THE SYSTEM DYNAMICS NATIONAL MODEL INVESTMENT FUNCTION:
A COMPARISON TO THE NEOCLASSICAL INVESTMENT FUNCTION

by

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Submitted to the Alfred P. Sloan School of Management
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degree of Doctor of Philosophy

ABSTRACT

This thesis presents a series of statistical and model-behavior
tests of the investment function in the System Dynamics National Model
(SDNM). The purpose of the research is two-fold. First, the tests
contribute to confidence in the SDNM as a sound representation of
economic structure and a useful tool for understanding economic
behavior. Second, the research attempts to demonstrate the usefulness of
model-behavior testing as an extension of traditional statistical tests
of investment-function specification.

To focus the testing, the SDNM investment function is compared
to the neoclassical investment function developed by Dale Jorgenson and
colleagues. The SDNM formulation is shown to provide a more general
theory of the determinants of investment. In particular, the SDNM
investment function relates capital ordering to desired and actual levels
of output inventory, backlog of unfilled orders for output, the
"supply-line" of unfilled orders for new capital, and to expectations of
future growth in shipments (sales). None of the above factors influence
investment in the Jorgenson neoclassical investment function. The SDNM
formulation also differs from the neoclassical formulation in identifying
a richer variety of delays underlying investment decision-making and the
acquisition of new capital.

Statistical tests show that the additional hypotheses included
in the SDNM investment function lead to consistent improvement in fit and
residual autocorrelation when both investment functions are fit to four
sets of industry-group data. Statistical analysis also shows that
plausible statistically significant estimates can be obtained for all
parameters and lag distributions in the SDNM formulation.
Model-behavior tests show that the additional elements of structure in the SDNM formulation are necessary for plausible behavior when the investment function is placed within a dynamic model of a consumer-goods producing sector. Model-behavior tests also show that the additional hypotheses in the SDNM investment function are important in generating two distinct oscillatory modes of consumer-goods sector behavior—short-term (approximately 5-year) fluctuations in employment and production and longer term (approximately 18-year) fluctuations in investment and capital stock.

Thesis Supervisor: Nathaniel J. Mass
Title: Professor of Management
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This thesis has been a great source of excitement and enjoyment during the past year, and I would like to thank the many people who have been part of it.

First, I want to thank Nathaniel Mass, who served as chairman of my doctoral committee. Nat and I have collaborated on many projects during the past few years, and there are few people I would rather work with. Over and above his extensive knowledge of system dynamics and the production sector of the System Dynamics National Model, Nat contributed the intangibles of successful supervision. He maintained an unwavering certainty in the project and in me, and he somehow always managed to find time to discuss difficulties, whenever they arose. I hope the quality of the product provides a measure of the quality of his contribution.

The two other members of my thesis committee, Edwin Kuh and Allen Sinai, likewise deserve a special note of thanks. Because this study attempts to present a portion of a system dynamics model for critical review by economists, successfully incorporating the econometric viewpoint into the study was essential. Ed and Allen contributed that viewpoint in a way which consistently supported the purpose of the project. It is my intention that such collaboration may prove the antidote for the acrimony and noncommunication which have typically characterized exchanges between system dynamicists and econometricians.

I owe a special debt to Jay W. Forrester, founder of the System Dynamics National Project. Jay's intellectual integrity and commitment create the context for all work done in the System Dynamics Group at MIT, of which I am a part. The extent to which that integrity and commitment extends to the national project as a whole is a tribute to my fellow research staff members on the project, Professor Alan Graham, Professor Gilbert Low, and Barry Richmond.

