that car owners chose not to make replacements while non-car owners went on a buying spree. Accordingly the figures for cars in operation have been adjusted upward as shown on Chart 9. It is hoped that an improved measure of this basic factor will later be provided.

The measure used in this study was that based on the mid-year car count. The car count has been estimated between 1926 and 1933 by General Motors statisticians by adjusting the Bureau of Public Roads data.
FACTORs GOVERNING CHANGES IN DEMAND

Section V—Age Distribution of Car Inventory and the Pressure for Replacement

Consumers' stocks have two principal aspects: (a) the number of cars which over the short run measure the transportation service at the disposal of consumers, and (b) the quality of the car population—its mechanical condition—which over the long term causes a pressure for replacement. The first aspect has been considered. A propos of the second, Scoville says: "It was largely because the American people had over a trillion miles of transportation in their garages when the depression began that car sales fell off so drastically." A car population of twenty million almost new cars would represent a very large inventory of unused mileage, and would give rise to but few replacement sales. The same number of very old cars may occasion a large number of replacement sales. A measure of this pressure for replacement is furnished by the age distribution of cars, combined with experience tables for scrapping.

Car Survival and Scrapping Curves. Several automobile survival curves have been constructed. The earliest study was that of Griffin, published in 1926. Next was a General Motors study of 1930. John Scoville presented two survival curves, one (1931) on the basis of ages of cars junked, the other (1935), on the basis of the Donnelley registrations of 1935. Still another survival curve can be constructed from the 1933-1937 registration data.

The principal results obtained by these studies are shown in Chart 10. The curves show the percentage of an original group of cars still in operation (i.e., still registered) after 1, 2, 3, ... years of service. One conclusion is obvious: cars now last much longer than formerly. Thus Griffin's study shows 50 per cent of the cars surviving between six and seven years; Scoville's 1931 study shows 50 per cent surviving seven years, and the 1933-1937 curve shows 50 per cent surviving about nine years. This is due chiefly to more durable construction—all-steel bodies, for instance—and also to improved highway and service facilities.

Corresponding to the survival curves are the scrapping curves of Chart 11. These show the percentage of an original group of cars scrapped during the first, second, third ... 24 year after introduction. These curves also bring out very clearly the lengthening car life. The Griffin curve shows a scrapping peak at seven years, and the latest registration experience curve, at ten years. However, the registration data on cars more than eight years old are not reliable, and little can be said about the course of either survival or scrapping curves beyond eight years of age. The location of the scrapping peak is therefore only roughly known. The right-hand portions of the survival and scrapping curves have been liberally studded with question marks to emphasize this uncertainty. Apparently

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[24] A car sold at any time during one model year (sometimes calendar year) and scrapped at any time during the next, is counted as one year old at time of scrapping.
The dynamics of automobile demand

car life has increased from about seven years in the 1920's to nine years at present. This is very important since such increase represents a twenty-five per cent decrease in replacement requirements, for a given car inventory, and a 25 per cent cut in the replacement cost of maintaining it. This has undoubtedly been an important factor in enabling consumers to build their car stocks to a position well above the 1929 level despite a much lower national income.

To measure car life is extremely difficult because the durability is constantly changing. As Scoville says: "No method is available for measuring the longevity of cars produced this year. The only life we can hope to measure is the life of cars produced six or more years ago." This uncertainty constitutes one of the most important obstacles to long-range planning by a durable goods industry to meet consumers' needs.

Though the factor of replacement cannot be known accurately, pressure for replacement is a factor determining new car sales and it must be measured as well as possible. One method is to apply information obtained from scrapping curves to retail sales or to the age distribution. Thus the 1930 replacement pressure could be defined as the sum of

1929 retail sales × percentage of cars scrapped during 1st year
+ 1928 retail sales × percentage of cars scrapped during 2nd year
+ 1927 retail sales × percentage of cars scrapped during 3rd year, etc.

48
Chart 12 shows theoretical scrapping computed from retail sales by the scrapping curve based on 1933-37 registrations experience. Actual scrapping is shown for comparison. It is clear that actual scrapping (in so far

- Actual" scrapping has been calculated as follows:
  - Mid-year car count, 1937: 23,843,000
  - New car registrations to July 1—1937 models: 2,383,000
  - Cars in operation, beginning of 1937 model year: 21,460,000
  - Mid-year car count, 1936: 22,295,000
  - New car registrations to July 1—1936 models: 2,181,000
  - Cars in operation, beginning of 1936 model year: 20,114,000
  - Increase in cars in operation, during 1936 model year (new owner sales): 1,346,000
  - Retail sales: 3,369,000
  - Cars scrapped: 2,023,000

(Footnote continued following page.)
THE DYNAMICS OF AUTOMOBILE DEMAND

as it is measured by registrations) is not at all closely related to theoretical scrapping, at least when the latter is computed on the basis of a fixed life curve.

_Age Distribution._ Another approach to replacement is through the age distribution. The latter is known approximately for each year 1933-1938 from the registration figures, though these must be adjusted for apparent errors.

Continued

The inaccuracies in the registration figures are magnified in the scrapping and new owners figures. In fact, 1933 scrapping on the basis of reported mid-year car count data was only 504,000. The scrapping figures really record failure to register. How well or how poorly they represent actual scrapping (however that be defined) is unknown.

An alternative method of computing scrapping, which has not been used in this study, is the following, based on the Bureau of Public Roads registration data:

_U. S. Passenger Cars—1930_  
CALCULATION OF SCRAPPAGE AND CARS IN USE

_Calculation of Scrappage for Year, 1930_  
Total Registrations During Year 1929 ................................ 23,122,000  
Plus Total New Car Sales to Consumers During Year 1930 ............. 2,648,893  

Less Total Registrations During Year 1930 ................................ 25,770,893  
Scrapage—Unadjusted—During Year 1930 .................................. 2,711,631  
Scrapage—Unadjusted—During Year 1931 .................................. 2,594,036  
Scrapage—Adjusted—During Year 1930 (Calculated by Averaging Unadjusted Scrapage for Years 1930 and 1931 Above) .................. 2,652,834  

_Calculation of Cars in Use End of 1930_  
Total New Car Sales to Consumers Since Inception ....................... 39,522,893  
Total Scrapage (Adjusted) Since Inception .............................. 17,755,650  
Estimated Cars in Use End of 1930 ...................................... 21,767,243

Adjusted scrapping for 1930 is the average of the unadjusted figures for 1930 and 1931. The purpose of this is to offset in part the duplications due to registration laws. Comparable figures for 1929-38 follow:

_U. S. Passenger Car Registrations_  
NUMBER IN USE AND ESTIMATED SCRAPPAGE

<table>
<thead>
<tr>
<th>Year</th>
<th>Total New Car Sales to Consumers</th>
<th>Cumulative from Inception</th>
<th>Total Registrations During Year</th>
<th>Estimated Pass. Cars In Use End of Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1929</td>
<td>4,026,000</td>
<td>36,874,000</td>
<td>23,122,000</td>
<td>21,771,184</td>
</tr>
<tr>
<td>1930</td>
<td>2,648,893</td>
<td>39,522,893</td>
<td>23,059,262</td>
<td>21,767,243</td>
</tr>
<tr>
<td>1931</td>
<td>1,901,087</td>
<td>41,423,980</td>
<td>22,366,313</td>
<td>21,083,593</td>
</tr>
<tr>
<td>1932</td>
<td>1,094,918</td>
<td>42,518,918</td>
<td>20,885,814</td>
<td>19,994,519</td>
</tr>
<tr>
<td>1933</td>
<td>1,525,006</td>
<td>44,041,924</td>
<td>20,616,234</td>
<td>20,115,441</td>
</tr>
<tr>
<td>1934</td>
<td>1,927,755</td>
<td>45,969,679</td>
<td>21,532,408</td>
<td>20,619,560</td>
</tr>
<tr>
<td>1935</td>
<td>2,666,130</td>
<td>48,635,809</td>
<td>22,562,847</td>
<td>21,627,262</td>
</tr>
<tr>
<td>1936</td>
<td>3,486,529</td>
<td>52,332,338</td>
<td>24,178,311</td>
<td>23,077,505</td>
</tr>
<tr>
<td>1937</td>
<td>3,483,119</td>
<td>55,815,457</td>
<td>25,449,924</td>
<td>24,329,959*</td>
</tr>
<tr>
<td>1938</td>
<td>1,950,000*</td>
<td>57,765,457*</td>
<td>25,150,000*</td>
<td>24,079,959*</td>
</tr>
</tbody>
</table>

(Footnote continued following page.)
FACTORS GOVERNING CHANGES IN DEMAND

The age distribution prior to 1933 can be derived approximately by applying various survival curves to retail sales, and interpolating the results so that the sum of survivals shall equal cars in operation. Tying in the constructed age distribution to the observed cars in operation eliminates some of the arbitrary element from the former. Chart 15 presents the age distribution, constructed and observed, 1919 to 1938. A theoretically sounder way of calculating replacement pressure is to add the expected replacements from each age group. The number of cars in each age group is multiplied by the “death rate” for that age, and the products are summed. “Death rate” curves are shown in Chart 13. Theoretical scrapping derived by applying these “death rates” to the age distribution is shown in Chart 14.

These three theoretical scrapping series do not agree with the observations any better than those based on retail sales. What is needed is a changing life table. If shifting weights are applied to the three theoretical scrapping series, a new curve is obtained which starts out as the Griffin curve and finishes as the curve derived from the 1933-37 registration experience. The new curve (Chart 14) comes closer to observed scrapping, but is far from explaining all of it. All the curves on this chart should end in question marks because the information necessary for computing the later positions of the curve will not be available until 1940.

Theoretical scrapping in the form of one or another of the above curves has been used in the demand equations presented in Section III.

Formulas for Replacement Sales. It will be recalled that de Wolff used economic factors in combination with scrapping in his formula for replacement sales. This was because people tend to scrap more cars than indicated by theoretical scrapping in times of prosperity, and to scrap fewer cars than indicated in depressions. In the following formula for replacement sales this situation has been met by using per capita supernumerary income and price in conjunction with theoretical scrapping as given by the changing life table (Chart 16).

<table>
<thead>
<tr>
<th>Year</th>
<th>Scrappage Adjusted</th>
<th>Scrappage Unadjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative from Inception</td>
<td>New Owners</td>
</tr>
<tr>
<td>1929</td>
<td>2,497,316</td>
<td>15,102,816</td>
</tr>
<tr>
<td>1930</td>
<td>2,652,834</td>
<td>17,755,650</td>
</tr>
<tr>
<td>1931</td>
<td>2,584,737</td>
<td>20,340,387</td>
</tr>
<tr>
<td>1932</td>
<td>2,184,012</td>
<td>22,524,399</td>
</tr>
<tr>
<td>1933</td>
<td>1,402,084</td>
<td>23,926,483</td>
</tr>
<tr>
<td>1934</td>
<td>1,423,636</td>
<td>25,350,119</td>
</tr>
<tr>
<td>1935</td>
<td>1,858,428</td>
<td>27,208,547</td>
</tr>
<tr>
<td>1936</td>
<td>2,046,286</td>
<td>29,254,833</td>
</tr>
<tr>
<td>1937</td>
<td>2,250,665</td>
<td>31,485,498*</td>
</tr>
<tr>
<td>1938</td>
<td>2,200,000*</td>
<td>33,685,438*</td>
</tr>
</tbody>
</table>

*Estimated.
(11) \[ \frac{\text{Replacement}}{\text{Sales}} = 0.92 \times (\text{Income})^{1.07} \times \left(\frac{\text{Price}}{\text{Scraping}}\right)^{-0.74}\left(\frac{\text{Theoretical}}{\text{Scraping}}\right)^{1.10} \]

Supernumerary income appears with an exponent of 1.07, meaning that replacement sales tend to vary more than proportionally with respect to this income factor (exact proportional variation would be indicated by an exponent of 1). The price exponent is -0.74. This indicates that an increase of 1 per cent in price will induce consumers to cut their replacement purchases by .74 per cent. When probable errors are taken into account the exponent 1.10 on theoretical scrapping does not differ significantly from 1. However, little significance should be attached to the exact values found. Choice of a different scrapping curve, or a revision of the age distribution, or a different path for progressing from the Griffin curve to the 1933-37 registrations curve, all of which are reasonable, might lead to materially different exponents.

It is interesting to note that, whereas de Wolff found price without significance for replacement sales, the above formula assigns it an exponent of -0.74 and somewhat different data might show a numerically larger exponent, say -1.0. But even without this statistical support it would be difficult to accept de Wolff's finding of zero elasticity for purely theoretical reasons and from the experience of the industry.
Section VI—New Owner Sales

New owner sales are the net increase in cars in operation, and are shown on Chart 9. If the raw registration figures are used for computing cars in operation, a sharp rise appears in new owner sales for 1934. This is presumably due to the reregistration of cars left in garages or on back lots during the severest depression years, and it was to eliminate this effect that the car stocks figures were adjusted as shown. The new owner sales computed from the adjusted figures are also shown, and they follow a more plausible course.

According to the theory of p. 34 above, new owner sales cannot be satisfactorily analyzed apart from replacement requirements; the amount of money that can be spent for additional cars depends somewhat on how much has to be spent for replacements. This theory, in fact, rejects any absolute distinction between the two markets. On p. 34 we proposed equations for total sales, the parts of which cannot be broken up simply into two parts representing the two types of sales.

Equations that are approximations can nevertheless be derived for new owner sales alone, neglecting any scrapping variable. These are useful for studying the mechanism by which the consumers' stock is built up. Moreover, through an analysis of the new owner sales an estimate can be made of the position of the maximum ownership level.

The formula

\[ \frac{\text{New Owner Sales}}{\text{Income}} = \left( \frac{\text{Price}}{\text{Constant}} \right) \times C(M_2 - C) \]

was chosen for fitting. The variable \( C \) is cars in operation and \( M_2 \) is the maximum ownership level (Chart 17).

The first step is to calculate the maximum ownership level \( M_2 \). This is done by making use of the fact that the per cent rate of growth of factors which are believed to follow the logistic growth curve should tend to plot
as a straight line function of the factor itself. New owner sales are the net increase of car stocks. They are readily converted into a rate of growth of the latter, which rate should be a linear function of the stocks.

Chart 18 shows the per cent rate of growth of consumers' stocks plotted against stocks. Rate of growth is increment $\div$ average level. The level of stocks is the average of stocks on January 1st and December 31st. The observations show a definite slope downward from left to right, the rate of growth being around 15 to 20 per cent per annum when the consumers' car stock is between 5 and 10 million, and 5 to 5 per cent when the car stock is around 20 million. The prosperity years tend to cluster about the

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upper line. This line implies a high rate of growth, and intersects the base line at 26 million, which point marks the car stock level at which growth should cease, i.e., the maximum ownership level. On the other hand, the depression years tend to cluster about a lower line which intersects the base line at 19.5 million. The observations on this chart can, then, be regarded as resulting from a line of constant slope shifting up and down according to the level of national income and other factors. As the line moves up with rising national income, its intercept on the base line moves to the right—the maximum ownership level rises. A line drawn through each observation with some as yet undetermined slope should indicate the maximum ownership level toward which the car stock was being
FACTORS GOVERNING CHANGES IN DEMAND

built in that year. A somewhat more accurate procedure can be used based on equation (1):

\[ S_N = A^t p^{-\alpha} C f m (I, q, t) - C \]

In this formula, \( q \) is the replacement cost, the ratio of price to durability. If the equation is divided through by \( A^t p^{-\alpha} C f \) and the resulting left-hand side is called \( A^t W \) we have

\[ A^t W = \frac{S_N}{A^t p^{-\alpha} C f} = m (I, q, t) - C/f \]

If an explicit functional form for \( m (I, q, t) \) is assumed, a solution for \( A \) and parameters in \( m (I, q, t) \) can be obtained. The formula for \( M_2 \), the maximum ownership level shown in Chart 4, is

\[ (13) \quad M_2 = f \times \left( \frac{.378 + .00068 \times \text{Real Supernumerary Income per Capita}}{\text{Replacement Cost}} \right) \times \left( \frac{\text{Replacement}}{\text{Cost}} \right)^{-3} \]

Chart 19 shows the calculated value of \( M_2/f \) (dashed line) plotted with the values (solid line) which would make equation (15) below fit exactly. Thus it can be seen that the \( M_2 \) formula gives too high a maximum ownership level in 1922 and 1923, and too low a level in 1934-1937.

Another formula used was

\[ (14) \quad M_3 = f \times \left( .500 + .000544 \times \frac{\text{Real Supernumerary Income per Capita}}{\text{Income per Capita}} \right) \times (\text{Durability})^{-3} \]

which does not involve price. This is the maximum ownership term in equation (16) below.

The following formula using \( M_2 \) was derived for new owner sales

\[ (15) \quad S_N = j^{1.50} p^{-90} \times .040 C^t (M_2 - C^t) \]

In this formula \( C^t \) is mid-year number of cars in operation, and the quantity \( j \) is the ratio of supernumerary income per capita to its mean value, $333. The fit of actual and calculated income is shown in Chart 17. Although the fit is good by the test of per cent of variation explained, it should be noted that there are rather large errors in some years—the 1926 residual is about 600,000 cars or over 17 per cent of the retail sales. Moreover, this formula neglects the probable though undoubtedly small influence of scrapping on new owner sales. Some of the errors arise from errors in the estimates of new owner sales rather than from inadequacy of the formula. In these cases the replacement formula on p. 52 should err in the opposite direction. See especially 1926.

On account of these compensating errors the sum of calculated new...
owner sales and replacement sales gives a fair approximation to retail sales. (See Chart 20.)

These formulas are not presented as the best demand functions because they assume (incorrectly) the independence of the replacement and new owner sales. The distinction between the two is difficult to maintain in a statistical analysis and the demand functions presented in the next section are to be preferred.

Section VII—Retail Sales Demand Functions

The analysis of the determination of automobile sales from the standpoint of general demand theory has led to the selection of certain factors
as probably of major importance, and the selection of a characteristic formula to represent the relation between them. The factors are:

1. Supernumerary income (a combination of disposable income and living costs)
2. Price (especially price of the lowest-priced cars)
3. Consumers' stocks—number of cars in operation
4. Consumers' stocks—the pressure for replacement to which it gives rise
5. Trade-in ratio—to measure effect of used car allowance, and, indirectly, of variation in used car stocks
6. Population or number of families—a trend factor
7. Durability—used in combination with price to measure replacement cost of a car fleet.
THE DYNAMICS OF AUTOMOBILE DEMAND

These factors have been measured, some accurately, some approximately. The next step is fitting the demand function

\[ Sales = [Income][Price][C(Maximum\ Ownership-C) + Replacement\ Pressure] \]

to the data. The mechanical process of fitting is covered in standard texts, and will not be described here. As the equations are non-linear, successive approximations are necessary.

Fitting formula (8) on p. 34 and neglecting the factor \( T \) gives

\[ S = j^{1.20} \beta^{-65} \{0.0254 C(M_\alpha - C) + 0.65 X_\alpha\} \]

This is not the best formula from a theoretical standpoint—it omits price from the maximum ownership level—but because of that it permits a simple determination of price elasticity.

The function \( X_\alpha \) is replacement pressure calculated by applying a shifting mortality table to the age distribution of passenger cars.

![Chart 21]

Actual and calculated values appear in Chart 21.

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Factors Governing Changes in Demand

Partial Relationships. The parts of the formula may be graphed separately to show how each contributes to the total result. Chart 22 shows retail sales and two of the components, the supernumerary income index $j$ and replacement pressure $X_2$, computed by applying the scrapping curve derived from a shifting mortality table to the age distribution. Chart 23 shows the maximum ownership level $M_3$, the "potential new owners" term, maximum ownership less cars in operation, $(M_3 - C)$, and cars in operation $C$. The product of these last two factors, $C(M_3 - C)$, multiplied by .0254, gives potential new owner sales (Chart 24).\(^{29}\)

Another way of studying the contribution of these terms is to plot the value of .0254 $C(M_3 - C)$ against $C/M_3$ which shows roughly the saturation ratio (Chart 24).\(^ {30}\) The curve on Chart 25 shows zero contribution to sales for zero saturation. This represents conditions prior to, say, 1900 when the automobile was little more than an idea in the minds of visionary inventors. As the degree of saturation rises, this term contributes more and more to sales until with 50 per cent saturation it reaches a maximum of 2,500,000 units.