A research staff can be no more successful than the production staff which supports it. In this light, Kelsey Thompson and Colleen Haag deserve special thanks for their assistance in debugging new computer programs and demystifying old ones. Without them, I would probably still be reading the DYNAMO User's Manual. Similarly, I want to thank Marilyn Nelson for her outstanding work in preparing the manuscript, a feat made even more challenging than usual by virtue of its being done on a new word processor, and Diane Leonard-Senge for her expert skill and unbelievable patience in preparing the large number of graphics. I would also like to thank Rob Kaplan, whose help in preparing the manuscript kept production on schedule at several crucial junctures.
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Lastly, I would like to acknowledge my wife Diane. As anyone who has experienced it knows, a thesis is a roller coaster. When done in the context of a relationship, you can either enjoy the ride together or take turns running over one another. Somewhere in the course of this thesis, Diane and I discovered that it was no longer possible for us to run over one another. That discovery alone would justify the entire undertaking.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>CHAPTER 1</td>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>I.</td>
<td>Preview</td>
<td>11</td>
</tr>
<tr>
<td>II.</td>
<td>Background Research</td>
<td>13</td>
</tr>
<tr>
<td>II.A</td>
<td>Review of Major Research Areas</td>
<td>13</td>
</tr>
<tr>
<td>II.B</td>
<td>Issues in Investment Research</td>
<td>16</td>
</tr>
<tr>
<td>III.</td>
<td>Objectives and Approach of the Research</td>
<td>24</td>
</tr>
<tr>
<td>IV.</td>
<td>Organization</td>
<td>27</td>
</tr>
<tr>
<td>CHAPTER 2</td>
<td>THE SDNM INVESTMENT FUNCTION</td>
<td></td>
</tr>
<tr>
<td>I.</td>
<td>Introduction</td>
<td>31</td>
</tr>
<tr>
<td>II.</td>
<td>Background: The SDNM Production-Sector Model</td>
<td>33</td>
</tr>
<tr>
<td>III.</td>
<td>Equations for the SDNM Investment Function</td>
<td>36</td>
</tr>
<tr>
<td>III.A</td>
<td>Overview</td>
<td>36</td>
</tr>
<tr>
<td>III.B</td>
<td>Details of the Formulation</td>
<td>41</td>
</tr>
<tr>
<td>III.C</td>
<td>Expressing the SDNM Formulation for Estimation</td>
<td>62</td>
</tr>
<tr>
<td>IV.</td>
<td>The Neoclassical Investment Function</td>
<td>64</td>
</tr>
<tr>
<td>IV.A</td>
<td>Desired Capital</td>
<td>64</td>
</tr>
<tr>
<td>IV.B</td>
<td>Relation Between Desired Stock and Investment Activity</td>
<td>66</td>
</tr>
<tr>
<td>IV.C</td>
<td>Summary of Differences in SDNM and Neoclassical Investment Functions</td>
<td>71</td>
</tr>
<tr>
<td>V.</td>
<td>The Influence of System Dynamics Modeling Principles on Investment-Function Specification</td>
<td>72</td>
</tr>
<tr>
<td>V.A</td>
<td>Explicit Representation of Real-Life Stocks and Flows</td>
<td>72</td>
</tr>
<tr>
<td>V.B</td>
<td>Flow-Rate Inputs Must be Information Actually Available to Decision Makers</td>
<td>73</td>
</tr>
<tr>
<td>V.C.</td>
<td>Summary</td>
<td>75</td>
</tr>
<tr>
<td>CHAPTER 3</td>
<td>STATISTICAL ESTIMATION AND TESTING</td>
<td></td>
</tr>
<tr>
<td>I.</td>
<td>Introduction and Preview of Results</td>
<td>77</td>
</tr>
<tr>
<td>II.</td>
<td>Simplifying the SDNM Investment Function for Statistical Analysis</td>
<td>79</td>
</tr>
</tbody>
</table>
II.A  Estimation Problems Posed by the SDNM Formulation.......................... 79
II.B  Simplifying the SDNM Delay Structure.............. 81
III.  Statistical Estimation and Testing of the SDNM
      Investment Function........................................... 85
      III.A  Data.......................................................... 85
      III.B  Estimation Procedure................................... 86
      III.C  Estimation Results..................................... 91
IV.   Comparison of Fits of SDNM and Neoclassical
      Investment Functions......................................... 112
      IV.A  Estimation Procedure................................. 113
      IV.B  Estimation Results...................................... 120
V.    Summary........................................................ 125
Appendix A of Chapter 3.
      Derivation of Structural Parameters and Delay Times.. 129

CHAPTER 4
MODEL-BEHAVIOR TESTS—PART 1: BEHAVIOR PLAUSIBILITY TESTS

I.  Introduction and Preview of Results.................... 155
II.  The Consumer-Goods Sector Model....................... 158
     II.A  Overview of Model Structure and Parameter Values................................. 158
     II.B  Choice of a Consumer-Goods Sector Model for Behavior Testing................. 164
III.  Production Sector Behavior with the Full SDNM
      Investment Function........................................... 166
     III.A  Response to a Step Increase in Orders for Output................................ 166
     III.B  Comparison to Behavior of an Econometric Production-Sector Model........... 175
     III.C  Summary................................................... 180
IV.   Tests of Behavior Plausibility......................... 181
     IV.A  Inventory and Backlog Corrections.................................................. 181
     IV.B  Supply-Line Correction...................................... 192
     IV.C  Expected Growth in Shipments.............................................. 200
     IV.D  Perceived Ratio of Capital Return to Cost..................................... 208
V.    Summary of Behavior Plausibility Tests................ 219

CHAPTER 5
MODEL-BEHAVIOR TESTS—PART II: BEHAVIOR-MODE TESTS

I.  Introduction and Preview of Results.................... 223
II.  Oscillatory Modes of Consumer-Goods Sector Behavior.. 226
     II.A  Behavior Modes Generated by the Consumer-Goods Sector Model.................. 226
     II.B  Comparison to Empirical Behavior Modes...................................... 236
     II.C  Summary................................................... 246
<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>III. Behavior Modes Generated with a Neoclassical-Type Equation for Capital Ordering</td>
</tr>
<tr>
<td>III.A Model-Generated Behavior Modes</td>
</tr>
<tr>
<td>III.B Comparison to Empirical Behavior Modes</td>
</tr>
<tr>
<td>III.C Summary</td>
</tr>
<tr>
<td>IV. The Importance of SDNM Investment Hypotheses in Generating Consumer-Goods Behavior Modes</td>
</tr>
<tr>
<td>IV.A Perceived Ratio of Capital Return to Cost</td>
</tr>
<tr>
<td>IV.B Inventory and Backlog Corrections</td>
</tr>
<tr>
<td>IV.C Supply-Line Correction</td>
</tr>
<tr>
<td>IV.D Expected Growth in Shipments</td>
</tr>
<tr>
<td>V. Parameter Sensitivity of Behavior-Mode Test Results</td>
</tr>
<tr>
<td>V.A Possible Effects of Parameter Variation on Behavior-Mode-Test Results</td>
</tr>
<tr>
<td>V.B Two Examples of the Effects of Parameter Variation on Behavior-Mode Test Results</td>
</tr>
<tr>
<td>VI. Summary of Behavior-Mode Tests</td>
</tr>
</tbody>
</table>

**CHAPTER 6**

**SUMMARY AND SUGGESTIONS FOR FUTURE WORK**

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Substantive Findings of the Research</td>
</tr>
<tr>
<td>II. Methodological Conclusions—The Usefulness of Model-Behavior Testing</td>
</tr>
<tr>
<td>III. Suggestions for Future Research</td>
</tr>
</tbody>
</table>

**APPENDICES**

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Equations for the Consumer-Goods Sector Model</td>
</tr>
<tr>
<td>B Rerun File for Model Simulations</td>
</tr>
<tr>
<td>C Data</td>
</tr>
<tr>
<td>D Estimation Problems Posed by the Delay Structure of System Dynamics Models</td>
</tr>
</tbody>
</table>

**BIBLIOGRAPHY** | 413 |
CHAPTER 1  INTRODUCTION

I.  PREVIEW

This study presents a series of tests of the System Dynamics National Model (SDNM) investment function. The tests reveal the consistency of the investment function with available data and knowledge of investment decision making. The tests also illuminate the usefulness of the SDNM investment function for understanding the effects of capital investment on the behavior of an aggregate economic production sector.

The research reported herein represents the first in-depth validation study of a component of the System Dynamics National Model (Forrester, Mass, and Ryan 1976, Forrester 1976.) The SDNM is

...a computer simulation model of social and economic change in the United States. It is designed for public policy analysis and contains a deep policy structure ranging from governmental, fiscal, and monetary policy down to corporate accounting, pricing, and ordering of the factors of production. The model will treat the highly interrelated issues of inflation, unemployment, recession, balance of payments, energy, and environment. With regard to each of these issues, the Model should help to explain the forces that underlie major national difficulties, clarify feasible futures, and examine policies that can lead to more desirable behavior. (Forrester, Mass, and Ryan 1976, p.51)

This study provides an opportunity to examine typical assumptions in the SDNM and the types of empirical evidence available for evaluating the assumptions. The SDNM investment function has been chosen for evaluation because capital investment appears to play a prominent role in several modes of economic behavior generated by the SDNM (see
Forrester 1976) and because of the large volume of past research in investment-function specification. By showing that the SDNM investment function outperforms a well known econometric investment function for a large variety of tests, the study hopes to begin to foster confidence in the SDNM as a tool for understanding economic structure and behavior. Such confidence is a necessary precursor to using the model to analyze national policies.