The dots in this and other charts show the adjusted observations or partial residuals. They represent sales adjusted for the effects of the other variables—what sales would have been if the other factors had been at their average values, or zero. Thus, the observations of Chart 25 are sales adjusted for the influence of the income and price terms, and replacement pressure. The original equation is

$$Sales = j^{1.2} p^{-65} \left\{ BC (M_3 - C) + A X_2 \right\} + Residuals,$$

where $A = .65$ and $B = .0254$. This is divided by $j^{1.2} p^{-65} M_3^2$ and the replacement pressure term .65 $X_2$ is transferred to the left-hand side of the equation, which becomes

$$\frac{Sales}{j^{1.2} p^{-65} M_3^2} - .65 \frac{X_2}{M_3} = B \frac{C}{M_3} \left( I - \frac{C}{M_3} \right) + \frac{Residuals}{j^{1.2} p^{-65} M_3^2}.$$

The adjusted sales are, in fact, Curve Values + (Residuals + $j^{1.2} p^{-65} M_3^2$). The positions of the adjusted sales around the curve indicate how much the variable in question contributes, and whether the curve should be changed.

Chart 26 shows the relation of sales to the pressure for replacements.

\(^{29}\) These terms are convenient, though inaccurate; the generalized equation does not divide neatly into two parts, one representing replacements and the other new owners. The term $C(M_3 - C)$ includes some replacement sales. See above, p. 34.

\(^{30}\) The caution of footnote 29 also applies to the phrase saturation ratio. The true saturation ratio must have been more than 1.0 during 1930-33 because the number of cars in operation actually declined. The ratio $C/M_3$, using $M_3$ of Section VI, is a better measure of saturation.
THE DYNAMICS OF AUTOMOBILE DEMAND

FORMULA 16 FOR RETAIL SALES AND COMPONENT TERMS

Charts 22-29

62
FACTORS GOVERNING CHANGES IN DEMAND

The straight line is \(0.65 X_2\) and the dots are

\[0.65 X_2 + \frac{\text{Residuals}}{j^{0.2} \rho^{0.65}}\]

The combination of \(0.0254 C(M_3 - C)\) and \(0.65 X_2\) may be called "potential sales." (Again footnote 29 applies.) This sum appears in Chart 27 together with actual sales. The deviations of actual sales from potential are in part accounted for by the remaining terms \(j\) and \(\rho\).

Chart 28 shows the adjustment to be applied to potential sales for various values of supernumerary income per capita. When this factor is \$200, potential sales are multiplied by 0.54; when \$450, by 1.43. The scatter of dots about the line seems to be random. There is very little evidence of circular arrangement of the dots around the curve, but a condition so clearly present in the correlation between sales and national income in Chart 4 of Mr. Horner's paper. Apparently the reformulation of the theory of demand excluding the change in national income as an explicit factor has proved satisfactory.

The contribution of price is shown in Chart 29. The curve shows how sales vary with this factor, a price of 90 tending to increase sales by between six and seven per cent relative to their level when the price is 100, and a price of 110 tending to decrease them by the same amount. The logarithmic slope of the line is \(-0.65\), and \textit{prima facie} the price elasticity is \(0.65\). The dots showing adjusted sales have considerable significance. The scatter around the price curve is wide, not tight and close as in Charts 26 and 25. In fact if the observations for 1919, 1920 and 1921 are eliminated, the remaining dots seem to scatter widely without clearly indicating any particular curve. The line of best graphical fit to the dots for 1922-1937 is probably the thin line, which has an elasticity of 1.5, but curves of 2 or even 2.5 fit the scatter tolerably well. Thus, about all that can be said is that the elasticity of demand with respect to price is probably near 1.5 but may be as small as 0.65 or as large as 2.5.

The equation can also be arranged so as to test the expression for maximum ownership. Both sides are divided by \(j^{0.2} \rho^{-0.65} BC\) giving

\[
\frac{Sales}{j^{0.2} \rho^{-0.65} BC} = \left(\frac{M_3 - C}{BC}\right) + \frac{AX_2}{BC} + \frac{\text{Residuals}}{j^{0.2} \rho^{-0.65} BC}
\]

\[\text{(11) What little circular regression remains could probably be diminished by using a cost of living index which is less sensitive than the Conference Board index to changes in rents and by introducing dealers' used car stocks as a variable. The Conference Board index of the cost of housing is essentially an asking rental index. Actual rental payments lag behind asking rentals because of leases entered at rent levels obtaining several months or a year earlier. For a discussion of the relationship of circular regressions to lags and the choice of function, see Herbert E. Jones, "The Nature of Regression Functions in the Correlation Analysis of Time Series," \textit{Econometrica}, Vol. V, 1937, pp. 305-325. The effect is similar to the physical phenomenon of hysteresis. For a definition of economic hysteresis see C. F. Roos, "A Mathematical Theory of Competition," \textit{American Journal of Mathematics}, 1925.}\]
THE DYNAMICS OF AUTOMOBILE DEMAND

The $C$ and $X_2$ terms are shifted to the left-hand side, and the result is

$$\frac{Sales}{j^t p^{-a}BC} + C - \frac{AX_2}{BC} = M_3 + \frac{Residuals}{j^t p^{-a}BC}$$

The adjusted observations for the relation of sales to the maximum ownership level can thus be computed by adding to $M_3$ the quotient, Residuals + ($j^t p^{-a}BC$). The variable $M_3$ does not reach up high enough in 1923, 1928, 1929 and 1937, nor low enough in 1932. Thus, the adjusted observations furnish a criterion for improving the maximum ownership formulas.

The Residuals. The average residual for the 19 year period 1919-1937 is 4.17 per cent. On the assumption that the observations are independent, the average error of estimate is approximately $4.17 \times \sqrt{\frac{19}{12}}$ or 5.25 per cent. As the observations are not independent, this figure is to be regarded as a lower limit.

Some of the residuals can be accounted for by special factors. The largest residual prior to 1938 was 18.5 per cent in 1927. This was due to the change-over from the Model T Ford to the Model A. Sales were low because production was insufficient. Another large residual was in 1923, in which year instalment selling gained momentum. Sales in 1933 exceeded the calculated level by 5.9 per cent. Perhaps this represented anticipation of higher prices due to NRA, and perhaps expectation of a reversal of the trend of national income. Sales were held down in 1934 by the low allowances for used cars sanctioned and enforced by the NRA dealers' code. In 1935 and 1936 financing terms were reduced sharply; carrying charges were cut and the term lengthened; and Ford came out with the $25-a-month plan. Sales in 1938 were below calculated, perhaps because dealers suddenly reversed their used car policy and liquidated a large portion of their used car stocks. With the exception of 1923 and 1927 none of these residual effects was large until 1938.

Some facts pertaining to this and other formulas follow.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Number of Observations</th>
<th>Number of Parameters</th>
<th>Period of Fit</th>
<th>Average Residual for Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>(16)</td>
<td>19</td>
<td>7</td>
<td>1919-37</td>
<td>4.2</td>
</tr>
<tr>
<td>Time Trend</td>
<td>12</td>
<td>9</td>
<td>1921-32</td>
<td>3.1</td>
</tr>
<tr>
<td>De Wolff</td>
<td>28</td>
<td>8</td>
<td>1921-34</td>
<td>11.0</td>
</tr>
</tbody>
</table>

(1) Formula (16) has nine or more independent parameters if the weights used in calculating replacement pressure according to a changing life table are counted.

The time trend formula fits well when extrapolated to 1933, 1934, 1935, and 1936.

(2) Separation of new owners and replacements gives 28 observations for the 14 year period. Some of the constants were determined from data for 1900-1920.
FACTORS GOVERNING CHANGES IN DEMAND

Formula (16) does not employ a time trend, the others do. Cars in operation furnishes the trend effect without the use of a time function, and in consequence the formula, as it were, feels its way forward from point to point in time on the basis of current physical and economic factors internal to the automobile market. The satisfactory fit without use of a trend is support of the completeness and correctness of the general features of the theoretical formulation.

Section VIII—Other Factors Affecting Retail Sales

Although the factors used in equation (16) account for all but a small part of the variation in retail sales, there are others for which, on theoretical considerations, claims can be advanced.

1. The Relation of Used Car Allowances to Automobile Sales.

Used car allowance is one of these factors. This is a highly variable quantity, depending on the age and condition of cars being offered for trade-in, and especially the ability of the dealers to discount this unique type of asset. The importance of this factor probably lies in the fact that it can bring into the flow of purchasing power for buying passenger cars a new tributary stream, viz., the net increase or decrease in dealer and finance company capital tied up in used cars. In a year of rapid building-up of dealer used car stocks such additional funds may amount to 3 per cent or 4 per cent of the wholesale value of sales. Later repayment of these funds during a downswing may amount to 4 per cent or 5 per cent of the wholesale value of cars sold.

Chart 30 shows the residuals from equation (16) compared with the ratio of trade-in allowance to price.

The ratio of trade-in allowance to price is proposed as one of the independent variables in equation (8), p. 34. This formula can be fitted by the usual methods using data for 1929-38, and it can also be fitted to the observations for the entire period 1919-38 in the form

\[ S = p^{\alpha} T^\beta \beta^\gamma \epsilon \quad \left\{ BC(M_3 - C) + AX \right\} \]

in which \( \epsilon \) takes the value 1 during 1919-27 and 0 thereafter, or vice versa, and \( a \) is a constant determined by the observations.
The amount of labor required for solutions in the above forms is not justified, however, and a simpler way to introduce the new variable is to fit the formula

\[ Sales = H K^n T^q \]

for the period 1928-37. The factor \( K \) is the calculated value from equation (16). The results are:

\[ Sales = .985 \ K^{1.024} \ T^{.01} \]

\[ Sales = 1.06 \ K^{1.0} \ T^{.06} \]

according as the exponent of \( K \) is assumed to be 1.0 or is determined from the observations.

The extra factor \( T \) receives an exponent of .06, which means that an increase of 1 per cent in the trade-in allowance stimulates sales by .06 per cent. This is clearly non-significant. The calculated values are about the same with and without this factor. The partial residuals are shown in Chart 31,
and are scattered pretty well at random. The slope of the line depends almost entirely on the 1934 observation. The case of 1934 has its peculiar interest. Used car allowances were kept down in that year by the NRA dealer code. The code was lifted in 1935 and there was an immediate rise both in the trade-in ratio and in retail sales. Sales were greater in 1935 than can be accounted for by the long-term factors of income, price and consumers' car stock.

The 1938 observation falls very far from the curve. The higher trade-in allowance of 1938 presumably reflects a higher quality of cars offered for trade as well as a shift of new car purchases toward the low priced group. But whatever the reason, the effect of this factor as measured was more than offset by the liquidation of used car stocks in 1938.
THE DYNAMICS OF AUTOMOBILE DEMAND

The negative result of such study does not prove that this factor is without effect. Slight changes in equation (16) would produce residuals strongly correlated with the trade-in ratio, and as a matter of fact some of the first demand equations developed (since discarded) included T with an exponent of .54. The statistical reason for the indeterminate result is that there are too few independent observations to permit accurate determination of the effects of so many interrelated variables; the degrees of freedom in the observations have already been used for determining the effects of other variables.

*A priori,* the significance of the trade-in ratio seems to be beyond question. If new car prices have an effect on sales, then used car allowances must also, for the net cash cost to the buyer is the difference between the two. If the elasticity of sales with respect to price is 1.5, and used car allowances approximate 1/3 of new car prices, sales elasticity with respect to allowances ought to be $\frac{1}{3} \times 1.5 = .5$, roughly. However, this reasoning is valid only for used cars of constant quality. The actual statistical series used is affected by many factors—the distribution of trade-ins offered, by age, original cost, and mechanical condition, and the distribution, by type and list price, of the new cars bought. In view of the statistical results, judgment must be suspended as to the significance of the trade-in ratio as measured.

2. Financing Terms.

Financing terms include the amount of the down payment as a percentage of price, the average instalment and the average term, *i.e.*, the number of monthly payments. The data on Chart 30 bring out in sharp relief how terms have become progressively easier. The percentage of instalment contracts on new and used passenger cars and trucks running more than twelve months has risen from 14.5 per cent in 1928 to 68 per cent in 1937 and the percentage of down payments under standard terms ($33\frac{1}{2}$ per cent on new cars, 40 per cent on used cars) has risen from 6.1 per cent to 23.3 in the same length of time. But the most significant fact shown by the chart is the sudden and drastic easing of terms beginning in 1935 and continuing in 1936 and 1937 which may well have contributed to the sales increases in those years. Clearly these changes must have had some effect. How much, cannot be said, because time series analysis cannot yield good results when the factors exhibit little variation or follow a trend without pronounced deviations from it. Moreover, the factors already used, particularly cars in operation, account for most of the variation, and as still others are added, the chances of spurious results increase.

Some economists of the automobile industry believe that making the terms easier does not induce more people to buy cars so much as induce those who were going to buy anyway, to buy a car of higher price.
FACTORS GOVERNING CHANGES IN DEMAND

While statistical analysis has been directed almost wholly to a limited number of major causal factors—income, price, replacement pressure, and cars in operation—there are undoubtedly others which, if more observations were available, would be worth examining. For example:

a. Highway Carrying Capacity and Car Servicing Facilities. The country's mileage of hard-surfaced roads has been and is still being increased rapidly, and what is more important, roads are being widened, over-passes and under-passes are being built and by-passes are being constructed around cities. This should raise the maximum ownership level. It is strictly a long-term trend factor, like the number of families, and is reflected in the number of cars in operation.

b. Operating Costs. This variable is believed to be the most important of the neglected factors; it is probably of more importance as a trend factor governing car ownership over a period of years than as a short-term cyclical factor like dealers' used car stocks. (See below.) The more cheaply cars can be run, the more of them consumers can maintain. Engineering improvements which cut down tire, oil and gas consumption, and repair bills, should raise the maximum ownership level. Garage rent is sometimes an important factor. Annual operating and other maintenance costs are three or four times as large as the cost of replacing scrapped cars with new cars, and therefore should influence the maximum ownership level more than new car prices.

Some operating and maintenance costs are given in the table on the following page. The first column shows the car population. The second column is an estimate of the cost of replacing cars retired from this population with new. It was obtained by raising the wholesale value by an average retail mark-up, and prorating the result in the ratio of unit replacement sales to total sales. The third column shows expenditures for replacement parts and tires, obtained by raising the wholesale value of "Replacements of parts, tires, etc." as given in Automobile Facts and Figures by 35 per cent. These figures do not include parts sold by automobile manufacturers. The fourth column shows estimated retail expenditures for gasoline. Reported gasoline consumption was reduced by a small but increasing percentage to allow for non-automotive uses, and the balance was multiplied by the ratio of passenger car registrations to total passenger car and truck registrations, one truck being counted as equivalent to three passenger cars for this purpose. The gasoline consumption in passenger automobiles so derived was then multiplied by the average retail price of gasoline in fifty cities.

What this table shows is the secondary importance, from the standpoint of replacements, of new car prices. During the last ten years costs of the one item of gasoline have apparently exceeded the cost of
THE DYNAMICS OF AUTOMOBILE DEMAND

CERTAIN PASSENGER CAR OPERATING
AND MAINTENANCE COSTS

<table>
<thead>
<tr>
<th>Year</th>
<th>(1) Car Population</th>
<th>(2) Cost of New Car Purchased for Replacement (Millions)</th>
<th>(3) Cost of Parts, Tires, etc. For Replacement (Millions)</th>
<th>(4) Cost of Gasoline, Passenger Cars (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>15.69</td>
<td>$2,285</td>
<td>$1,160</td>
<td>$1,749</td>
</tr>
<tr>
<td>1927</td>
<td>16.82</td>
<td>2,040</td>
<td>1,165</td>
<td>1,782</td>
</tr>
<tr>
<td>1928</td>
<td>17.55</td>
<td>2,156</td>
<td>1,170</td>
<td>1,950</td>
</tr>
<tr>
<td>1929</td>
<td>18.74</td>
<td>2,732</td>
<td>1,144</td>
<td>2,240</td>
</tr>
<tr>
<td>1930</td>
<td>19.73</td>
<td>2,262</td>
<td>874</td>
<td>2,140</td>
</tr>
<tr>
<td>1931</td>
<td>19.58</td>
<td>1,534</td>
<td>676</td>
<td>1,842</td>
</tr>
<tr>
<td>1932</td>
<td>19.16</td>
<td>851</td>
<td>705</td>
<td>1,800</td>
</tr>
<tr>
<td>1933</td>
<td>18.56</td>
<td>791</td>
<td>592</td>
<td>1,785</td>
</tr>
<tr>
<td>1934</td>
<td>18.88</td>
<td>999</td>
<td>688</td>
<td>2,021</td>
</tr>
<tr>
<td>1935</td>
<td>19.36</td>
<td>1,268**</td>
<td>771</td>
<td>2,110</td>
</tr>
<tr>
<td>1936</td>
<td>20.11*</td>
<td>1,418**</td>
<td>865</td>
<td>2,385</td>
</tr>
<tr>
<td>1937</td>
<td>21.46*</td>
<td>2,087**</td>
<td>938</td>
<td>2,620</td>
</tr>
<tr>
<td>1938</td>
<td>22.31*</td>
<td>1,452**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total 1928-37</td>
<td></td>
<td>$16,098</td>
<td>$8,423</td>
<td>$20,893</td>
</tr>
</tbody>
</table>

Notes on Computation:

Column 2: Sales for replacement (total retail sales when there was a net decrease in cars in operation) \* average retail unit value.

Column 3: Wholesale value of "replacements of parts, tires, etc." reported by the Motor and Equipment Manufacturers Association and published in Facts and Figures, adjusted by the same formula used in Column (4) to obtain replacements for passenger cars, and raised 35 per cent to allow for distributors' margin.

Column 4: Gasoline consumption was reduced by 2 per cent in 1919 and thereafter by a percentage uniformly increasing to 10 per cent in 1937 to allow for non-automotive uses. The resulting automotive consumption was then multiplied by the ratio of passenger car registrations to total registrations, in which total one truck was counted equal to three passenger cars for this purpose. Passenger car gasoline consumption, as derived by this formula, was then multiplied by the average retail price per gallon in 50 cities (Automobile Facts and Figures).

* November 1 of previous year.
** Twelve months ending October.
new cars by about 30 per cent. A full accounting of upkeep costs, including lubricants, repairs, service, garage rent, licenses, etc., would probably show that new car costs are not over one-third or one-quarter of total operating and maintenance costs. "It isn't the original cost—it's the upkeep." In view of this, the low price exponent of \(-.74\) in the replacement sales equation is not unreasonable.

Although operating costs do not appear explicitly in the formulas, their effects are included because these factors are correlated with automobile prices. The automobile price index can transmit not only the effect of automobile prices as such, but also the effect of any omitted factor to the extent that it parallels automobile prices. Some, at least, of these upkeep factors are highly correlated with automobile prices. Thus for the period 1919-1937 retail gasoline prices and wholesale tire prices are correlated .914 and .927 with automobile prices. (Correlations were calculated between the logarithms of the variables.) This means that, whatever effect these two variables have, over 90 per cent of it can be transmitted by the automobile price index. Thus they are well represented in the demand function by proxy.

c. Purchasing Power Sources Other Than Income. Those associated with financing and the "discounting" of used cars have been discussed. There are probably others, such as the net increase in loans on securities held by individuals.

d. Dealers' Used Car Stocks. Of all the neglected factors, dealers' used car stocks are believed to be most important for the medium term, particularly at times when there is a cyclical reversal. They are not wholly neglected, to be sure, because dealers' used cars which are registered appear in the figure "cars in operation," but their effect is probably not measured adequately.