The study is also intended as an experiment in integrating two hitherto separate approaches to testing investment-function specification. The first approach is single-equation statistical testing, which entails examining fit and other measures of equation performance in single-equation regressions. Single-equation statistical testing is the primary approach employed in testing econometric models. The second approach is model-behavior testing, which entails analysis of the implications of equation specification for the behavior of a system model. Model-behavior testing is the primary approach employed in testing system dynamics models. Few system dynamics models have been subjected to statistical testing. Similarly, model-behavior testing is relatively new to econometric model building. Though econometric system modelers are beginning to utilize model-behavior testing more extensively, the present study is the first effort to apply model-behavior analysis to systematically test a set of investment hypotheses.
II. BACKGROUND RESEARCH

Two distinct areas of theoretical and empirical research lie behind the present study: system dynamics studies of the structure and behavior of industrial systems and econometric studies of investment-function specification. The following discussion reviews historical developments in each area and identifies the particular investment issues within each area upon which the present study focuses.

II.A REVIEW OF MAJOR RESEARCH AREAS

System Dynamics Studies of the Structure and Behavior of Industrial Systems. Beginning in the mid-1950's, system dynamics models have been constructed to examine the relationships between corporate policies and the growth and instability of firms and industries. The basic tools applied in examining industrial structure and behavior have been the theory of feedback systems and the technique of computer simulation. As combined in the system dynamics methodology, feedback theory provides general guidelines for organizing system structure, and computer simulation provides a means of deducing the behavior arising from a particular system structure. System dynamics models have identified causes for many common industrial problems and have resulted in general
insights into the consequences of alternative corporate policies.¹

More recently, system dynamics studies of industrial systems have provided a foundation for a generic production-sector model constructed as part of the System Dynamics National Model. The SDNM production sector is intended to provide a common framework for modeling diverse production sectors. The production-sector model attempts to identify and interrelate common managerial policies for ordering factors of production (labor, capital plant and equipment, materials, energy, land, transportation, services), managing output inventories and backlogs of unfilled orders for output, determining delivery delays, setting prices, borrowing, saving, and holding money. The model includes finished and in-process inventories of output, factor inventories, backlogs of unfilled orders for output and for factors, and a full balance sheet of accounts receivable, short and long-term borrowing, savings, money, and the value of physical assets. The SDNM investment function tested in the present study derives from the equations governing capital ordering in the SDNM production sector.²

¹Several overviews of the system dynamics method applied to industrial systems are available. Forrester (1961) lays out the basic foundations for constructing and testing system dynamics models of industrial systems. An exchange between Forrester and Ansoff and Slevin identifies key issues arising in the first ten years of application (Forrester 1968a, b, Ansoff and Slevin 1968). Surveys of industrial cases and summaries of basic findings in industrial dynamics research have been compiled by Roberts (1964, 1978) and Lyneis (1975).

²Mass (1977a) presents an introduction to the SDNM production-sector model. Mass and Forrester (1978) provide a preliminary equation description of the complete model.
Econometric Studies of Investment-Function Specification. Econometric studies of capital investment may be traced back to Tinbergen's pioneering study of business-cycle theories (Tinbergen 1939). The studies use statistical inference techniques to examine the consistency of theoretical propositions with empirical data. Econometric investment studies have examined investment functions based on a broad array of theoretical underpinnings. In addition, several major cross-model comparisons have been published in which a collection of alternative investment functions are fit to a common set of data (Jorgenson and Siebert 1968; Jorgenson, Hunter and Nadiri 1970a, b; and Bischoff 1971b).