If data on the number and value of used cars in dealers' stocks were available, they might be introduced into the formula as follows. It could be assumed that the amount of capital dealers are willing to have tied up in used cars is some fraction of the sales value of new cars, e.g.,

\[
\text{Desired Used Car Inventory} = K \cdot p \cdot S
\]

where \(K\) is a constant, \(p\) is the price of new cars, and \(S\) is new car sales. The actual used car inventory may be written \(u \cdot n\), where \(u\) and \(n\) are respectively average value and number of used cars. The actual inventory tends to reflect new car sales in the recent past and it can easily get out of line with current dollar sales from time to time, particularly when the latter change suddenly. Dealers may be assumed to adjust their policies so as to keep

\[ u \cdot n = K \cdot p \cdot S, \]

by buying used cars on balance when \(u \cdot n\) is less than \(K \cdot p \cdot S\) and selling on...
THE DYNAMICS OF AUTOMOBILE DEMAND

balance when \( u \) is greater than \( KpS \). A plausible assumption is that the net value of purchases or sales is proportional to the difference between the two quantities

\[
\text{Consumer Net Purchases of Used Cars} = h(u - KpS) \text{ dollars}
\]

Consumer net purchases equal dealer net sales of used cars. The quantities \( u \) and \( n \) are as of the beginning of the year or other interval. The factor \( h \) measures the speed with which equilibrium between used car inventory and sales value is restored. This dollar amount can be converted into a new car equivalent by dividing it by some price index of new cars. The total number of new cars purchased, including the "equivalent," should follow a formula like (8), i.e.,

\[
S + \frac{h(u - KpS)}{p} = f^\gamma p^{-\alpha} Z
\]

Here \( Z \) represents the other terms in the equation. Rearranged, it becomes

\[
S = -\frac{h}{1 - hK} \frac{u}{p} n + \frac{I}{1 - hK} f^\gamma p^{-\alpha} Z
\]

or, since the constants \( h \) and \( K \) are arbitrary,

\[
S = -C_1 \frac{u}{p} n + C_2 f^\gamma p^{-\alpha} Z
\]

If it be assumed that the normal used car inventory is 5 per cent of gross sales and that it takes about 1 year to bring used car inventory back to normal, \( K = .05 \) and \( h = 1 \). Then

\[
\text{Sales} = 1.05^{f^\gamma p^{-\alpha} Z} - 1.05 \frac{u}{p}
\]

Sales are equal to a term of the type used in Sections II-VII, less a fraction of the new car equivalent of dealers' used car stocks.

It seems probable that a formula of this type would eliminate all the circular movement between sales and the income factor. (See footnote 31.)

e. The Price of Goods Competitive with Automobiles, competitive at least as far as the consumers' dollar is concerned—furniture, household appliances, residence, travel, railroad passenger rates, amusement, and so on. The better the bargains offered in these competitive fields, the less consumers may be inclined to spend for automobiles. In default of a price index of competitive goods, the cost of living was used to deflate supernumerary income in the maximum ownership formulas on page 57.

f. The Style Factor. This is a qualitative factor of some importance. It is associated with the new model stimulus (see Section IX).
FACTORS GOVERNING CHANGES IN DEMAND

The present number of observations (19 years) is too limited to permit measurement of the effects of the neglected factors. Apparently these are not of much importance, since the factors used account for the actual sales very well.

Section IX—Month-to-Month Fluctuations in Automobile Sales

The demand functions just presented account for the broad cyclical swings of automobile demand. Section IX is concerned with how annual totals of automobile sales are distributed from month to month, in particular with the effects of the following short-term factors:

1. seasonal variation and new model stimulus
2. price change anticipation
3. supply of new cars—field stocks and production
4. trend of general business activity and national income throughout the year.

1. Seasonal Variation and New Model Stimulus.

The first two of the above factors, new model stimulus and seasonal variation are clearly of major importance. By "seasonal" is meant the regularly recurring rise and fall in retail sales due to regularly recurring weather and calendar events: it may be split into a "pure" seasonal due chiefly to weather, and a calendar seasonal due to varying lengths of months. By new model stimulus is meant the sales shift resulting from introducing new models at one time rather than another.

Chart 32 shows monthly retail sales 1926 through 1938. These have been adjusted to a constant month of 30 5/12 days in order to eliminate the calendar variation, and then smoothed by a type of 12 month moving average. The smooth line on the chart represents the presumed course of sales associated with the general year-to-year factors. The ratio of actual retail sales to the smooth line appears at the top of Chart 33. The seasonal movement stands out very clearly. One fact that is obvious immediately is that the month-to-month fluctuation has narrowed a great deal in 1936, 1937, and 1938.

The second line on Chart 33 shows a combination of the constant seasonal function and the variable new model stimulus. The seasonal function is shown below.
Chart 32

Seasonal Variation, Passenger Car Sales
(All months on 30 5/12 day basis)
Average month = 100

Jan. 59       May 134       Sept. 94
Feb. 72      June 133       Oct. 89
Mar. 110     July 118       Nov. 76
Apr. 139     Aug. 108       Dec. 68

At the beginning of the year sales (aside from calendar influences) run around 40 per cent below their value for the average month. Next there is a sharp advance in February and March, and in April, May and June sales run from 30 to 40 per cent above the average month. Sales start to drop off in July and decline irregularly to a point 32 per cent below average in December.
FACTORs GOVERNING CHANGES IN DEMAND

Chart 33

By adjustment of the above seasonal function to the actual calendar lengths of months, the following seasonal, shown on Chart 34, is obtained:

Seasonal Variation, Passenger Car Sales
(Calendar months)
Average month = 100

<table>
<thead>
<tr>
<th>Calendar Month</th>
<th>Seasonal Index</th>
<th>Per Cent of Year Total</th>
<th>Calendar Month</th>
<th>Seasonal Index</th>
<th>Per Cent of Year Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>60</td>
<td>5.0</td>
<td>July</td>
<td>120</td>
<td>10.0</td>
</tr>
<tr>
<td>Feb.</td>
<td>66</td>
<td>5.5</td>
<td>Aug.</td>
<td>110</td>
<td>9.2</td>
</tr>
<tr>
<td>Mar.</td>
<td>112</td>
<td>9.3</td>
<td>Sept.</td>
<td>93</td>
<td>7.7</td>
</tr>
<tr>
<td>Apr.</td>
<td>137</td>
<td>11.4</td>
<td>Oct.</td>
<td>91</td>
<td>7.5</td>
</tr>
<tr>
<td>May</td>
<td>136</td>
<td>11.4</td>
<td>Nov.</td>
<td>75</td>
<td>6.3</td>
</tr>
<tr>
<td>June</td>
<td>131</td>
<td>10.9</td>
<td>Dec.</td>
<td>69</td>
<td>5.8</td>
</tr>
</tbody>
</table>

The new model stimulus curve, also shown on Chart 34, shows the apparent effect of new model introduction on total industry sales, other
things being equal. It is assumed that the new model is introduced on the first of the month. The curve is:

**New Model Stimulus**

<table>
<thead>
<tr>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fourth month before new model introduction</td>
</tr>
<tr>
<td>Third month before new model introduction</td>
</tr>
<tr>
<td>Second month before new model introduction</td>
</tr>
<tr>
<td>First month before new model introduction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>+28</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Model Introduced on First of Month</td>
<td></td>
</tr>
<tr>
<td>First month of new model introduction</td>
<td>+26</td>
</tr>
<tr>
<td>Second month after new model introduction</td>
<td>+15</td>
</tr>
<tr>
<td>Third month after new model introduction</td>
<td></td>
</tr>
<tr>
<td>Fourth month after new model introduction</td>
<td>+8</td>
</tr>
</tbody>
</table>

About four months before a model change, sales begin to drop off; a loss of about 6 per cent of the average monthly sales occurs. As the model change date approaches, sales drop off still further, until in the month just before the model change the sales loss amounts to about 38 per cent of the average monthly sales. Sales in the two months immediately after the change rise to approximately 28 and 26 per cent respectively above the monthly average. The effect seems to be zero in the fifth and sixth months.

It must be emphasized that the function represents the stimulus to total sales; that individual makes of cars may enjoy a much greater new model stimulus; and that the effect on industry sales depends to a large degree on intangible style factors.

No one can know in advance what the new model stimulus is going to be in a particular case. It may be very marked in some years and small in others, and to determine the effect it is necessary to wait until some months after the event. However, in any particular case, the course of the stimulus should agree approximately with the curve shown. The stimulus curve has been determined only to a first approximation.

The seasonal and new model stimulus curves can be used to find out how sales will probably be distributed with given introduction dates.
FACTORS GOVERNING CHANGES IN DEMAND

Suppose it is desired to find out how sales of the industry probably will be distributed with model introduction in November. For this, the pure seasonal and the new model stimulus are combined by addition as follows.

<table>
<thead>
<tr>
<th></th>
<th>Pure Seasonal</th>
<th>New Model Stimulus</th>
<th>Sum</th>
<th>Calendar Month Basis</th>
<th>Per Cent of Year Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>59</td>
<td>+15</td>
<td>74</td>
<td>75</td>
<td>6.3</td>
</tr>
<tr>
<td>Feb.</td>
<td>72</td>
<td>+8</td>
<td>80</td>
<td>74</td>
<td>6.1</td>
</tr>
<tr>
<td>Mar.</td>
<td>110</td>
<td>—</td>
<td>110</td>
<td>112</td>
<td>9.3</td>
</tr>
<tr>
<td>Apr.</td>
<td>139</td>
<td>—</td>
<td>139</td>
<td>137</td>
<td>11.4</td>
</tr>
<tr>
<td>May</td>
<td>134</td>
<td>—</td>
<td>134</td>
<td>136</td>
<td>11.4</td>
</tr>
<tr>
<td>June</td>
<td>133</td>
<td>—</td>
<td>133</td>
<td>131</td>
<td>10.9</td>
</tr>
<tr>
<td>July</td>
<td>118</td>
<td>—6</td>
<td>112</td>
<td>114</td>
<td>9.5</td>
</tr>
<tr>
<td>Aug.</td>
<td>108</td>
<td>—10</td>
<td>98</td>
<td>100</td>
<td>8.3</td>
</tr>
<tr>
<td>Sept.</td>
<td>94</td>
<td>—23</td>
<td>71</td>
<td>70</td>
<td>5.9</td>
</tr>
<tr>
<td>Oct.</td>
<td>89</td>
<td>—38</td>
<td>51</td>
<td>52</td>
<td>4.3</td>
</tr>
<tr>
<td>Nov.</td>
<td>76</td>
<td>+28</td>
<td>104</td>
<td>103</td>
<td>8.6</td>
</tr>
<tr>
<td>Dec.</td>
<td>68</td>
<td>+26</td>
<td>94</td>
<td>96</td>
<td>8.0</td>
</tr>
</tbody>
</table>

The sum in column 4 shows the composite index of month-to-month variation on the basis of uniform 30 5/12 day months; column 5 shows the variation on the basis of calendar months; and column 6 shows each calendar month expressed as a percentage of the annual total. If the introductions are to be 10 per cent in October, 70 per cent in November and 20 per cent in January, the result will be as shown:

New Model Stimulus

<table>
<thead>
<tr>
<th></th>
<th>Pure Seasonal</th>
<th>Combined Seasonal and New Model Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>59</td>
<td>77</td>
</tr>
<tr>
<td>Feb.</td>
<td>72</td>
<td>82</td>
</tr>
<tr>
<td>Mar.</td>
<td>110</td>
<td>113</td>
</tr>
<tr>
<td>Apr.</td>
<td>139</td>
<td>141</td>
</tr>
<tr>
<td>May</td>
<td>134</td>
<td>134</td>
</tr>
<tr>
<td>June</td>
<td>133</td>
<td>132</td>
</tr>
<tr>
<td>July</td>
<td>118</td>
<td>113</td>
</tr>
<tr>
<td>Aug.</td>
<td>108</td>
<td>99</td>
</tr>
<tr>
<td>Sept.</td>
<td>94</td>
<td>73</td>
</tr>
<tr>
<td>Oct.</td>
<td>89</td>
<td>64</td>
</tr>
<tr>
<td>Nov.</td>
<td>76</td>
<td>93</td>
</tr>
<tr>
<td>Dec.</td>
<td>68</td>
<td>79</td>
</tr>
</tbody>
</table>

Thus it is possible to calculate the probable distribution resulting from introducing new models at any given time of the year.

The third line of Chart 31 is a composite new model stimulus curve for each month of 1926-1938. This was constructed as follows. The columns of the table below show the model stimulus curves staggered according to the months in 1929 in which new models were introduced. The
volume of new models introduced in January, 1929, constituted about 70 per cent of the industry, on the basis of 1929 new car registrations. Accordingly the stimulus curve for January introduction receives a .70 weight. Four per cent of the industry, on the same basis, introduced models in February, 2 per cent in July and 3 per cent in August. Of the 1930 models, 2 per cent were introduced in October, 1929 and 37 per cent in November, 1929. The distribution of this year was also influenced by the 33 per cent of 1930 models introduced in January of 1930, 2 per cent brought out in February, and 5 per cent in March. The stimulus curves are weighted as indicated, and added. The composite new model stimulus curve appears in the last column.

**Composite New Model Stimulus For 1929**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>(.70)</td>
<td>(.04)</td>
<td>(.60)</td>
<td>(.02)</td>
<td>(.03)</td>
<td>(.02)</td>
<td>(.37)</td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td>28</td>
<td>-38</td>
<td>-23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18.1</td>
</tr>
<tr>
<td>Feb.</td>
<td>26</td>
<td>28</td>
<td>-38</td>
<td>(.02)</td>
<td></td>
<td></td>
<td></td>
<td>19.3</td>
</tr>
<tr>
<td>Mar.</td>
<td>15</td>
<td>26</td>
<td>28</td>
<td>-6</td>
<td>(.03)</td>
<td></td>
<td></td>
<td>11.4</td>
</tr>
<tr>
<td>Apr.</td>
<td>8</td>
<td>15</td>
<td>26</td>
<td>-10</td>
<td>-6</td>
<td></td>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td>May</td>
<td>8</td>
<td>15</td>
<td>-23</td>
<td>-10</td>
<td>(.02)</td>
<td></td>
<td></td>
<td>.4</td>
</tr>
<tr>
<td>June</td>
<td>8</td>
<td>-38</td>
<td>-23</td>
<td>-6</td>
<td>(.37)</td>
<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>July</td>
<td>28</td>
<td>-38</td>
<td>-10</td>
<td>-6</td>
<td></td>
<td></td>
<td></td>
<td>2.9</td>
</tr>
<tr>
<td>Aug.</td>
<td>(.33)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept.</td>
<td>-6</td>
<td>(.02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct.</td>
<td>-10</td>
<td>-6</td>
<td>(.05)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>-23</td>
<td>-10</td>
<td>-6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec.</td>
<td>-38</td>
<td>-23</td>
<td>-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
</tbody>
</table>

The composite for other years was computed in exactly the same way. Little new model effect was shown in 1926-1927 because some makers, e.g., Ford, did not have new models and moreover new model introduction dates of other cars were scattered throughout the year, thus tending to offset one another. Beginning in 1929, however, there was a tendency to concentrate new model introductions around the turn of the year, with the result that the new model effect became prominent. There was a change in 1932, in which year the Ford V-8 was brought out in May, but thereafter January 1st introduction prevailed until 1935, when fall was chosen in order to stabilize employment throughout the year.

**Method of Analysis.** The above seasonal and new model stimulus curves were derived by the following method. The sales are assumed to be given by a formula of the type

\[
\text{Sales (30 5/12 day basis)} = \text{Smooth Trend} \times \left[ \frac{\text{Pure Seasonal}}{\text{New Model Stimulus}} \right]
\]

78
FACTORS GOVERNING CHANGES IN DEMAND

The pure seasonal and the new model stimulus are assumed to be independent. When the basic factors represented by the smooth trend are constant the result of a change in the model introduction date is simply to change the monthly distribution of sales without altering the yearly total. An alternative theory is that the seasonal and new model stimulus should be multiplied by the new model stimulus, thus:

\[ Sales = \frac{\text{Smooth}}{\text{Trend}} \times \sigma \times \mu \]

where \( \sigma \) is the pure seasonal and \( \mu \) is the new stimulus. Both are periodic functions. One implication of the product formula is that the yearly total of sales can be raised or lowered apart from the general factors of income, etc., by altering the model introduction date; for \( \int \sigma \mu \, dt \) over one year depends on the phases of \( \sigma \) and \( \mu \), whereas \( \int (\sigma + \mu) \, dt \) does not. Another implication is that the summer sales peak could be made extremely high by introducing models on April 1. On the basis of the seasonal and stimulus curves given on p. 76 the April peak would be 175 by the product formula. Both these implications seem implausible, and therefore the sum formula is preferred.

The ratio \( Z \) of sales to trend, shown on Chart 33, is the observed monthly distribution to be explained by the seasonal and new model stimulus. A first approximation to a new model stimulus was chosen on the basis of previous exploratory work by S. M. DuBrul.

A composite new model stimulus was built up for 1926-1938 on the basis of the percentage of the total industry sales introduced on specific dates, exactly as described on page 78. The composite so obtained is similar to the third line on Chart 33 and differs from it only in amplitude. Call this series \( m \). Then the observed ratio of sales to smooth trend, \( Z \), may be written

\[ Z_i = s_i + km_i \]

where \( s_i \) is a seasonal function of the usual type and \( k \) is a coefficient introduced to allow for the possibility that the true new model stimulus differs from the assumed new model stimulus by a constant factor. There are thirteen unknowns in all, which can be determined simultaneously by least squares. The least squares normal equations are

\[
\begin{align*}
\sum s_1 + km_1 &= Z_1 \\
\sum s_2 + km_2 &= Z_2 \\
\sum s_3 + km_3 &= Z_3 \\
\vdots \\
\sum s_{12} + km_{12} &= Z_{12} \\
\sum m_1 + m_2 + \ldots + \Sigma m^2 &= \Sigma Zm,
\end{align*}
\]
THE DYNAMICS OF AUTOMOBILE DEMAND

in which \( n_1 \) is the number of Januaries in the series, \( n_2 \) the number of Februaries, \( \ldots \) \( n_{12} \) the number of Decembers; \( s_1, s_2, \ldots, s_{12} \) are the twelve seasonal indexes; \( m_1, m_2, \ldots \) represent the sums of \( m \) for all Januaries, all Februaries, etc.; and \( Z_1, Z_2, \ldots, Z_{12} \) are the sums of \( Z \) for all Januaries, all Februaries, \( \ldots \) all Decembers. The unknowns are found to be

The Twelve Seasonal Indexes

<table>
<thead>
<tr>
<th></th>
<th>From Equations</th>
<th>Adjusted</th>
<th>Adjusted to Calendar Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>58.9</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>February</td>
<td>71.7</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>March</td>
<td>110.0</td>
<td>110</td>
<td>112</td>
</tr>
<tr>
<td>April</td>
<td>139.1</td>
<td>139</td>
<td>137</td>
</tr>
<tr>
<td>May</td>
<td>134.5</td>
<td>134</td>
<td>136</td>
</tr>
<tr>
<td>June</td>
<td>132.8</td>
<td>133</td>
<td>131</td>
</tr>
<tr>
<td>July</td>
<td>118.2</td>
<td>118</td>
<td>120</td>
</tr>
<tr>
<td>August</td>
<td>108.3</td>
<td>108</td>
<td>110</td>
</tr>
<tr>
<td>September</td>
<td>93.7</td>
<td>94</td>
<td>93</td>
</tr>
<tr>
<td>October</td>
<td>89.0</td>
<td>89</td>
<td>91</td>
</tr>
<tr>
<td>November</td>
<td>76.5</td>
<td>76</td>
<td>75</td>
</tr>
<tr>
<td>December</td>
<td>68.6</td>
<td>68</td>
<td>69</td>
</tr>
</tbody>
</table>

The constant \( k \) proved to be 1.27, showing that the first approximation to the new model stimulus was too small. The second approximation is 1.27 times the first.

New Model Stimulus

<table>
<thead>
<tr>
<th>Months Before and After Introduction</th>
<th>First Approximation</th>
<th>Second Approximation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>–4</td>
<td>– 5</td>
</tr>
<tr>
<td>–3</td>
<td>–3</td>
<td>–10</td>
</tr>
<tr>
<td>–2</td>
<td>–2</td>
<td>–23</td>
</tr>
<tr>
<td>–1 Before</td>
<td>–18</td>
<td>–38</td>
</tr>
<tr>
<td>–0 After</td>
<td>–30</td>
<td></td>
</tr>
<tr>
<td>+1 After</td>
<td>+22</td>
<td>+28</td>
</tr>
<tr>
<td>+2</td>
<td>+21</td>
<td>+26</td>
</tr>
<tr>
<td>+3</td>
<td>+12</td>
<td>+15</td>
</tr>
<tr>
<td>+4</td>
<td>+ 6</td>
<td>+ 8</td>
</tr>
</tbody>
</table>

The curve of seasonally adjusted retail sales shown on Chart 35 is not as smooth as could be wished. Moreover, certain irregularities tend to repeat themselves, which shows that the adjustment has not removed all the periodic variation. Thus the points for March in 1935, 1936, 1937 and 1938 are high, and the Februaries in 1936, 1937 and 1938 are low. It should be pointed out that the pure seasonal was taken as

---

This method does not redetermine the shape of the stimulus curve. It is possible to check and improve the shape by successive approximation methods such as those used by Ezekiel, op. cit.
constant throughout the period, a restriction which puts quite a strain on any method of adjustment. In view of the steady increase in the proportion of cars on the road which are comfortable in cold weather and with good winter maintenance of highways, it is probable that the pure seasonal has decreased in amplitude over the period. Allowance for a gradual damping of the seasonal swing should therefore improve the adjustment. A second approximation on the shape of the stimulus curve is also highly desirable. Inspection of the seasonally adjusted sales suggests that the stimulus amplitude may be greater than shown at the bottom of Chart 34, and that the curve may be sustained somewhat longer before dropping back to zero. It may be, too, that the amplitude is increasing. Some of the dips in seasonally adjusted sales are traceable to deficient stocks or production, as can be seen by comparing the graph with the bottom line of Chart 33. Other minor fluctuations are believed to represent anticipation of price changes.

2. Price Change Anticipation.

Price change anticipation on the part of the customer brings about an increase in sales before an expected price increase, followed by a decrease when the change takes effect; or it causes a drop in sales before an expected price decrease, followed by an increase when the change takes effect. This
short-term price effect merely shifts sales from one month to another without changing the total sales over a period; whereas the long-term price effect examined in Sections II-VIII does change the total. The short-term phenomenon is well known in staple commodity markets, e.g., textile fabrics where anticipated slight changes can bring about large shifts in buying.

Chart 35 shows seasonally adjusted retail sales compared with the new Chilton index of short-term price changes. A correlation involving factors previously considered and changes in this price index fails to establish the significance of price change, but its economic logic is so strong that it must be accepted as an important short-term factor. Moreover, a few instances of the apparent effect of price change anticipation can be seen on the chart. Among these is October 1937 when a rise in sales occurred prior to the advance of prices to the highest levels; in the summer of 1933 sales increased in anticipation of higher prices under the NRA and fell off when higher prices took effect. The excise tax on automobiles went into effect in July 1932. There was a sharp rise in sales in June, followed by a drop in July. Apparently consumers decided to buy ahead. Significant is the fact that as far as can be seen in each case considered, the effect of price anticipation on sales was only of short duration.

3. Field Stocks and Production.

The apparent effects of field stocks and new production on sales retardation during a single month are shown in Chart 36. The mode of action of these factors is conceived to be as follows. The long-term factors and the seasonal and new model stimulus in combination tend to produce a certain level of sales in January, another level in February, and so on. These may be called "theoretical sales." If factory shipments and dealers' stocks exceed certain critical levels relative to theoretical sales, actual sales tend to equal theoretical sales. If either production or stocks are below these critical levels, actual sales fall short of theoretical sales by an amount depending on the deficiency of supply.

Chart 36 presents rough measures of sales retardation due to this cause. The scale along the bottom of the chart shows field stocks as a percentage of theoretical sales. The scale at the left-hand margin shows production as a percentage of theoretical sales. The contours show sales retardation as a function of the two foregoing ratios. The chart may be read as follows: with field stocks equal to the expected theoretical sales for the month (100 per cent) and production at about 110 per cent, there is no sales retardation. With the same field stocks but production at 90 per cent, the contours indicate a 10 per cent retardation of sales; with production at approximately 50 per cent, a 20 per cent retardation; and with production at approximately 40 per cent, a 30 per cent sales retardation. Other areas of the chart are read in the same way. For example, a 200 per cent inventory compensates for an 80 per cent production, so that there is no loss of sales. The sales retardation computed from this chart
for 1930-38 is shown at the bottom of Chart 33. This line is to be regarded only as a first approximation.

The method of constructing the contours was as follows: an approximation to theoretical sales was derived by drawing a smooth curve through seasonally adjusted monthly retail sales, and then superimposing on it the seasonal and new model stimulus. The smoothing curve was drawn rather high and without reference to the random low points in the series, especially those of certain months in which stocks or production were known to be deficient. The ratios

\[
\text{Actual Sales} \div \text{Theoretical Sales}
\]
\[
\text{ Dealers' Stocks Beginning of Month} \div \text{Theoretical Sales}
\]
\[
\text{ Factory Shipments} \div \text{Theoretical Sales}
\]

were computed, and the first charted as a joint function of the other two.
Contours were drawn following Ezekiel's technique, giving Chart 36. These results are only meant to be suggestive. No attempt has been made to obtain more than the roughest approximations. It would be extremely difficult to separate the sales retardation due to lack of supply from that due to anticipation of a model change. However, as a practical matter, the former type of retardation can be considered as part of the new model stimulus because it is most in evidence just before model changes. Only the model changes need therefore be studied.

4. Combination of Short-Term and Long-Term Factors. The short-term and long-term factors can be combined to give a monthly calculated sales. The long-term factors of income, price, car stocks and scrapping can be put on a monthly basis, by interpolation if necessary, and used in equation (16), preferably on a seasonally adjusted basis. Chart 37 shows monthly sales values calculated from an equation very like number (16). This was one of the approximations leading up to the latter and which is similar enough to it to use for illustrative purposes. Seasonally adjusted retail sales are shown for comparison.

The seasonal and new model stimulus can be superimposed upon the calculated value for the long-term factors. This is shown in Chart 38 compared with actual retail sales. Agreement between the two series is close, and it shows that almost all the variation in passenger car sales has been accounted for by the short-term and long-term factors. The short-term and long-term formulas provide instruments well adapted for the analysis and interpretation of retail passenger car sales statistics.

Ezekiel, op. cit., p. 308.
FACTORs GOVERNING CHANGES IN DEMAND

Section X—Discussion and Summary of the Results

With the derivation of the demand function for passenger car sales presented in Sections I-IX, the objective of this study has been attained. The following features of this study seem to have most significance.

1. The Concept of Demand. Not least in importance from the point of view of the automobile industry and economic theory is a broadening of the notion of demand determination. Demand, usually regarded as depending on price alone or on price and national income, unfortunately overlaid in practical life by the intrusion of "disturbing factors," is accepted as a multi-factor phenomenon in which price and income and the "disturbing factors" appear on equal footing. No particular social requirements are laid down for admission to the circle of demand factors; any factor is admitted which does in fact influence demand. For instance, the seasonal characteristics of automobile sales belong in an economic analysis of demand no less than price itself.

2. Formulation of a Hypothesis. One of the most vital steps in the analysis was hammering out a precise hypothesis by give-and-take discussion with specialists intimately acquainted with the industry, guided by criteria of logical and mathematical consistency and by economic theory. The hypothesis embraced (a) precise definitions of the significant factors, (b) a broad picture of the organic mechanism of which they are parts, and (c) the mode of interconnection of these parts. So vital in economics is the coherence and economic persuasiveness of a theory that it can be more properly said that the theory accounts for, illumines, and gives significance to the correlations found, rather than that the correlations verify or confirm the theory. Many statistical formulas represent the data with substantially equal goodness of fit, and consequently statistical tests of goodness of fit fail to distinguish between those made up of purely empirical covariations and those which are causally significant formulations. The logical implications of the formula and economic theory are marks of the best formula.38

Thus, the analysis of the factors likely to influence automobile demand led to the rejection of the usual national income series in preference to another, disposable income, which is believed to reflect more accurately the stream of money available for the purchase of automobiles. The chief differentiating characteristics of disposable income are the exclusion of direct taxes and the inclusion of entrepreneurial savings. From this new income series was eliminated necessitous living cost to obtain a better figure of money available for non-necessitous expenditure. The resulting series is called supernumerary income. As another example, analysis of the price

---

38 The relative and unavoidable vagueness of hypotheses in economics and the lack of criteria to guide mathematical formulation of the hypotheses are handicaps to the more rapid progress of economics. Contrast with this the role of hypotheses in physics, as described in the chapter of that title in H. Poincare's Science and Hypothesis and see also Morris Cohen's "The Statistical View of Nature," Journal of the American Statistical Association, June 1936.
situation led to the selection of the price of the lowest price cars freely available in volume as the most appropriate index of price. A new variable, the consumers' car stock, was shown to be of great importance.

The guiding concept in developing the formula was that what consumers consume is not new cars, but transportation service from their car stock; the new car sales are a derived demand incidental to replacing cars in this stock, or building it to a higher level. The principal factor in determining how this car stock is to be built up is the eventual ownership objective of the consumers, or the maximum ownership level. The concept of this level varying with income and car life has apparently not been used in previous demand analyses. In fact, as the majority of previous demand studies have been concerned with perishable and semi-perishable goods, no occasion has previously arisen to make use of either this idea or that of consumers' stocks.

Simple assumptions about the action of consumers vis-à-vis their maximum ownership level objective and their present status as regards car ownership, led to the adoption of a mathematical formula which mathematicians will recognize as a generalization of the differential equation of an autocatalytic chemical reaction.\(^{37}\) This equation is

\[
\frac{dy}{dt} = ry\left(1 - \frac{y}{u}\right)
\]

where \(u\) is the upper limit of growth regarded as fixed in the cases to which it has previously been applied, and \(y\) is the current value of the variate (human population or the quantity of reagent in a chemical reaction) and \(r\) is the unimpeded rate of growth.

The equation used for automobile sales differs from the above only in the addition of a term to represent scrapping and in the assumption that \(u\) and \(r\) are variables, functions of income, price, and the number of families.

This formula has been fitted to the observations. The fit agrees very well with actual sales experience of the industry. This tends to confirm the picture of the mechanism of new car demand presented above, though the confirmation is far from absolute because any number of other formulas can be devised which also fit the data. This lack of conclusiveness must always be present in any science, physical or social, in which verification must be by analysis of a limited number of observations affected simultaneously by a multitude of factors for which it is difficult to obtain actual measures, and in which no opportunity is presented to control unwanted factors by an experimental technique.

It is necessary to consider carefully what is proved by a fit secured by multiple correlation methods. Correspondence of calculated and observed

\(^{37}\) See Raymond Pearl, *Studies in Human Biology*, and A. J. Lotka, *Elements of Physical Biology*. The assumptions back of this formula have such suggestive analogies that the equation has come to be used in biological studies and in studies of population growth.
values tends to establish two types of conclusions which must be carefully distinguished. (1) The fit may simply show that the dependent variable (retail sales) is closely paralleled by a particular combination of the independent variables (income, price, etc.), without any implication that the parts of the combination measure accurately the effects of the individual factors upon the dependent variable. Thus an equation may give an incorrect picture of the effect of a specific factor on sales, and yet the combination of factors may be quite adequate for predicting sales. This is always so when some of the independent variables are highly intercorrelated.\textsuperscript{38} If one factor in a combination has too great a weight, the least squares method of fitting almost necessarily assures that another correlated factor has too little; exaggeration of one term is offset by attenuation of another. (2) The fit may, however, have wider significance; it may tend to show that the separate terms in the formula measure, within a computed degree of accuracy, the effects of individual factors (e.g., the effect of price on sales). As a rule causal relationships of this type are very difficult to establish by multiple correlation methods; “where we do not isolate a single determinant we cannot expect to find a determinate relation,” (Morris Cohen, op. cit., p. 345). To establish causal relationship, all factors of importance must be included in the equation, the functional form of the equation must be appropriate, and there must be a sufficiently large number of observations.

3. Statistical Results.

The Maximum Ownership Level. The concept of a maximum ownership level is believed to be of considerable importance in the analysis of durable goods demand. Several formulas have been obtained for this factor:

\[
M_1 = \text{Population} \times (0.087 + 0.000252 \times \frac{\text{Real Supernumerary}}{\text{Income per Capita}})
\]

\[
M_2 = f \times (0.378 + 0.00068 \times \frac{\text{Real Supernumerary}}{\text{Income per Capita}}) \times \left(\frac{\text{Replacement}}{\text{Cost}}\right)^3
\]

\[
M_3 = f \times (0.500 + 0.000544 \times \frac{\text{Real Supernumerary}}{\text{Income per Capita}}) \times (\text{Durability})^3
\]

The first of these depends on population and per capita real supernumerary income. The second which, in addition, takes price and durability of cars into account and uses the number of families in place of population, is

more satisfactory; it is derived from the new owner sales. The third, derived from the total sales equation (16), is useful for studying elasticity of demand with respect to price. None of these equations includes explicitly the presumably important factor of operating costs.

Calculations based on the second formula show that an increase of one billion dollars in supernumerary income raises the maximum ownership level by .9 per cent at present, or 200,000 cars, and a price decrease of 1 per cent raises the calculated value of $M_2$ by .3 per cent. The term $p^{-3}$ is believed to transmit a substantial portion of the effect of operating costs because automobile prices have in the past closely paralleled the prices of such important items as tires and gasoline. As the total dollar cost of operating the consumers’ car stock—gasoline, oil, tires, repair parts, labor, taxes, garage, etc.—exceeds the cost of new cars for replacement by a large margin, it is possible that the exponent $-3$ grossly exaggerates the influence of automobile price as such on the number of cars maintained by consumers. A crude index of durability has been used to convert price into replacement cost as in the factor $p/d$, where $p$ is price and $d$ is average car life. Durability and operating costs, measures of the quality of automobiles, seem together to be more important than price alone. Other important factors affecting the maximum ownership level are highway carrying capacity and service facilities.

The maximum ownership level, as measured by the above formulas, has fallen twice, in 1929-32 and again in 1938. On the first occasion consumers definitely decreased the number of cars in operation, and in all likelihood when data are available they will show the same result in 1938.

The difference between the current size of consumers’ stocks and the maximum ownership level may be called potential new owners. This factor has been found to contribute in an important way to the fluctuations of new car demand. It is very sensitive to changes in national income, particularly when the current stock has been built up near the maximum ownership level. As a result the sensitivity of new car sales to changes in income has apparently been increased recently. Also in recent years car durability has increased. With the better cars of today, consumers are well able to put off buying new cars for short periods without serious inconvenience to themselves. In 1938 a slight change in national income resulted in a sharp drop in new car sales down to 1932-33 depression levels. This suggests that increased durability of automobiles is rendering the industry more subject to large cyclical swings and increasing its resemblance as regards economic position to residential building.

The Income Factor. Disposable income as defined in this study is believed to represent the income available for the consumers’ market more accurately than any of the national income series in current use, and supernumerary income, which is disposable income less necessitous living costs, is believed to be the best series to use in demand studies for commodities in the non-necessity class. The income factor appears in two places in the
FACTORS GOVERNING CHANGES IN DEMAND

equation, in the maximum ownership term, and as a multiplier. It is thus regarded as having a compound effect—(a) in raising or lowering the objective toward which consumers build their car stock, and (b) in increasing or decreasing the speed toward the objective. A convenient way to summarize the action of national income is in terms of elasticity.

This is given by the partial logarithmic derivative, viz.,

$$\frac{j}{S} \frac{dS}{dj} = 1.20 + .0046 \frac{j}{L} d^3 f C \frac{f}{y}$$

where $y$ is the term $.0254(M_3 - C) + .65X_2$.

Values of the income elasticity computed from equation (16) for the years 1919-1938 are:

<table>
<thead>
<tr>
<th>Year</th>
<th>1919</th>
<th>1.55</th>
<th>1929</th>
<th>2.39</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1920</td>
<td>1.55</td>
<td>1930</td>
<td>2.62</td>
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<td>1921</td>
<td>1.56</td>
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<td></td>
<td>1922</td>
<td>1.61</td>
<td>1932</td>
<td>2.44</td>
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<tr>
<td></td>
<td>1923</td>
<td>1.69</td>
<td>1933</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td>1924</td>
<td>1.80</td>
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<td>2.19</td>
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<td>1925</td>
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<td></td>
<td>1928</td>
<td>2.25</td>
<td>1938</td>
<td>2.58</td>
</tr>
</tbody>
</table>

This table shows that given conditions of an almost saturated market, as in 1938, the income elasticity can be as high as 2.5. Under more favorable conditions of an only partially saturated market, income elasticity may be only 1.5.

Replacement Sales. Studies of scrapping of passenger automobiles show great variability and a distinct trend toward longer life. Thus the 1933-37 registration data apparently show 93 per cent of the cars surviving five years, while Griffin's table of 1926 shows 67 per cent; furthermore, the registrations indicate (by extrapolation, for they give no count of cars more than eight years old) that the scrapping peak is beyond the ninth year, as compared with a peak at seven years shown in the earlier study. The scrapping curve is so variable that it does not furnish a secure basis for predicting replacement sales. The longer life at present is largely due to better construction by the automobile manufacturers, all-steel construction, for example, and to smoother roadways. The pressure for replacement can be calculated by applying various scrapping tables to the age distribution. The tendency toward longer car life can be allowed for by splicing calculations from different scrapping tables. (See page 51.) Replacement sales are fairly well represented by the following formula:

$$(11) \quad S_R = .92 j^{.07} p^{-.24} (Theoretical Scarping)^{1.10}$$

89
THE DYNAMICS OF AUTOMOBILE DEMAND

New Owner Sales: New owner sales (net additions to car population) were found to be represented fairly well by the equation

\[ S_N = f^{1.5} p\cdot 9 \times .040 C^1 (M_2 - C^1) \]

in which \( C^1 \) is the mid-year value. The residuals in the two preceding formulas are partly compensating, with the result that their sum gives a close approximation to retail sales.

Retail Sales: A separate analysis of new owner and replacement sales is impractical for statistical reasons (p. 34) and moreover there is some theoretical basis for doubting the complete independence of the two markets. In the equation for total sales, replacement sales and new owner sales do not appear separately as such. A replacement pressure term is included in the formula on a par with the new owners' term. These, however, are only convenient names for parts of the mathematical expression which, in combination, represent sales. The equation obtained was

\[ Sales = f^{1.2} p^{-65} \left\{ .0234 C (M_2 - C) + .65 X_1 \right\} \]


The original purpose of this study was the determination of the price elasticity for automobiles. As the problem was analyzed it became evident that the first task was necessarily that of solving the multi-factor problem of total demand, that is, to derive a satisfactory demand function for passenger cars. The effect of price could then be determined from this as a by-product.