A major outcome of econometric investment studies has been convergence on the basic neoclassical framework for modeling investment decision making. In neoclassical investment functions, the demand for capital services is obtained by optimizing some performance index for the firm. Virtually all cross-model studies have favored one or another neoclassical investment function. Most major macroeconomic models employ investment functions from the neoclassical mold. Probably the best

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3Reviews of econometric investment studies conducted prior to the early 1960's are presented by Eisner and Strotz (1963) and Kuh (1963). Jorgenson, Hunter and Nadiri (1970a) identify over 15 studies conducted since 1962 and examine four proposed investment functions in detail.

4Examples include the DRI model (see Eckstein, Green, and Sinai 1974), the MPS model (see Ando, et. al. 1974), and the Brookings model (Duesenberry, et. al. 1965); as well as the teaching model developed by Kuh and Schmalensee (1973).
known and most influential neoclassical investment function is the
investment function developed by Dale Jorgenson and colleagues (Jorgenson
1963, 1965; Jorgenson and Stephenson 1967a,b, 1969; and Jorgenson and
Siebert 1968.) The present study utilizes the Jorgenson neoclassical
investment function, henceforth referred to as the neoclassical
investment function, as a basis for comparison to the SDNM investment
function.

II.B ISSUES IN INVESTMENT RESEARCH

The preceeding discussion has identified the two major areas of
background research for the present study. However, such a broad-brush
treatment provides an incomplete picture of the background for the
present study. Within each major research area lie particular threads
which must be identified to appreciate the objectives of the present
research.

Analysis of the Dynamic Implications of Alternative Econometric
Investment Functions. In recent years, econometricians have begun to pay
increasing attention to the dynamic behavior implied by alternative
investment functions. For example, at least two criticisms of the
neoclassical investment function have focused on dynamic shortcomings in
the formulation. Gould (1969) points out that the neoclassical
formulation for desired capital depends only on past output, price of
output, and the cost of capital services. If relative prices stay fixed, desired capital can expand only if output expands. But, Gould argues, if output is determined by current production capacity, then output cannot expand until capacity first expands. Gould concludes that the neoclassical investment function cannot correctly describe the dynamics of capital expansion because desired output is constrained by current production capacity.\footnote{Griliches (1968), Coen (1969), and Borch (1963) have raised similar criticisms of the dynamics induced by the neoclassical investment function. Jorgenson (1972) has responded with an alternative interpretation of the dynamics induced by the neoclassical investment function.}

Whereas Gould limits himself to a theoretical analysis of dynamic problems with the neoclassical investment function, Bischoff formulates and test an alternative investment function intended to improve the dynamic response of the neoclassical investment function (Bischoff 1969, 1971 a, b.) In particular, Bischoff argues that

\[\text{...(the neoclassical investment function) is basically misspecified, in so far as it assumes that the response of investment spending to a change in relative prices (wages, interest rates, the investment deflator, tax credits, and so on) is the same as the response to a change in output...If the assumption of identical response patterns is invalid,...(the neoclassical investment function) fails to distinguish an explosive response to output from a gradual response to relative prices. (Bischoff 1971b, p. 26)}\]
To correct the perceived shortcoming in the neoclassical formulation, Bischoff formulates an alternative investment function which permits a differential response of investment to changes in output and relative prices. In addition to fitting both investment functions to aggregate data, Bischoff (1971b) examines the dynamic response of each investment function to changes in the determinants of capital spending. That is, he examines the response of investment expenditures to changes in output, price of output, and the variables which determine the cost of capital services (such as the price of capital, interest rate, and corporate taxation rate) assuming that the investment response does not in turn affect future determinants of investment.

Though Bischoff's analysis represents an important step in considering dynamic implications of alternative investment functions, a more complete dynamic analysis requires examination of the feedbacks that link current investment behavior to future investment incentives. The need to examine the effects of equation specification on complete system models has become widely recognized. For example, Allen Sinai has observed that,

...standard regression methods of testing may not provide all the information necessary on the performance of an econometric model. All too often, regression estimation produces sufficient regression statistics; but when individual equations are combined into a multi-equation model, the good results of the regression work are not obtained. (Sinai 1976, p. 24)
Similarly, Robert Pindyck and Daniel Rubinfeld note that,

...when individual regression equations, which may fit the historical data very well, are combined to form a simultaneous equation model, simulation results may bear little resemblance to reality.... ...the model as a whole will have a dynamic structure which is much richer than that of any one of the individual equations of which it is composed. Thus even if all the individual equations fit the data well and are statistically significant, we have no guarantee that the model as a whole, when simulated, will reproduce those same data series closely...