The exponent of price is \(-.65\) in equation (16) and \(-.74\) in equation (11) and on the surface this indicates an elasticity of less than unity. The standard error of the \(-.65\) exponent is found to be .23 by the usual sampling theory formula, which might indicate that the chances are 5 out of 6 that the true exponent lies between \(-.88\) and \(-.42\). However, sampling theory is not applicable to economic time series, and this determination merely indicates a possible limit of error. The diversity of results obtained by various methods and with different price series shows that the elasticity can not be determined accurately. The principal reason for this indeterminateness of the exponent is that price has not had very many or very large swings during the period under investigation; price has been in a general down trend. As a matter of fact, the slope of the price relationship in Chart 29 is almost wholly determined by the observations for 1919, 1920, and 1921. Cut these out, and the remaining residuals on Chart 29 indicate a price curve of elasticity somewhere between .65 and 2.5. If one figure is to be chosen from this scatter, perhaps 1.5 is the

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\[(39)\] How to compute the standard error of regression coefficients derived from time series is a matter of controversy. The writers hold the view of Walter Shewhart, Corrado Gini and others that the errors formulas of sampling theory apply only to cases in which samples are drawn from constant universes and that, in general, economic time series do not satisfy this condition.
FACTORs GOVERNING CHANGES IN DEMAND

best. Such a figure is broadly confirmed by the experience of Canada; a Canadian tariff of approximately one-third has been accompanied by a per capita car population of one-half that of the United States.

Another reason why the price elasticity is so indeterminate is that this factor has a fairly high correlation with national income and a high correlation with the cost of living. While it is possible to determine with reasonable accuracy the effect of the combination of these two factors, it is not possible to assign with accuracy a definite part of the effect to each.10

How far are the above results dependent on the particular price series selected? A partial answer to this question was obtained by making a time trend analysis with several other price indexes. The following equations were derived for the period 1919-1938:

\[
\log S = \text{Constant} - 0.0048t + 0.0010t^2 - 2.22 \log P_1 + 1.65 \log j \\
\log S = \text{Constant} - 0.0042t + 0.0012t^2 - 1.89 \log P_2 + 1.61 \log j \\
\log S = \text{Constant} - 0.0012t + 0.0011t^2 - 2.08 \log P_3 + 2.18 \log j \\
\log S = \text{Constant} - 0.0031t + 0.0016t^2 - 1.93 \log P_4 + 1.58 \log j
\]

The origin of \( t \) is 1928.5. The price series \( P_1 \) is the Bureau of Labor Statistics index 1919-1926 and the unit value of Ford, Chevrolet and Plymouth during 1926-1938. This shows an apparent elasticity of 2.2. The index \( P_2 \) is the B.L.S. index 1919-1936 and the low-priced group 1937-1938. An elasticity of 1.9 is indicated by this series. Scoville's unit value index is represented by \( P_3 \), which receives an exponent of -2.1. The fourth series, \( P_4 \), is the B.L.S. index for 1919-1926 and a unit-value index for 1926-1938 adjusted to eliminate a good deal of the effect of volume shifts among price classes. It shows a price elasticity of 1.9. The highest elasticity coefficient is the one derived by using the unit value of low-priced cars.

10 The effect of the cost of living as it occurs in supernumerary income was determined independently from data on all durable goods including automobiles.

The intercorrelations between price and cost of living are high enough to make difficult allocation of the effects of each but the coefficient for the cost of living was obtained by correlating disposable income and cost of living with the consumption of all durable consumers' goods reported by the U.S. Census or in Kuznets' Commodity Flow and Capital Formation. Hence, if, instead of the price of automobiles, the price of furniture or of any other commodity—the price of which also chiefly depends upon the same cost of living factor and technological advances—had been used in the equation, a correlation would have been found. This parallelism of many other prices with automobile prices still further increases the difficulty of analyzing automobile demand by purely empirical methods. The high correlations of .91 and .93 between automobile prices and gasoline, and automobile prices and tires, show that both tire prices and gasoline prices could be used in the equation instead of automobile prices, and that statistically about the same results would be found. This would not prove that automobile sales were caused by tire prices, or gasoline prices, to the extent of the calculated exponent of price. Furniture has a .94 correlation and might actually give a better result than tires or gasoline. Hence the emphasis in this study on approaching the problem from the side of economics with the aid of mathematical reasoning. The distinction between causation and covariation is vital for the elasticity problem. See articles by Sewall Wright: "Correlation and Causation," Journal of Agricultural Research, 1921; "Method of Path Coefficients," Annals of Mathematical Statistics, 1934.
THE DYNAMICS OF AUTOMOBILE DEMAND

The following results were obtained for 1926-1938:

(18)

\[
\log S = \text{Constant} + .0232t - 3.59 \log P_1 + 2.27 \log j
\]

\[
\log S = \text{Constant} + .0222t - .45 \log P_2 + 1.77 \log j
\]

\[
\log S = \text{Constant} + .0213t - .29 \log P_3 + 1.80 \log j
\]

\[
\log S = \text{Constant} + .0236t - .61 \log P_4 + 1.80 \log j
\]

The extent to which the 1919, 1920 and 1921 observations influence the correlations is shown by the sharp decreases in the exponents of \(P_2\), \(P_3\) and \(P_4\) when the earlier period is excluded. The elasticities indicated by these price indexes are very low indeed. On the other hand the exponent of \(P_1\) increases to 3.6. It is clear that the elasticity found depends on the price index originally selected. These results, in view of their diversity, do not call for any modification of the other findings.

The exponents of \(j\) in the eight equations are consistent with the income elasticity \(m\) between 1.5 and 2.5 found above.

Elasticity can also be obtained from equations (11) and (15), which employ price in the upper limit. This has better theoretical justification. The price elasticity according to these formulas is

\[
- \left( 1.90 + .3 \times \left( \frac{M_2}{M_1-C} \right) \right) \frac{S_N}{S} + .74 \frac{S_R}{S}
\]

where \(S_N\) = calculated new owner sales, \(S_R\) = calculated replacement sales, \(S = S_N + S_R\), \(M_2\) = maximum ownership level, and \(C\) = cars in use (mid-year). This, it will be seen, is the weighted sum of the elasticities derivable from the separate new owners equation (15) and the replacement equation (11).

Values of this elasticity coefficient in each year from 1919 to date are

<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1919</td>
<td>1.38</td>
</tr>
<tr>
<td>1920</td>
<td>1.45</td>
</tr>
<tr>
<td>1921</td>
<td>1.49</td>
</tr>
<tr>
<td>1922</td>
<td>1.51</td>
</tr>
<tr>
<td>1923</td>
<td>1.60</td>
</tr>
<tr>
<td>1924</td>
<td>1.86</td>
</tr>
<tr>
<td>1925</td>
<td>2.13</td>
</tr>
<tr>
<td>1926</td>
<td>2.28</td>
</tr>
<tr>
<td>1927</td>
<td>2.55</td>
</tr>
<tr>
<td>1928</td>
<td>2.72</td>
</tr>
<tr>
<td>1929</td>
<td>2.85</td>
</tr>
<tr>
<td>1930</td>
<td>3.30</td>
</tr>
<tr>
<td>1931</td>
<td>3.13</td>
</tr>
<tr>
<td>1932</td>
<td>3.16</td>
</tr>
<tr>
<td>1933</td>
<td>2.56</td>
</tr>
<tr>
<td>1934</td>
<td>2.69</td>
</tr>
<tr>
<td>1935</td>
<td>2.69</td>
</tr>
<tr>
<td>1936</td>
<td>2.62</td>
</tr>
<tr>
<td>1937</td>
<td>2.83</td>
</tr>
<tr>
<td>1938</td>
<td>3.51</td>
</tr>
</tbody>
</table>

Can the above results be accepted as measures of the effect of automobile prices as such on sales, or do the high correlations between automobile prices and various operating costs prohibit drawing conclusions on this point? These intercorrelations do admittedly constitute an obstacle, though
FACTORS GOVERNING CHANGES IN DEMAND

not an insuperable one. The influence of operating costs on the derived elasticity coefficient can be partially eliminated by the following considerations.41

The price factor which determines how large a car stock consumers will maintain is a composite of all operating costs rather than automobile prices alone. This composite, denoted by $Q$, is given by the sum,

$$Q = w_1 p_1 + w_2 p_2 + w_3 p_3 + \ldots$$

$$= w_1 p_1 + q$$

in which the $p$'s are index numbers of the price of automobiles, etc., as above. The average value of each $p$ is 1.0 and the sum of the weights is unity. A simplifying assumption will now be made that the weights $w$ are proportional to the total dollar amount of each cost for the period. On this basis $w_1 < w_2$ and $w_1 > w_3$. As total operating costs are about three times the cost of replacements alone, $w_1 = .3$. The sub-index excluding the automobile price term is $q = w_2 p_2 + \ldots + w_3 p_3$, and this is highly correlated with automobile prices. As correlations greater than .9 have been found between the latter factor and gasoline, and tires, it is conservative to assume a correlation of .8 between automobile prices $p_1$ and the sub-index $q$.

The composite $Q$ may therefore be written

$$Q = .3 p_1 + .8 \times .7 \pi + r$$

$$= .3 p_1 + .56 \pi + r$$

in which $r$ is a remainder uncorrelated with $p_1$; $p_1$ is the price of autos, and $\pi$ is automobile prices, not as such, but as representative of other costs.

The maximum ownership level $M_4$ can now be written as $M_4$:

$$M_4 = f \times \left[ Income \right] \times Q^{-30} \ d^{30}$$

$$= f \times \left[ Income \right] \times (0.3 p_1 + 0.56 \pi + r)^{-30} \ d^{30}$$

The new owners-replacement sales equation, combining formulas (11) and (15), is

$$(17) \quad S = j^{15} p^{-9} \left\{ .040 \ C^1 (M_4 - C^1) \right\} + .92 j^{1.07} p^{-74} X^1 \ ^{1.10}$$

The price elasticity according to this formula is

$$\left\{ .90 + .30 \times \frac{M_4}{M_4 - C^1} \times \frac{3 p_1}{Q} \right\} \frac{S_Y}{S} + .74 \frac{S_X}{S}$$

---

(41) See Sewall Wright, The Method of Path Coefficients.
THE DYNAMICS OF AUTOMOBILE DEMAND

and the following results were obtained by assigning the average value .3 to the fraction \( \frac{3p_1}{Q} \).

<table>
<thead>
<tr>
<th>Year</th>
<th>( \frac{1.03}{Q} )</th>
<th>( \frac{1.04}{Q} )</th>
<th>( \frac{1.05}{Q} )</th>
<th>( \frac{1.05}{Q} )</th>
<th>( \frac{1.15}{Q} )</th>
<th>( \frac{1.33}{Q} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1919</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1920</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1921</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1922</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1923</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1924</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
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<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
<tr>
<td>1928</td>
<td>1.41</td>
<td>1.51</td>
<td>1.46</td>
<td>1.30</td>
<td>1.26</td>
<td>1.38</td>
</tr>
</tbody>
</table>

It is believed that this table gives the most accurate picture of the price elasticity for automobiles. It shows values ranging between 1.0 and 1.5, and a value of about 1.4 for the elasticity during 1937. This means that, in order to maintain 1938 sales at the 1937 level, each one per cent drop in sales due to the depression could be offset by a price decrease of .7 of one per cent.

Summarizing this evidence, the writers believe that 1.5 may be accepted as the elasticity of passenger car sales with respect to price, when price is defined as the unit value of low-priced cars; that it may be as high as 2.0 or as low as 1.0; that even the value of .65 indicated by equation (16) is not unreasonable; and that other price indexes indicate generally lower elasticities.

How are these conclusions related to a view sometimes expressed that the price elasticity for automobiles ought to be very high, because automobiles are a luxury and price elasticities of most luxuries are, as a rule, high or greater than unity? A principal reason why elasticity is not higher lies in the durable character of automobiles, and in the fact that consumers have, over the short term, other ways of obtaining their automobile transportation. They can run their existing cars longer at the cost of somewhat higher repair bills, or they can obtain cars from the used car stock of dealers. As the used car stocks of dealers are in the neighborhood of three-quarters of a million at the top of the business cycle, consumers thus have access to a considerable source of supply independent of new car production. This factor is becoming of increased importance on account of a general rise in the durability and quality of cars in dealers' stocks. Another important reason is that the cost which determines how many automobiles the population will maintain in service is a joint cost, of which new car cost is only one item. Automobile sales can probably be stimulated more by development of cars with radically improved operating characteristics than by price cuts. Further, the classification of automobiles as luxuries is open to objection.

The influence of price on sales is outweighed by the powerful effect
FACTORS GOVERNING CHANGES IN DEMAND

of the income factor, and also by changes in the policies of dealers on used car allowances and on used car stocks. As has been shown earlier in the discussion, dealers tend to stimulate new car sales during periods of prosperity by "discounting" used cars, that is, by exchanging cash or credits for them, and depress new car sales by selling off their stocks of used cars during periods of recession.

The secondary importance of price also appears from the experience of other durable goods industries such as residential building and railway equipment. Response to price is present in these durable goods industries, and the price elasticities may be as high as 2 or 3, but these elasticities are insufficient to offset the large cyclical swings arising from the stocks of these goods in the hands of users and the variations in general production and national income.

This statistical analysis of price elasticity seems to have considerable relevance to the durable goods problem, which is the outstanding problem of our twentieth century economy. An abundance of durable goods characterizes a high level economy and with durable goods go instability and wide cyclical swings. The appalling complexities posed by this characteristic feature of a high level economy have even induced some persons to give it up entirely and recommend a return to the simple life of an economy centered mainly on the production of perishable goods, controlled (i.e., impeded) production, or a moratorium on invention.

This defeatist attitude seems to be entirely unwarranted. What really is needed is extensive research designed to lay bare the fundamental economic problems of a durable goods economy. One principle that already stands out is that the consumer of a durable good has much to say about the use of his income. Hence, if a high level of consumption is to be maintained, consumer confidence, which will induce the spending of income at a constant rate, is essential. Once this and similar problems are understood and practical economic principles are established, increasing stability and continued growth should be possible with a high level of durable goods production.
HEDONIC PRICE INDEXES
With Automotive Examples

Price index construction depends on price comparisons between periods of time. These necessitate adequate commodity standards, i.e., definitions of the articles priced. In the case of complex, rapidly evolving goods, serious errors result from identifications based on brand name and other superficial standards.

Among semi-adequate techniques for establishing continuous price comparisons are: 1) overlapping quotations; 2) averaging prices within broad definitions, and 3) price-specification comparisons.

The HEDONIC suggestion proposes that the significance of the physical specifications for product usefulness and desirability be established by multiple regression analysis of the specifications and prices, and perhaps even the sales, of the various products offered in a given classification during any period. Prices can then be stated in terms of an objective composite reflecting product usefulness. In other words, the net relation between price and time is computed, while making allowance mathematically for changes in specifications reflecting product usefulness and desirability.

Since the validity of any price comparison rests upon pricing articles comparable in terms of useful qualities, the prerequisite of any realistic price index where exactly identical articles are not available for successive and overlapping periods of time is product specifications which actually reflect useful and desirable qualities.
HEDONIC PRICE INDEXES
With Automotive Examples

A. T. COURT
Automobile Manufacturers Association*

Importance of Problem

Commodity price indexes are to be taken seriously. With farm policy tied to so-called-"pre-war parity," and cost-of-living clauses included in wage contracts, measurement of price change has more than academic significance.

Commodity price indexes originally were based almost entirely on prices of standardized raw materials or semi-fabricated products whose specifications remained unchanged over long periods. The problems were mainly those of weights and the formula to be used.

Recently, however, articles fabricated from hundreds of separate parts, designed for complex functioning, and subject to rapid improvement in design and construction, have played an expanding role. Particular difficulties arise in constructing price indexes for these evolving products of twentieth century technology.

Automobiles constitute one of the most important of this new group of products. If better ways of measuring changes in their prices can be developed, the techniques may well be important for the general problem.

* The facts and opinions advanced in this analysis represent only the personal conclusions of the author and of no other. They are in no sense a statement of the point of view of the Automobile Manufacturers Association, his employers, or of any of its members. The author is indebted to the Automobile Manufacturers Association for clerical assistance and research facilities in preparing this study.

A double debt is owed Sidney W. Wilcox, Chief Statistician of the U. S. Bureau of Labor Statistics, for stimulating the train of investigation which led to the Hedonic suggestions and for patiently correcting several egregious errors of fact which appeared in early versions. Although Mr. Wilcox inspired and helped rectify the analysis, it cannot be considered, in any sense, a statement of his views.
THE DYNAMICS OF AUTOMOBILE DEMAND

Price Index Essentials

No valid price comparisons can be made without adequate commodity standards, i.e., definition of the articles priced in terms of their useful and desirable physical characteristics.

The importance of selecting realistically useful characteristics in establishing comparisons may be illustrated by cattle prices. Slaughter stock, being useful for their beef, are quoted and sold by weight and grade. Grade is largely determined by the estimated yield of beef of various qualities per hundred pounds of animal. Value is in terms of potential beef. In contrast, milk cows are quoted by the head and the price is a function of the animal's productivity, expected life and perhaps breeding value. Here, value is in terms of potential milk, butter fat and calves. To quote milk cattle on a poundage basis or beef cattle by the head without regard to weight, might well be misleading.

In the case of evolving, complex-functioned manufactured goods, like automobiles, the problem of choosing product standards for use in price comparisons is even more important and difficult. Serious errors have resulted from nominalistic identifications, i.e., comparisons based on brand name or other completely inadequate standards.

A Few Errors

Until recently the U. S. Bureau of Labor Statistics passenger car price index was based almost entirely on such nominalistic identifications.¹

In constructing this index, car prices were considered comparable so long as they referred to products of the same brand name, regardless of body type or size of vehicle represented. No distinction was made between standard, fully equipped cars and special, stripped, economy models offered without starter, battery, generator, speedometer, and other normal equipment.

The table on the following page compares 1935 models with 1925 by body types for a single leading make of car. The values of the recently discontinued B.L.S. index for the same make of car for the same periods are also shown.

Note that comparable body types were reduced in prices from 9 to 16 per cent. At the same time the size and capacity of the car improved immensely. Also the cost of extra equipment² and features included in the

¹ Much credit is due Commissioner Isadore Lubin and his staff for disclosing this situation. He has enlisted the aid of the industry to collect the information necessary to the construction of a more realistic measure.

² In any realistic price comparison it is necessary, of course, to consider the amount of equipment included. For example, in January 1937 almost all advertised car prices increased although delivered prices remained unchanged. Automobile manufacturers had decided to include bumpers, spare tire and wheel, and similar basic equipment in the list price rather than as a standard accessory group. There was no actual price advance. Any satisfactory price comparison would have been forced to recognize that the advance in nominal prices was entirely the result of added equipment. This factor in the situation is so obvious that it will not be mentioned again, although, of necessity, it qualifies all price comparisons which may be made.
HEDONIC PRICE INDEXES

list price in 1935, but not in 1925, totaled more than $100, at 1925 catalogue prices.

In spite of the decline in actual prices of comparable body types, the tremendous increase in car size and quality, and the fact that more than a hundred dollars of additional equipment was thrown in "free," the B.L.S. price index for this make advanced 45 per cent from 1925 to 1935.

The specific errors which explain this departure from reality are too numerous to list here. For example, at certain times basic equipment such as starter, generator, battery and balloon tires was included in the published prices, while at others they were treated as accessory equipment. As a result, the price index moved up or down ten or fifteen per cent whenever the form of the catalogue was changed, even though there was no significant change in actual prices of comparable cars.

1925 vs. 1935 MODELS

of a

LEADING MAKE OF PASSENGER CAR

<table>
<thead>
<tr>
<th>Body Type*</th>
<th>List Price 1925</th>
<th>List Price 1935</th>
<th>Per Cent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupe</td>
<td>$545</td>
<td>$495</td>
<td>-9%</td>
</tr>
<tr>
<td>Two door sedan</td>
<td>605</td>
<td>510</td>
<td>-16</td>
</tr>
<tr>
<td>Four door sedan</td>
<td>685</td>
<td>575</td>
<td>-16</td>
</tr>
</tbody>
</table>

B.L.S. Index‡ (1925 = 100) (recently discontinued) 100 145 +45

* Covers all comparable body types manufactured in both years. In addition to the body types shown, standard roadsters and touring models were offered in 1925 but not in 1935, while deluxe and trunk model sedans were important in 1935 but not available in 1925.

† Including low pressure cord tires which were optional in 1925 but have been standard equipment since 1928.

‡ The B.L.S. passenger car price indexes (though nominally wholesale) are based on factory list retail prices. If actual wholesale prices were compared with the index, the discrepancy in movements would have been even greater, for the dealer discount allowed by this manufacturer was larger in 1935 than in 1925.

(1) The automobile industry is to blame for not supplying adequate price quotations on a well-defined and uniform basis. It was not very cooperative at the time the index was revised in the mid-twenties and did not take the trouble even to check its movements until 1936.
THE DYNAMICS OF AUTOMOBILE DEMAND

Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>1925</th>
<th>1935</th>
<th>Per Cent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheelbase, inches</td>
<td>100</td>
<td>112</td>
<td>+ 12%</td>
</tr>
<tr>
<td>Horsepower, Maximum Developed</td>
<td>20</td>
<td>90</td>
<td>+ 350</td>
</tr>
<tr>
<td>Weight (Two Door Sedan), pounds</td>
<td>1900</td>
<td>2700</td>
<td>+ 42</td>
</tr>
<tr>
<td>Piston Displacement, cu. in.</td>
<td>177</td>
<td>221</td>
<td>+ 25</td>
</tr>
<tr>
<td>Front Spring Frequencies, o.p.m.</td>
<td>160</td>
<td>85</td>
<td>- 47</td>
</tr>
<tr>
<td>Acceleration, Max., 10-25 m.p.h., f.p.s.²</td>
<td>1.8</td>
<td>4.1</td>
<td>+ 128</td>
</tr>
<tr>
<td>Deceleration, Max., f.p.s.²</td>
<td>12</td>
<td>21</td>
<td>+ 75</td>
</tr>
<tr>
<td>Speed, Maximum, m. p. h.</td>
<td>40</td>
<td>80</td>
<td>+ 100</td>
</tr>
</tbody>
</table>

Note:—These specifications are derived from a variety of unofficial sources. They are believed to be approximately correct.

o.p.m.—Oscillations per minute under normal load.
f.p.s.²—Feet per second per second.
m.p.h.—Miles per hour.

Equipment

Included in the list price in 1935 but not in 1925, with 1925 catalogue prices:

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
<th>Item</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Cleaner, Intake</td>
<td>$5.00</td>
<td>Pedal</td>
<td>$1.00</td>
</tr>
<tr>
<td>Anti-Rattle</td>
<td></td>
<td>Pads (3)</td>
<td></td>
</tr>
<tr>
<td>Steering (3)</td>
<td>.75</td>
<td>Pants (4)</td>
<td>1.40</td>
</tr>
<tr>
<td>Brake (2)</td>
<td>.50</td>
<td>Pump, Water</td>
<td>2.15</td>
</tr>
<tr>
<td>Door Windows (4)</td>
<td>1.40</td>
<td>Shock Absorbers,</td>
<td></td>
</tr>
<tr>
<td>Radius Rod (2)</td>
<td>.70</td>
<td>Hydraulic (4)</td>
<td>30.00</td>
</tr>
<tr>
<td>Hood</td>
<td>.62</td>
<td>Speedometer</td>
<td>15.00</td>
</tr>
<tr>
<td>Braces</td>
<td></td>
<td>Stop-Light and Switch</td>
<td>1.28</td>
</tr>
<tr>
<td>Engine</td>
<td>3.00</td>
<td>Thermometer, Dash</td>
<td>8.00</td>
</tr>
<tr>
<td>Fender</td>
<td>1.00</td>
<td>Throttle, Foot</td>
<td>1.00</td>
</tr>
<tr>
<td>Brake, Rear Wheel, Service</td>
<td>12.50</td>
<td>Ventilator, Cowl</td>
<td>.98</td>
</tr>
<tr>
<td>Crankshaft, Counterbalanced</td>
<td>19.00</td>
<td>Windshield Safety Glass,</td>
<td></td>
</tr>
<tr>
<td>Gas Gauge, Dash</td>
<td>3.50</td>
<td>Exchange</td>
<td>15.00</td>
</tr>
<tr>
<td>Light, Parking</td>
<td>1.40</td>
<td>Windshield Wiper,</td>
<td></td>
</tr>
<tr>
<td>Lock, Steering</td>
<td>12.00</td>
<td>Automatic</td>
<td>3.50</td>
</tr>
<tr>
<td>Oil Retainers, Rear Axle (2)</td>
<td>2.00</td>
<td>Total</td>
<td>$142.68</td>
</tr>
</tbody>
</table>

Probably this contradiction between actual price movements and the index number is unique. There is every evidence that the B.L.S. seeks carefully to establish price comparisons for products identified by their significant physical characteristics.

As tangible evidence of the acute difficulties which have beset the makers of passenger automobile price index numbers, note the fact that, among all the commodity definitions used in compiling the B.L.S. wholesale price
HEDONIC PRICE INDEXES

index, passenger car definitions alone do not include any physical specifications whatsoever. The passenger car definitions are in terms of brand name alone, although automobile trucks and farm tractors are both specified in terms of physical characteristics, as are all other products in the wholesale commodity price index.

In the case of passenger automobiles, the established techniques proved inadequate because of the complexity of the problem.

Establishing Price Comparisons

How can valid price comparisons be made when the various products offered in any one year do not correspond exactly in specifications with those offered at any earlier period? No exact counterparts can be found today for the automobiles of the twenties.

There are three approaches to this problem:

1. Overlapping series.
2. Averages within broad definitions.

Overlapping Series are widely used for evolving products in constructing the B.L.S. and other commodity price indexes. (See table on page 104.) This is a valid approach when the new and old products are competitively priced.

Frequently it is impossible to use this method. The economics of mass-production, as in the case of automobiles, often makes it necessary to drop the manufacture of an old product as soon as a new design serving the same market goes into assembly. No overlap exists. The method, though sound, proves inadequate.

Broad Definitions provide another valid but limited approach to the problem of price comparisons. For example, the B.L.S. uses a specification range in connection with its auto truck price index which is described as "Trucks, weighted average 3½ Tons and Under of 3 Makes, Each, F.O.B. Factory." The farm tractor price indexes are described as

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(4) The automobile prices used in this study are the advertised retail prices of passenger cars at the factory. In every case, allowance is made for the shift from so-called factory list to advertised delivered price basis in early 1997.

In practical application, automobile price quotations must be qualified by consideration of both freight charges and trade-in allowance. Since these are local, individual situations not reflected in any available figures, they are ignored in this analysis of the over-all trends of prices and values. They must be allowed for, however, in any realistic interpretation of the actual level of automobile prices to the final customer.

(5) From 1926 to 1933 the B.L.S. truck price index declined 32 per cent while their passenger car price index fell only 13 per cent. During the same period, actual prices of leading makes of passenger cars fell slightly more rapidly than did the actual prices of trucks of the same makes. Lacking any official explanation, it might be assumed that this disagreement between index number trends and actual price movements resulted from the use of specification ranges for trucks and nominalistic identification for passenger cars.
### Table 9.—Average wholesale prices of commodities, 1913 to 1928—Continued

<table>
<thead>
<tr>
<th>Year or month</th>
<th>Men's, work, medium grade</th>
<th>Women's</th>
<th>80% inch boot, average price</th>
<th>75% inch boot, average price</th>
<th>Dress Oxford, average price</th>
<th>Rel. price, 1925 equals 100</th>
<th>Gun metal buckle, average price</th>
<th>Black kid, lace, Oxford, average price</th>
<th>Rel. price, 1925 equals 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1913</td>
<td>43.000</td>
<td>68.9</td>
<td>1.636</td>
<td>41.4</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>1914</td>
<td>3.900</td>
<td>68.9</td>
<td>1.741</td>
<td>43.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1915</td>
<td>3.900</td>
<td>68.9</td>
<td>1.500</td>
<td>45.1</td>
<td></td>
<td></td>
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<td>1916</td>
<td>3.442</td>
<td>79.1</td>
<td>2.332</td>
<td>58.3</td>
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<tr>
<td>1917</td>
<td>4.256</td>
<td>103.3</td>
<td>3.230</td>
<td>81.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1918</td>
<td>4.375</td>
<td>104.4</td>
<td>3.708</td>
<td>92.4</td>
<td></td>
<td></td>
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<tr>
<td>1919</td>
<td>6.596</td>
<td>151.3</td>
<td>5.029</td>
<td>125.4</td>
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<tr>
<td>1920</td>
<td>7.963</td>
<td>173.8</td>
<td>7.088</td>
<td>140.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1921</td>
<td>5.900</td>
<td>110.1</td>
<td>5.200</td>
<td>110.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1922</td>
<td>4.356</td>
<td>99.6</td>
<td>3.550</td>
<td>93.1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1923</td>
<td>4.250</td>
<td>97.5</td>
<td>3.478</td>
<td>96.6</td>
<td></td>
<td></td>
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<tr>
<td>1924</td>
<td>5.554</td>
<td>97.7</td>
<td>3.500</td>
<td>97.2</td>
<td></td>
<td></td>
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<td>1925</td>
<td>4.125</td>
<td>101.3</td>
<td>3.500</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1926</td>
<td>4.074</td>
<td>100.0</td>
<td>3.500</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>4.000</td>
<td>98.3</td>
<td>3.500</td>
<td>100.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>4.160</td>
<td>100.6</td>
<td>3.729</td>
<td>108.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reproduced from B.L.S. Bulletin No. 493—"Wholesale Prices, 1913 to 1928."

"Tractor, 10-20 H.P., Each, Factory" and "Tractor, Farm, 15-30 H.P., Gear Drive with Friction Clutch Pulley and Steel Lugs, Each, Factory."

This procedure is a valid method for establishing price comparisons. In the case of trucks and farm tractors, a single specification is of sufficient importance. It is simple to apply.

By contrast, the uses of passenger cars are manifold. No single specification comes near to reflecting adequately their useful and desirable qualities. Where it is necessary to set the specification range in terms of more than one variable, it becomes difficult to find ranges which will provide reasonably close definition without eliminating so many quotations that the resulting averages become unstable.
HEDONIC PRICE INDEXES

As an example, the passenger car specification range8 2400-3200 pounds dry weight, 106-120 inches wheelbase, 60-100 developed horsepower was chosen. This range was broad enough to include over ninety per cent of all production in 1935, yet not a single car came within it before 1925, and the number of cars qualifying before 1930 was inadequate for a significant average. In order to establish price comparisons back to 1920, it was necessary to select three sets of car weight, wheelbase, horsepower ranges covering the periods 1920-25, 1925-30, 1930-39. The averages based on each of these ranges were linked together on the overlapping years to form the continuous index, shown on Chart 2, page 112.

Although fundamentally valid, the specification range approach is unsatisfactory in several respects. The range chosen is necessarily arbitrary and products may fall into or out of it as a result of inconsequential changes in specifications. The effects are likely to be distorted movements of the average. Although this method can yield a satisfactory approximation of broad price trends, it lacks any delicacy and may be positively misleading in the short term.

Product analogies provide another approach to the price comparison problem within the broad definition framework. The table which follows compares a popular current series of each manufacturing group with the car most nearly analogous in terms of car weight, wheelbase, and horsepower in 1920. Note that in seven of the eight manufacturing groups where analogous cars could be found in 1920 and 1939, the name was different. In seven cases out of eight, nominalistic price comparisons on the basis of brand name would have been misleading. The difficulties lie in finding adequate analogies, e.g., in earlier years no cars had the horsepower of recent models. The index based on the analogies tabulated is plotted on Chart 2 below in comparison with the specification range index. If really significant specifications had been used as criteria, the problem of finding analogies would have been even more difficult. Specifically, nothing approaching the comfort and performance of the cheapest 1939 models was available in 1920, at any price. When an exact analogy can not be found, a subjective element is necessarily injected into the analysis.

In addition to the overlap and broad definition procedures described above, there remains the technique of establishing price comparisons in terms of specification units. This approach includes established methods and the Hedonic suggestions.

8) For illustrative purposes, it has been assumed that passenger car usefulness is reflected by, and can be measured in terms of, the three specifications, dry weight, wheelbase, and advertised horsepower. These specifications have the advantage of being available for all makes over a long period of time from published sources. They do not really begin to reflect the useful and desirable characteristics of passenger cars. Since, however, this is a discussion of possible methods rather than a definitive analysis of price trends, they will serve.
### THE DYNAMICS OF AUTOMOBILE DEMAND

**ANALOGOUS CAR SEQUENCES**
based on
**CERTAIN SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Make and Series</th>
<th>Year</th>
<th>Weight Lbs.</th>
<th>Wheelbase Inches</th>
<th>Brake Horsepower</th>
<th>Factory Delivered Price</th>
<th>Per Cent of 1920 Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHRYSLER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plymouth Roadking</td>
<td>1939</td>
<td>2824</td>
<td>114</td>
<td>82</td>
<td>$685</td>
<td>21.6%</td>
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<tr>
<td>Chalmers 35C</td>
<td>1920</td>
<td>3100</td>
<td>117</td>
<td>45</td>
<td>3170</td>
<td>100.0</td>
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<tr>
<td>GENERAL MOTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chevrolet Master</td>
<td>1939</td>
<td>2820</td>
<td>112</td>
<td>85</td>
<td>648</td>
<td>26.6</td>
</tr>
<tr>
<td>Oldsmobile 37B</td>
<td>1920</td>
<td>2739</td>
<td>112</td>
<td>44</td>
<td>2435</td>
<td>100.0</td>
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<tr>
<td>GRAHAM-PAIGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Graham Standard</td>
<td>1939</td>
<td>3250</td>
<td>120</td>
<td>90</td>
<td>940</td>
<td>28.8</td>
</tr>
<tr>
<td>Paige 6-42</td>
<td>1920</td>
<td>3150</td>
<td>119</td>
<td>43</td>
<td>3260</td>
<td>100.0</td>
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<td>HUDSON</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hudson 112</td>
<td>1939</td>
<td>2634</td>
<td>112</td>
<td>86</td>
<td>775</td>
<td>25.7</td>
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<tr>
<td>Essex A</td>
<td>1920</td>
<td>2955</td>
<td>109</td>
<td>55</td>
<td>3010</td>
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<td>HUPP</td>
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<tr>
<td>Hupmobile Std. 6</td>
<td>1939</td>
<td>3280</td>
<td>122</td>
<td>101</td>
<td>995</td>
<td>29.3</td>
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<td>Chandler NS</td>
<td>1920</td>
<td>3400</td>
<td>123</td>
<td>45</td>
<td>3400</td>
<td>100.0</td>
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<tr>
<td>NASH-KELVINATOR</td>
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<tr>
<td>Nash-Lafayette Mstr.</td>
<td>1939</td>
<td>3200</td>
<td>117</td>
<td>99</td>
<td>810</td>
<td>24.7</td>
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<tr>
<td>Nash 685</td>
<td>1920</td>
<td>3455</td>
<td>121</td>
<td>35</td>
<td>3285</td>
<td>100.0</td>
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<tr>
<td>STUDEBAKER</td>
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<tr>
<td>Studebaker Comm. 6</td>
<td>1939</td>
<td>3160</td>
<td>116</td>
<td>90</td>
<td>955</td>
<td>34.4</td>
</tr>
<tr>
<td>Studebaker Light 6</td>
<td>1920</td>
<td>2900</td>
<td>112</td>
<td>45</td>
<td>2780</td>
<td>100.0</td>
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<tr>
<td>WILLYS-OVERLAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willys 4</td>
<td>1939</td>
<td>2300</td>
<td>100</td>
<td>48</td>
<td>555</td>
<td>33.1</td>
</tr>
<tr>
<td>Overland 4-90</td>
<td>1920</td>
<td>2152</td>
<td>100</td>
<td>35</td>
<td>1675</td>
<td>100.0</td>
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<td>AVERAGES</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1939</td>
<td>2934</td>
<td>114</td>
<td>85</td>
<td>795</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>1935</td>
<td>2933</td>
<td>114</td>
<td>83</td>
<td>806</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>2930</td>
<td>113</td>
<td>64</td>
<td>1118</td>
<td>38.9</td>
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<tr>
<td>1925</td>
<td>2875</td>
<td>113</td>
<td>50</td>
<td>1387</td>
<td>48.2</td>
<td></td>
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<tr>
<td>1920</td>
<td>2981</td>
<td>114</td>
<td>43</td>
<td>2877</td>
<td>100.0</td>
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</tr>
</tbody>
</table>

**Notes:**

No satisfactory comparison is possible for Ford and Packard.

All prices refer to cheapest 4 passenger closed car in series. Delivered prices at main factory city are estimated by adding 13 1/2 per cent to f.o.b. list. This has not always been exactly applicable to all makes, but the error involved is negligible for the purposes of this presentation.

The averages are unweighted and are based on the most nearly analogous products of each of the eight manufacturers listed.
Prices in Terms of Specifications reflecting usefulness has long been recognized as a valid basis of price comparison. In the early days of index number construction, bread was quoted by the loaf although it was known that the weight of the loaf typically varied inversely with the price of flour. In fact, the average weight of the loaves quoted was published along with the average price.7

After a period, the basis of pricing was shifted from the loaf to the pound, giving public recognition to the importance of relating price to those physical specifications which measure product usefulness (where it is impossible to get quotations on comparable articles from period to period).

Price per unit is a satisfactory procedure where the useful and desirable qualities of an article can be roughly summarized in terms of a single specification. Passenger cars serve so many diverse purposes that such a single, most important specification can not be found (like rated tonnage in the case of trucks). The simple method is inapplicable, but why not combine several specifications to form a single composite measure?

The Hedonic8 suggestions are addressed to this problem of establishing an objective composite measure of usefulness and desirability in terms of which prices of products of complex function can be compared. In the case of passenger cars, if the relative importance to the customer of horsepower, braking capacity, window area, seat width, tire size, etc., could be established, the data reflecting these characteristics could be combined into an index of usefulness and desirability. Prices per vehicle divided by this index of Hedonic content would yield valid comparisons in the face of changing specifications.

It has been proposed that the specification weights (coefficients of relative importance) be based upon a survey of the opinions of owners, or of professional consumer groups. This has much to commend it. Unfortunately, it is expensive and not applicable to the historical problem.

Probably the persons most familiar with the desires and needs of automobile users are the designers and engineers who lay out the cars, and the sales managers with whom they work. Their judgment as to the balance between customer preference and cost of manufacture is reflected in the prices and specifications of the products which they offer. With higher

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7 Some students of the problem have contended that it is best in cases like this to continue to compute and tabulate a price index per loaf and a changing average weight per loaf, since this gives the maximum detail of information.

8 Webster's New International says "Utilitarianism, seeking the good in the greatest happiness of the community as a whole, is the chief hedonistic doctrine." Thus, Hedonic price comparisons are those which recognize the potential contribution of any commodity, a motor car in this instance, to the welfare and happiness of its purchasers and the community.

Alexander Sachs suggested this use of HEDONIC.
THE DYNAMICS OF AUTOMOBILE DEMAND

priced cars, there is more margin available with which to cater to the less
important desires. The automobile buyer has a good deal to say about
these decisions, for it is only in so far as he is pleased at a price that the
engineers continue their work.

Actual prices and specifications for the various makes and series of auto-
mobiles offered each year reflect the relative importance of each specifi-
cation for car buyers. For example, if two series of a certain make of car
are identical, except for the motor and the price, which show an inter-series
differential of say 20 horsepower and 30 dollars, it is possible to say that,
as far as these two cars are concerned, each additional horsepower costs
the customer, and is presumably worth to him, an average of $1.50.

The existence at any one time of quite a number of cars of different
makes and series selling for a wide variety of prices, and having different
specifications, provides a guide. A multiple regression analysis10 covering
all the various cars offered during the index base period, and using the
prices of individual makes and series as the dependent observations, and
relevant specifications as the independents, will give those weights best as-
signed various specifications in explaining prices existing at that time.

Solution of the normal equations gives the coefficients of net regression,
the “b’s,” of price on the various specifications. These “b’s,” used as
weights, are multiplied by the specifications to which they apply. The re-
sulting products are added to yield a composite measure of Hedonic con-
tent11 for cars in periods preceding or following the base period.

The relation between prices and Hedonic content of all cars offered at
any period of time provides a Hedonic Price Index. The ratio is always
1.00 for the base period.

The weights assigned to the various specifications in estimating the
Hedonic content of any car or group of cars are based on relationships be-
tween prices and specifications during the base period chosen.11 The prob-

10 This approach of letting the actual price and specifications of the various cars offered in any year
determine the relative importance of each specification was first suggested by Sidney W. Wilcox.

11 The deviation between actual price and Hedonic content for individual cars should reflect over-
pricing and under-pricing, in so far as the analysis is realistic and complete. This deviation might
reasonably be expected to correlate with sales trends of individual cars, although there are so many
other factors in sales that the possibilities of any useful analysis along these lines are nebulous.

111 The multiple regression analysis suggested above neglects the factor of different levels of sales
of different makes and series. A car selling in large volume is more certainly attuned to consumer
needs and desires than one selling in much smaller volume. There is no question about the
significance of any of the mass-production cars for this analysis, but should the V-16s be included
at all? If so, their prices and specifications are certainly much less important.

This difference in importance can be nicely allowed for by setting up the multiple regression equa-
tion not with one set of observations for each make or series, but rather one set for each car sold.
This sounds complicated, but really it is not much more difficult to compute cross products for
100,000 Buicks, 10,000 Cadillacs, and 1,000,000 Chevrolets than it is to compute them for one car
of each make.

The problem is that the great relative weight given the leading makes is equivalent to cutting
down the number of observations. Perhaps, the weighting might better be based on the logarithm
of the sales total rather than the actual volume.
HEDONIC PRICE INDEXES

lems of choosing and shifting bases are similar to those in any normal price index computation.

Hedonic suggestion number two is really a variant of the first proposal. It consists of setting up the multiple regression equation, including various makes, series, and body types using price as the dependent observation and specifications as the independent observations. Instead of limiting the equation to the base period, as in the first suggestion, the variant proposal includes in one multiple regression equation observations from two or more periods the price levels of which it is desired to relate. An additional factor, time, is included in the analysis. The equations are solved, and the net regression of price on time, holding specifications constant (the "b" of the trend factor), is a direct generalized approximation of the change in price for a car of constant specifications between the periods included in the equation.

If the net price change between two periods only is to be computed, one trend series will be sufficient.

If more than two periods are to be included in one equation, however, it will be necessary to use additional trend series to the number of one less than the number of periods to be considered. Since the purpose of the analysis is to determine the net regression of price on time, the time factors chosen must not prejudge the nature of the result. If five different periods of time were to be included in a single equation, four trends must be used.

Applied to three periods in time and using the three specifications chosen for illustrative purposes, the trend factors would be designated $t_1$ and $t_2$; where $p =$ price, $w =$ car weight, $f =$ wheelbase, and $h =$ horsepower, the equation would be:

$$p = k + b_{p,w,f,h} + b_{p,w,f} + b_{p,w,h} + b_{p,f,h} + b_{p,w} + b_{p,f} + b_{p,h}$$

An oversimplified picture of this second procedure is presented by Chart 1. Using car weight as the only specification, taking the cheapest series in each make for the years 1925 and 1935, and using the logarithm of car prices, it appears that each 1,000 pounds increase in car weight has been associated with a doubling of price. Moreover, it appears that during this ten-year period, the price of a car of a given weight has come down about 45 per cent. This represents the net price change during the period, holding specifications (car weight only in this case) constant.

In practical application, using many specifications, the net price change during a period would be the distance between two parallel multi-dimensional surfaces reflecting the effect of all the various specifications used on price.

To explore the Hedonic proposals, computations were made following the second suggestion using a pair of years in each equation: 1920-1925, 1925-1930, 1930-1935, 1935-1937 f.o.b., 1937-1939 advertised delivered price. These periods overlapped so that the net price change could be
linked to form a continuous index for the period. Prices and specifications for the years listed were used in five multiple regression equations as described above, including a trend in each equation. Prices were included in the form of their logarithms, since preliminary analysis indicated that this gave more nearly linear and higher simple correlations.
HEDONIC PRICE INDEXES

The specifications used were car weight, wheelbase, and horsepower, since the purpose was to explore methods, and not to measure actual net price movements.

The net regression of price on each of the specifications and on time, and the "R" for each period are shown below:

NET REGRESSION OF PRICE ON SPECIFICATIONS AND TIME

<table>
<thead>
<tr>
<th>Period</th>
<th>Per Cent Change in Price</th>
<th>Coefficient of Multiple Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per Inch</td>
<td>Per Cwt.</td>
</tr>
<tr>
<td>1920-1925</td>
<td>.01%</td>
<td>.02%</td>
</tr>
<tr>
<td>1925-1930</td>
<td>.82</td>
<td>4.02</td>
</tr>
<tr>
<td>1930-1935</td>
<td>.31</td>
<td>5.66</td>
</tr>
<tr>
<td>1935-1937</td>
<td>.01</td>
<td>5.76</td>
</tr>
<tr>
<td>1937-1939</td>
<td>.15</td>
<td>2.95</td>
</tr>
</tbody>
</table>

The net regressions on time shown above are in effect price link relatives for cars of constant specifications. By joining these together, a continuous index is secured. Chart 2 compares the Hedonic price index with the specification range and analogous car averages described above.

The parallelism between the trends shown is rather good, indicating that the various types of analyses do measure the same thing. The Hedonic suggestion yields results in general agreement with the commonly accepted method of specification range averages and the common sense, analogous car approach.

The Hedonic method has several advantages over either of the other methods:

1. The various specifications can be assigned weights on an objective basis.
2. It is feasible to use in weighted form all the observations (cars offered) each year.
3. Determination of short-term and long-term fluctuations is of equal validity. The method does not inject any artificial instability into the results.
4. A comparatively large number of specifications can be handled by the Hedonic technique with a given number of observations.

A question arises. In the event of engineering advances making any particular specification less important for car value, how would the Hedonic suggestion meet the situation? One of the three specifications chosen for this analysis provides an example.

The net regression of price on wheelbase has been decreasing since 1930, and the gross correlation coefficient is smaller for the 1937-39 period than

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previously. This suggests that recently wheelbase has been less important for car value than it was earlier. If this checks with general engineering observation, other specifications should supplant wheelbase in the analysis.

It must be remembered that car weight, wheelbase and horsepower are used only to illustrate methods with easily available figures. These specifications do not begin to reflect car usefulness and durability.

*Data which measure useful and desirable car characteristics are prerequisite to any realistic measurement of net price change by any method.*

112
HEDONIC PRICE INDEXES

An approach to the problem of objectively weighting car specifications for use as measures of value has been outlined. Three comments seem appropriate:

1. Before any results of this or any other statistical analysis are accepted as significant measures, they should be examined for probable error and net significance of determination after allowance for degrees of freedom.

2. For purposes of the simplified example, the regression between actual specification and the logarithm of price was assumed to be straight line. A completely adequate analysis would recognize the real nature of the relationship between specifications and usefulness.

3. This whole approach rests on the assumption that the significance of any specification for car usefulness and desirability can be measured approximately in terms of the net association of variations in the specifications and in price as between various makes and series within any period. There are two corollaries:

   a. It is necessary in the second approach to inject enough flexibility into the trend factor to permit every period under consideration to find its own best level without any limiting assumptions.

   b. If variations in any specification and in price show no net association with each other within each of the periods under consideration, there will be no significant net regression of price on that particular specification, and change in that specification from year to year will have no effect on the net regression of price on time even though the average change in the specifications from year to year may show some relation to the average change in prices from year to year. This is logical. The determination of the weights to be assigned various specifications hinges entirely on the price-specification relation during the base period.

The two Hedonic suggestions described provide mathematical methods for determining the relation between price and time, while making allowance mathematically for changes in specifications reflecting product usefulness and desirability. If these or any other methods are to yield realistic measures of net price trend, the specifications used in the analysis must truly reflect useful and desirable properties of the product and the lines of net regression must have logical shapes. The weight, wheelbase, and horsepower data used in the examples\(^{(12)}\) are inadequate. In fact, car weight per se is undesirable and in a complete analysis would have a negative net regression.

Having set up a technique of computation, the next problem is the development of specifications relevant to the usefulness and desirability of passenger cars.

\(^{(12)}\) See footnote 6, p. 105.
THE DYNAMICS OF AUTOMOBILE DEMAND

Significant Specifications

Inquiry of the sales and engineering staffs of automobile and parts manufacturing companies, and of fleet operators who have kept detailed records, has given much new information. Since the data from different sources were not always comparable as between makes, however, it seemed unwise to attempt to use them directly in a Hedonic analysis.

These data, in the form of industry averages, are charted below under broad classifications. The averages are weighted by sales of the various makes and are based on data covering all important makes. An exception is the chart on economy which is based on an unweighted average of operating costs of six large fleets of popular priced passenger cars. Better cars,
better roads, fuels, oils, and tires, and more intelligent fleet management and simplified repair procedure have all contributed substantially to these gains.

**Summary**

These Hedonic proposals seem rather complicated, when all the qualifications and precautions are enumerated. However, the basis of computation is simply the measurement of the relation of price to time, holding usefulness (as reflected by specifications) constant. The statistical technique involved is standard multiple regression procedure.

The results of any Hedonic analysis can be checked for rough accuracy using the established specification range technique. The Hedonic procedure
has several advantages over specification ranges: it is free from exaggerated movements; it can recognize many more specifications simultaneously; it uses all observations; validity of results is subject to testing through established procedures.

Whether the Hedonic or specification range procedure be used, it is most important that price comparisons be made in terms of truly comparable objects. When identification is based on brand name alone or some other equally immaterial characteristic, the resulting price comparisons can be misleading.

Price indexes in gross error have been widely used as the basis for serious, official discussions of national policy.

Realistic measures of the price trends of manufactured goods are vitally important to the intelligent consideration of national economic problems.
HEDONIC PRICE INDEXES

OPERATING COST INDEXES
1925 = 100

1925  1930  1935  1937

100

Gasoline Gallons per Mile

Total Operating Costs per Mile

Repair Expense per Mile

Tire Expense per Mile

Operating cost excludes garaging, depreciation, licenses, insurance, and other fixed costs.

Chart 6
THE DYNAMICS OF AUTOMOBILE DEMAND

DISCUSSION OF MR. COURT'S PAPER ON HEDONIC PRICE INDEXES

LOUIS H. BEAN

Economic Adviser,
Agricultural Adjustment Administration

The gist of Mr. Court’s paper on Hedonic Price Indexes is (1) that in measuring automobile prices and values we take into account the fact that a car today differs greatly from that of 20 years ago and (2) that the effect of changes in quality factors can be determined statistically and thus a price series obtained which would represent the hedonic value of a car to the consumer on the assumption that the characteristics of the car in the same base period be held constant. There can be little argument on the first point. The second calls for precautionary remarks.

I do not want to appear to minimize the importance of having prices that represent the same kind of commodity in our work with index numbers and with price analysis; but Mr. Court’s suggestion that prices of automobiles be placed on a hedonic basis to represent the growing amount of consumer satisfactions by holding certain factors like weight, wheelbase and horsepower constant deals with only one-half of the problem. The other half is the changing consumer. The consumers’ appraisal of values and the nature of their satisfactions tend to change simultaneously with improvements. It is true that a 1939 car is a much more comfortable and useful vehicle than the 1919 car was, but this does not mean that it gives the 1939 consumer more satisfaction in the light of what a 1939 consumer expects than the 1919 consumer got in terms of his 1919 expectations. A real hedonic index must deal with both sides of the problem, but since that would call for dealing quantitatively with subjective factors, the practical utility of Mr. Court’s suggestion as a device that can be used in index number making is not all that Mr. Court claims for it. Certainly there are a multitude of problems involved that Mr. Court hasn’t hinted at or, I am afraid, surmised.

Mr. Court overestimates the contribution that multiple correlation can make to this problem.” In spite of the existence of standard methods for multiple correlation analysis, there are pitfalls that the standard methods serve to hide or fail to deal with realistically. Our own experience with much simpler problems in price analyses where market prices are related to well-known and readily measured supply and demand factors suggests that it is not at all easy to determine a generalized price change holding weight constant during the period, and that this procedure cannot easily be extended to cover several value specifications held constant, getting the net effect of time on price. Quite often because of difficulties that inher in time series, such as intercorrelation among the independent variables, it is almost impossible to determine the effect of one factor on price holding other factors constant. In such cases, the time factor cannot be determined with any degree of accuracy in spite of very high correlation coefficients.

Mr. Court’s experience with this correlation device is also not at all promising. An examination of his Chart 1 where the bracket indicates a decline of a little less than fifty per cent will reveal that the margin of error in the location of the upper regression of weight on price is unusually great and increases with the weight of the cars involved. A different location of the upper regression or the use of a different formula than the logarithmic would give other analysts entirely different results.

Those interested in Court’s suggestion of the use of correlation in studying the effect of quality factors on price may also be interested in Dr. F. V. Waugh’s study published by Columbia University Press in 1929 entitled Quality as a Determinant of Vegetable Prices, A Statistical Study of Quality Factors Influencing Vegetable Prices in the Boston Wholesale Market.

118
In our efforts to study the relations of volume of production and consumption to price and their bearing on current questions of competitive or monopolistic practices in the automobile industry, Court's hedonic index is not likely to be particularly useful. Such work as we have done in this field suggests that volume has a definite bearing on price. In an industrial product like automobiles, producers quite naturally undertake to protect themselves against loss of demand by reducing volume and thus in effect create scarcity value as a support for a policy of relatively stable prices. For a given business situation there is a fairly definite proportion of the national consumer purchasing power that is spent for automobiles. The facts as to (1) the way a rise in demand serves to offset the tendency of price to fall with increasing volume and (2) the way reduced volume serves to offset the tendency of prices to fall with falling demand, would not be revealed by the hedonic price measure. Such relationships are, however, revealed if the price series favored by Mr. Scoville are used, namely, the average price of all cars sold. In analyses of this sort the hedonic price measure would have to be related to volume series constructed on the same hedonic basis and subject to the same inaccuracies and uncertainties due to efforts to deal quantitatively with subjective factors.

It is generally assumed that because the automobile industry has so vastly improved its product, a greater share of the consumer's budget is being spent for automobiles, and that this is a direct reflection of the fact that the number of hedonic units created by the automobile industry is much greater than that indicated by the number of cars sold. Actually, however, this test does not support the implications of Mr. Court's hedonic price measure, for the wholesale or retail value of cars sold has shown no material increase in relation to national income. In each of the relatively prosperous years—1923, 1926, 1929, 1937—the wholesale value of cars sold represented 3.6 to 3.7 per cent of the national income.

Mr. Court's interesting work should be carried much further, as he suggests. We should, however, not be disappointed if neither public agencies nor trade associations adopt the policy of publishing prices, values and index numbers based on the relatively tricky results that one is sure to get by applying the device of multiple correlation. The only group who would sponsor such a procedure would be the non-existent National Association of Experts in Multiple Correlation, the demand for whose services would be enormously increased.
SIGNIFICANCE OF THE FINDINGS

An analysis of the financial statements of the various automobile manufacturers shows conclusively that the margin between the "avoidable" cost of production per unit and selling price per unit is so narrow that even if the elasticity of demand for automobiles were as great as 2, it would be impossible to increase volume by cutting prices under these conditions without inviting insolvency. A policy of price adjustment that would be designed to lower prices when the intensity of demand has shrunk would have to be accompanied by a policy of increasing prices sharply in periods of active demand in order to accumulate the required reserves with which to cover the losses in the periods of reduced prices. Since this is impossible competitively, it would necessitate the reorganization of the industry on a cartel basis.

The facts of the preceding analyses indicate also that the elasticity of demand with respect to price in the case of durable goods may be very low in periods of falling national income and consequently a price adjustment would be ineffective in stimulating demand. This is simply another aspect of the law of diminishing marginal utility. The analyses also brought out the tremendous necessity in the automobile industry of maintaining its previous rate of progress in order to maintain its demand, because if progress is not maintained the life of the product will be prolonged and the current demand will fall.

The fact also stands out clearly that analyses of this type are tremendously involved and much work remains to be done in the field of methodology before simple answers can be obtained.
SIGNIFICANCE OF THE FINDINGS

S. M. DUBRUL
General Motors Corporation

The question now arises as to the significance of these analyses by Messrs. Horner, Roos, Von Szeliski and Court. The idea has been advanced in certain quarters that if automobile manufacturers adjusted their prices from month to month by the dictates of some "overhead" authority or by industry-wide action or state-controlled cartel, presumably in accordance with changes in the intensity of demand, automobile sales and employment could be stabilized to the great benefit of the whole country. If this is a practicable plan it would be worth trying. Let us, therefore, pursue that proposal in the light of the findings of these papers.

Obviously, elasticity is one key factor in any such price administration. Unless the elasticity under all sets of conditions is known, the prices cannot be administered in the manner proposed because no one would know what to expect when the prices changed. Messrs. Roos and Von Szeliski in their study have shown that the elasticity of sales with respect to price may be somewhere between .65 and 2.5. A price elasticity of 2.0 would appear to be the maximum upper limit, however, when a proper allowance is made for the correlation between price and operating costs.

But another factor in such a policy is solvency. Even the Russian state-owned trusts appear to be required to maintain solvency. Therefore a
very practical question arises as to the limits within which prices of automobiles can be "administered" without inviting financial disaster. In order to ascertain these facts, it is necessary to turn to the financial statements of the motor manufacturers.

The Supply Problem: Illustrations of Effects of Price and Cost Changes

Chart 1 shows the relation between net earnings and net sales in value for each year since 1924 of four representative automobile manufacturing companies for which financial statements are publicly available. In order to show the effect on earnings of the relative change in sales volume, the data have been plotted on proportionate scales. It will be readily seen that this method produces a similar relation between earnings and sales for all four companies. It will also be seen that the relation of earnings to sales has been declining—that is, net earnings have been lower at the same rate of operation in the latter years than in the earlier ones. The most abrupt shift in this respect took place in 1937 when the earnings of each of the four companies decreased sharply although sales for three of them actually increased.

Having established the general similarity in the trend of sales and earnings of four typical automobile companies, the subsequent analysis will be based on the data of only one of them.

Chart 2 shows for the selected company in 1937 a familiar sales-expense-profit analysis, commonly known as a "break-even" chart. This analysis is based on the company's annual published data. Unit volume is plotted on the abscissa. Sales, profits and the various elements of cost are shown in total on the left-hand ordinate and on a unit basis on the right-hand ordinate.

Three kinds of costs have been distinguished in this chart, namely,

(a) Variable costs—that is, costs for which cash outlay is required and which are practically constant per unit of production. These costs in the aggregate vary directly and linearly with unit volume of production. These consist principally of raw material and productive labor. Variable costs per unit were estimated at $548 per car.

(b) Non-variable cash costs—that is, cash costs, the aggregate of which does not vary directly with volume. These costs include such items as tools, administrative salaries, rents, property taxes and similar indirect and relatively constant costs. Based upon an analysis of the company's published data, it is estimated that these costs amounted to slightly less than $44 million or $38 per unit sold in 1937.

(c) Non-variable, non-cash costs. Depreciation is the only non-cash cost in this case. In the long run, of course, depreciation is the cash cost of capital assets consumed, but in any given year failure to recover depreciation does not imperil the net working capital
SIGNIFICANCE OF THE FINDINGS

NET EARNINGS VS. DOLLAR SALES
YEARS 1924-1938

(Year 1938 is based on first nine months at annual rate)

Chart 1

125
SIGNIFICANCE OF THE FINDINGS

position of the business. It will be seen that this cost is relatively small, amounting to about $6 million or $5 per car sold in 1937.

The intercept of the line of accumulated sales income with the line of accumulated variable and non-variable cash costs indicates that a minimum volume of 450,000 cars and trucks is required by this company under the stated conditions of costs and selling prices to maintain an unimpaired cash position. This may be called the critical operating point, for whenever the cash resources of a concern are threatened with gradual depletion, its credit and operating position will eventually be impaired and the existence of the enterprise jeopardized.

Likewise, the intercept of the line of accumulated sales income with the line of accumulated total cost (variable and non-variable) indicates the "break-even point," or the minimum volume required before any profits are earned. This was 513,000 units.

Chart 3 shows what would have happened to the critical cash and total cost break-even points in this establishment if the variable costs had been only 5 per cent higher with no change in selling prices. Offhand, an increase of 5 per cent in variable costs may appear insignificant, but Chart 3 indicates that it is of tremendous significance since it increases the critical break-even points by 39 per cent or almost eight times the proportionate increase in variable costs.

Chart 4 shows what would have happened to these same critical points if selling prices had been reduced 5 per cent with no change in costs. Here the effect on break-even points and profits is even more spectacular. The break-even points would have risen 49 per cent or almost ten times the proportionate reduction in prices.

Chart 5 shows the effect, under the same conditions, of a reduction of 10 per cent in selling prices with no reduction in costs. Ordinarily one would not be inclined to think of a 10 per cent price reduction as particularly significant. However, this chart shows that a reduction of that percentage would produce an increase in the break-even points of 196 per cent or nearly twenty times as great as the proportionate change in prices.

Nor is that all. The cash break-even point of this company would have risen to a volume greater than the largest annual volume which this company has ever attained. The year under study was the peak year of this company's sales. It was the largest year in unit sales for the entire industry with the exception of 1929. It was a year in which the industry was publicly accused by high authorities of having over-produced or over-sold its market. But a 10 per cent price reduction would have had to produce a greater sales volume than ever before for the industry to have maintained the cash position of the producers at the existing level. Not only would such a volume have been grossly in excess of the demand—this company has not enough capacity to build any such quantity.

127
SIGNIFICANCE OF THE FINDINGS

X MOTOR COMPANY
SALES-EXPENSE-PROFIT ANALYSIS FOR YEAR 1937

1937 Actual Net Sales
$613
Total Net Sales ($613 per unit)
$594
Net Profit (Before Surplus)
$580
Federal Income Taxes
$546

Total Cost (Excl. Federal Income Taxes)
Depreciation
Net Variable Cash Costs
Variable Costs ($546 per unit) (Excl. Federal Income Taxes)

Volume (672,000 units)
Necessary to Recover Total Cash Costs
(Increase of 222,500 units or 49%)

Break-Even Point: Volume (744,000 units)
Necessary to Recover Total Costs
(Increase of 253,000 units or 49%)

* Based on 1,200,000 Units

Chart 4
129
THE DYNAMICS OF AUTOMOBILE DEMAND

X MOTOR COMPANY
SALES-EXPENSE-PROFIT ANALYSIS FOR YEAR 1937

Note that horizontal scale of Chart 5 is twice that of Charts 2, 3 and 4.

Chart 5
130
SIGNIFICANCE OF THE FINDINGS

The Demand Problem: Effectiveness of Price Changes Limited by Demand Conditions

Messrs. Roos and Von Szeliski have shown that even under an optimistic conclusion, the elasticity of the demand for automobiles with respect to price may be 2 to 1. Consequently, an optimistic expectation of increased sales volume with a 10 per cent reduction in price would be a maximum of about 20 per cent. But if the volume rose only about 20 per cent this company, one of the most efficient in the industry, would have been losing, not making, money. The aggregate loss to all producers under these circumstances would have been proportionately greater.

Let us now take an historical view of what actually did happen to this company's volume, costs and prices from the summer of 1937 to the summer of 1938.

Charts 6 and 7 are the standard type of demand curve chart with unit volume on the horizontal scale and price on the vertical scale. Double logarithmic scale has been chosen because curves of constant elasticity plot as straight lines on this scale.

Chart 6 is introduced to illustrate the practical circumstances which face an automobile producer in a saturated market, under an assumption regarding elasticity.

In the third quarter of 1937 this company was selling cars at an annual rate of 1,000,000 units at an average wholesale price of $637 per car. Assuming an elasticity of demand of 2 to 1, it is possible to draw a demand curve through the intercept of these points.

In October 1937 this company began to sell its new 1938 models. The average price of the new models was $704, or about 10 per cent higher. Assuming no increase in value of the new car as compared to the previous model, sales would have fallen about 20 per cent with an assumed elasticity of 2 to 1. It will be noted that the actual variable out-of-pocket costs of producing the 1938 models were $587 per car. At its old selling price of $637, this company would have just broken even at the old rate of 1,000,000 cars per year.

The period of new model introduction in the automobile industry is a "blind spot" during which it is not possible for any producer accurately to judge the actual rate of seasonally corrected demand because of the distortion which results in the seasonal movement at this time. It is not until all important producers have introduced their new offerings, have completely liquidated their old model stock that may have been carried over, and have built up the field stock of the new models, that it is possible accurately to appraise the true rate of retail demand. Consequently, during this period the fact that one line of cars is moving very well is not indicative of the general level of the market.
SIGNIFICANCE OF THE FINDINGS

It was not until November that this company had any clear indications of the current actual rate of sale of its products on an annual basis, when that rate appeared to be 653,000 cars. Again, assuming an elasticity of 2 to 1, it is possible to draw the demand curve as of November through the intercept of the seasonally adjusted annual rate of sales in November and the November price. It is clear that what had actually happened was that the demand curve had sharply shifted to the left, i.e., the intensity of demand had diminished.

In order to have maintained demand at 1,000,000 cars under these circumstances and assumptions, the price would have had to be reduced from $704 a car to $569 (the intercept of the November demand curve and 1,000,000 on the horizontal scale), a price below the variable out-of-pocket costs per unit, which would have put the company not only in the position of losing money, but in an even worse position, namely, that the more they sold the more they would lose. Furthermore, it would have been necessary to have known in advance of November that the demand was going to diminish in intensity and how much!

By January 1938 the intensity of demand had fallen still further as shown by the demand curve drawn through the price-volume relation in that month. By this time, under the assumed conditions, it would have required a price of $493 to have sustained the demand at 1,000,000 cars.

By June the intensity of demand had so shrunk that it would have required a price of about $429 (the intercept of the June demand curve and the ordinate of 1,000,000 cars) to have sustained the demand, a price that would have recovered only about three-quarters of the actual variable out-of-pocket costs per car produced.

By August the demand had risen and the price required under these assumptions to maintain a volume of 1,000,000 cars had risen to about $467.

Chart 7 shows the same data but with an assumed price elasticity of 1 to 1. Under this assumption in June 1938 the price would have had to be below $300 to have sustained the volume at 1,000,000 cars per year.

Prices Controlled by Costs, Not by Concentration: Demand Controls Production

There is a certain school of economic thought that characterizes the automobile industry as an "oligopoly." According to this school, each producer controls such a large proportion of the total market that he must reckon with the effect of his own actions upon the actions of his competitors and consequently is restrained from cutting prices because he knows that a price reduction would promptly be met by his competitors. Therefore, the subscribers to this doctrine maintain that prices fail to fall in oligopolistic industries in response to sudden reductions in the intensity of demand, whereas in industries in which there is little concentration, prices respond very quickly to changes in the intensity of demand. This analysis shows
that the above line of reasoning, at least as applied to the automobile industry, is specious. Concentration has nothing to do with it but costs have everything to do with it, and the nature of costs is entirely independent of concentration of production in a few hands. Regardless of concentration, no producer is going to cut prices below the cash cost of replacing his existing supply (inventory) because to do so would put him in the position that the more he sells the sooner he exhausts his working capital. This is just as true of farmers as it is of businessmen. There isn't a farmer in the country who will pick and pack a crop when he knows that the market price will return him less cash than he must pay out for picking and packing. He will let the crop rot instead, as everyone knows, which causes unemployment among agricultural workers just as the businessman's refusal to sell for less than his cost of production for any length of time results in unemployment of workers in his plant.

In the face of this contraction of demand, there was nothing for the producers to do last winter except reduce production. There are some who will say that the managements should have chosen to "produce and produce" and "spend and spend." But automobile manufacturers are unlike the Government. They can't "tax and tax," or "print and print" money. Under a policy of sustained production, every manufacturer would, as we have seen, have seriously impaired if not exhausted his working capital within six months, to say nothing of the fact that there was simply no practicable place to store any large additional quantity of new cars by January of 1938. Automobiles cannot be piled up like pig iron or pig aluminum. If prices had also been cut, the impairment of working capital would have been imminent within six months. Instead, the managements followed the policy that was in the best interests of the group to whom they owe their first duty, namely, their stockholders, as Mr. W. O. Douglas, the Chairman of the Securities and Exchange Commission, has recently insisted managements must do.

The Narrow Range of Feasible Price Adjustments

From this analysis it is clear that the range of price adjustment by automobile manufacturers is wholly inadequate, within the limits of even the most daring financial policy, to have any appreciably stimulating effect on volume under the conditions that prevailed in the latter part of 1937. A policy of violent price reductions could have been feasible only if a company had built up gigantic financial reserves during the good years. That is, such a policy cannot be a one-way policy. By definition, to fluctuate means to rise and fall. This of course would necessitate materially higher prices in good years to hold the volume of production and employment down to the level of statistical stability. Obviously no one producer could follow such a policy alone because competitively he would lose his volume
SIGNIFICANCE OF THE FINDINGS

if he attempted to do so. Accordingly it would be possible only by co-opera-tive action among producers on an industry-wide basis. Those who advocate drastic downward revisions of price in poor years, even at the risk of the investment, do not seem to realize how great the price increases would have to be in good years to build the required reserves.

Let us assume for the moment that such an industry-wide price policy were inaugurated in order to raise and lower prices in an effort to stabilize demand, production and employment. By definition a policy is an established course of action. If there were such a common price policy of this type in the automobile industry, demand would dry up completely as soon as there was the smallest sign of the condition under which prices were to be reduced, because no one would buy at all until the price cut was made. But that would create the very state of panic which in theory the policy was designed to prevent!

Obviously no one would buy until all prices had reached zero or some pre-determined irreducible minimum. There is such a minimum now—the cost to the marginal producer and his unwillingness to sell for less. If a lower minimum is to be established, even by subsidy, no higher price will attract any buying at all. The elasticity of demand for practically all durable goods is clearly insufficient to maintain volume by any reasonable price reduction, without insolvency or subsidy. In fact, as Messrs. Roos and Von Szeliiski have pointed out, under certain conditions in durable goods industries, demand falls off sharply because of consumers' stocks and the temporary saturation of the market which leads consumers actually to liquidate their stocks. During these short periods, demand is beyond resuscitation by feasible price adjustment. But these short periods are the critical periods for the policy. If it fails then, the damage has already been done. So the theory of reducing the prices of all goods in the face of a sharp decline in general demand would require a social underwriting of the losses of all producers out of the public treasury, a case of the snake swallowing itself.

In fact, the whole theory that lowering the prices of all goods when a depression begins would check a further drop in demand, is silly. Even the proponents of it never advocate that wage rates, the greatest single element of cost, be reduced at the same time. The fact of the matter is that the usual theory of the law of supply and demand frequently works in reverse, that is, when buyers believe prices will rise, buying increases. It is significant that business activity is usually the greatest when prices are rising. When prices begin falling, however, most purchasers stop buying which makes a bad matter worse. Accordingly, I recommend that the proponents of the flexible prices theory give consideration to designing some scheme whereby all prices will promptly rise further when a depression begins so as to induce a scramble for the available supply of goods and thus arrest the developing depression! At least this idea is as sound as
THE DYNAMICS OF AUTOMOBILE DEMAND

the opposite theory and has some historical statistical data rather than only fine-spun arguments to support it.

Other Weaknesses of Flexible Price Theory

There are other practical weaknesses in this theory of price flexibility as applied to automobiles. Speculation on pure price change is roundly condemned by many as a contributing cause of economic instability. Practically all of the speculative security and commodity markets have been put under some sort of legal restraint in an effort to eliminate plain price gambling. Unions have been organized to stabilize wage rates which, together with taxes, have caused the rigidity of industrial costs. This in turn has created the rigidity of prices so greatly deplored in some quarters.

There has been very little speculation on the price of automobiles in the past, either by dealers or by users, because the only real price trend the public has come to expect in the automobile industry is downward. Only twice in recent years does there appear to have been any real evidence of a fear of price increase, namely, for a few months in 1933, and again in the late summer of 1937, when in each case the fear resulted from the efforts of government and organized labor to raise wages summarily in accordance with the purchasing power theory.

However, if automobile prices were to become as unstable, for example, as the price of copper, speculation on a real scale would enter our market with chaotic results. The situation is difficult enough now with a rather erratic seasonal pattern and an unknowable business cycle pattern. If price speculation were added, it is impossible to visualize the consequences other than to say that employment would become more unstable than ever and the average costs would rise greatly because of the erratic rate of operation that would result.

Those who advocate price fluctuations per se as a cure-all for our economic ills have missed the whole point of the problem of economic stability in our modern economy. Messrs. Roos and Von Szeliiski have already pointed out the fallacy of reasoning from the price elasticity of farm crops to the elasticity of all durable goods in the face of falling income. I should like to add a word to emphasize this point as applied to automobiles.

The real problem of cyclical industrial unemployment arises out of the nature of our modern standard of living. Our modern standard includes an increasing number of durable articles that in large part we can do without or at least postpone replacing on our normal buying schedule for a long time. But these sudden postponements of buying precipitate cumulative forces which make for unemployment. It is well illustrated by what happened in the automobile industry last year. A small decline in production from the 1936-1937 level was expected by many persons in the industry. However, the decline of 50 per cent in the rate of retail buying
SIGNIFICANCE OF THE FINDINGS

within a matter of weeks was wholly abnormal and was due clearly to the development of a liquidity preference, that is, to a sudden change in the value of money to its owners as a result of a panic. It is noteworthy that automobile sales fell about as rapidly in Washington, D. C. as in the rest of the country.

The Limitations of Price Elasticity Analysis

The most important conclusion from these analyses of the elasticity of demand for automobiles with respect to price is that no exact answer to the question has been obtained. It may be less than one. It may be as great as two, in so far as the available data can be made to shed light on the problem.

The reason why the analysis cannot be more exact in its conclusion is plain to the statistician familiar with the methods used. It is simply that there haven’t been enough wide swings in the prices of cars for the data to respond more exactly to the treatment. Unfortunately for the statistician, the manufacturers’ “administration” of the real price of cars has been chronically in only one direction—down. Except in the past year or so, there has been an uninterrupted decline in both real and nominal automobile prices as measured by practically all of the indexes. The decline, according to the index suggested by Mr. Wilcox, greatly exceeds the decline in the Bureau of Labor Statistics Wholesale Commodity Price Index during the same period. Unlike the B.L.S. Index, automobile prices remained low in the face of tremendous increases in material and labor costs.

By the criterion of the number of fluctuations in price in the course of a year, I suppose the index of auto prices is prima facie evidence to some few people of an anti-social attitude by the producers. By the criteria of low prices to the consumer, increased employment and high wages, however, the automobile industry presents a record of which any industry might well be proud.

The analysis indicates that elasticity of demand is not constant, but rather as P. de Wolff has also contended, is a variable factor depending on the degree of saturation of the market. P. de Wolff’s formula shows zero elasticity for replacement sales so that in a fully saturated market, dependent almost wholly on replacements, elasticity must be very low. This is thoroughly good common sense for when everyone has all of a product that he can possibly use, there is no inducement to purchase more just because the article may be cheap. Thus a low elasticity in a saturated market is simply another way of stating the principle of diminishing marginal utility.

This condition of complete saturation can be approximated at any time by a sharp contraction of national income, especially when it occurs in the income brackets that constitute the bulk of the new car market. If all
THE DYNAMICS OF AUTOMOBILE DEMAND

prospective new car owners had new cars they had purchased yesterday, obviously we could sell no cars today at any price. Very much the same condition would obtain if all new car buyers were well supplied with relatively new cars and the incomes of all in that class were cut simultaneously. Of course this has not yet happened to all of them at the same time but it happens to enough of them so that the elasticity of price becomes of little significance. When practically every prospective owner has a car, he is much less sensitive to price change than when his buying power is a few dollars short of the amount required to realize his ambition. After he gets a car, however, he can only hope to buy a better one. The margin of improvement of the new car over the one he has, then becomes a relative matter and can easily become of no importance in the face of serious economic conditions.

No Measure of Quality Elements in Price Indexes

Furthermore, Mr. Court has demonstrated statistically how improvements in the product have accounted for a greater lowering of real price than current automobile price indexes show, and how these improvements have been reflected in a marked reduction in the depreciation rate and operating costs of cars in use by the public. Messrs. Roos and von Szeliski have pointed out that these improvements in quality of cars over the past ten years have enabled the country to maintain a much higher number of cars in use on a materially lower national income than in previous years. The entire analysis has thus emphasized the necessity for the industry to continue to offer an ever-increasing value to the consumer for his money.

Were it not for this continuous progress, maintained only by enormous expenditures for research, new tools, new equipment and new methods, it would appear that the industry could not have reached anything like the levels of reemployment it did reach in 1937 and as a result the country would probably not have recovered to the extent that it did after 1934. If we had giant corporations doing in residential housing what has been done in automobiles, there would probably be no serious unemployment problem in the country today and no demand for laws to spread a lower standard of living more equitably throughout the country.

Other Significant Factors

One of the most important phases of this analysis is the concept of a shifting maximum ownership level of cars in use as a function of real national income. This is of significance, not only to the automobile industry but to the economy as a whole. It is the counterpart of the previously established relationships which indicate clearly that in the hands of many
SIGNIFICANCE OF THE FINDINGS

passenger car owners, cars and their use are marginal expenditures. Accordingly, it indicates the importance to the automobile industry of general economic policies and the general level of economic well-being. If the country has full employment, the automobile industry will be very active and the usage of automobiles will broaden. On the other hand, if we have chronic depression and chronic unemployment, the automobile industry will suffer severely and this suffering will in time be communicated to other important industries dependent upon it. The indicated difference of about two and one-half million passenger cars in use between the two maximum ownership levels of 1930 and 1937 could account for a difference in employment of almost half a million persons in the service trades that depend upon the level of cars in use for their living.

Mr. Court has pointed out that the problem of measuring the price of automobiles is quite complicated because the value of automobiles contains so much of the subjective. Not only has he demonstrated that practically all of the present published indexes are themselves seriously inaccurate even within the narrow limitations of proper use but also that it is necessary to devise a different measurement for each of the various points of view from which analyses may be made.

It is clear that the problem of durable goods demand is complicated. Hence analyses of this type are necessarily complicated and yield approximations rather than absolutely reliable conclusions. Even in retrospect, with an adequate knowledge of facts not available at the time of their occurrence, these studies are difficult. Extrapolations of them into the future are extraordinarily dangerous. Particular attention should be called to the fact that this analysis includes no forecasts of what the future may hold for the automobile industry.

In conclusion, I should like to point out that the answer to the problem of stabilizing the demand for automobiles still lies in the unknown future. Certainly it lies largely beyond the present powers of the automobile manufacturers, so long as free citizens continue to have the right to make their own choices of values and, what is more important, to change those choices without advance notice to the producers. Perhaps some day some brilliant statistician will develop a technique for making rational projections of the future on the basis of the non-rational past. Until that time comes, however, our present economic statistics and statistical techniques will remain an untrustworthy basis upon which to predicate irrevocable long-term economic plans and Burns’ famous line about the best laid plans of mice and men will continue to be a wise caution both to businessmen and to economic planners.