In practice, it may be necessary to use specifications for some of the equations in the model that are less desirable from a statistical point of view, but that improve the ability of the model to simulate "well." (Pindyck and Rubinfeld 1976, pp. 309, 315, 316)

Similar views of the usefulness of model-behavior testing as an extension of traditional statistical testing have been expressed by Holt (1965) and Sowey (1973). 6

Despite widespread acceptance of the basic premise of testing equation specification through analysis of model behavior, an important gap exists between the principle and practice of model-behavior testing of econometric models. In contrast to the abundance of published statistical studies, thorough specification studies using model behavior testing are rare. In the area of investment-function specification, no published model-behavior studies are known to the author. Model-behavior

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6For discussion of the relative strengths of the two testing approaches from a system dynamics perspective, see Mats and Senge (1977).
testing remains "backstage" in econometric investment research. Though used extensively to revise specification during model-construction, model-behavior tests rarely share the spotlight with statistical tests when equation specification is presented for critical review.

System Dynamics Studies of the Effects of Capital Investment on Economic Behavior. If model-behavior testing is backstage in econometric research, it is center stage in system dynamics studies of economic structure. In particular, model-behavior tests have been employed extensively to analyze the role of capital investment in generating different modes of production-sector behavior. Research to date suggests that capital investment is intrinsic to two modes of oscillatory behavior generated within production sectors--an approximate 18-year cycle in capital stock and capital investment in consumer-goods sectors and an approximate 50-year cycle emanating from capital-producing sectors (see Forester 1976 and Mass 1976a.) Though both modes are clearly tied to capital investment, their dependence on particular features of investment-function specification has not been assessed.

Unfortunately, examination of both oscillatory behavior modes is not possible in the present study. In order to explore the usefulness of relating investment-function specification to particular modes of
oscillatory behavior, the present study focuses on the 18-year cycle.\textsuperscript{7} In particular, the study builds on the initial analysis of the 18-year cycle presented by Nathaniel Mass (1975). Mass analyzes the 18-year cycle using a simplified version of the SDNM production-sector model. The model includes two factors of production, labor and capital, and a slightly modified version of the SDNM investment function. Mass shows that the model generates two distinct patterns of oscillatory behavior—three- to seven-year-period fluctuations in inventory, employment, and production, and longer term fluctuations in investment and capital stock. The short-term fluctuations resemble typical business cycles in period and phase relationships among model variables. Mass suggests that the longer term fluctuations, which have an average period of about 18 years, resemble to so-called "Kuznets cycle" observed primarily in empirical data on rates of growth in output and capital stock by Kuznets (1930, 1958), Burns (1934), Abramowitz (1961), and many others.\textsuperscript{8}

\textsuperscript{7}The present focus on the 18-year cycle should not be taken to imply that this mode of behavior is of greater significance for economic behavior or policy. On the contrary, the apparent amplitude and insensitivity of the 50-year cycle suggest that, of the two longer-term cycles, it has the greater impact on economic behavior. Nonetheless, focus on the 20-year cycle is justified by the progress which has already been made in understanding this cycle and the greater likelihood of identifying such a periodicity in available data.

\textsuperscript{8}The large number of empirical studies which have identified Kuznets cycles in US data and in data from other industrial countries include: Wardwell (1927), Riggleman (1933), Long (1940), Isard (1942), Cairncross (1953), Thomas (1954), Lewis and O'Leary (1955), Esterlin (1961a, 1961b), Campbell (1963), Hickman (1963), Williamson (1964), Wilkinson (1967), and Kelley (1969).
By examining model behavior with and without capital investment, Mass concludes that capital investment is not essential to generating the four-year cycle but plays a central role in the 18-year cycle:

...the long delays in capital acquisition and depreciation cast doubt on any role for investment in fixed capital as an integral factor in generating four-year business cycles. On the other hand,...fluctuations in fixed capital investment may underlie the fifteen to twenty-year fluctuations in the rate of growth of aggregate output and capital stock observed in many countries. (Mass 1975, p. 4.)

He arrives at this conclusion by finding that the character of short-term fluctuations generated by the model is unchanged by inclusion or exclusion of capital investment, and similarly that the character of the longer-term fluctuations is unchanged by inclusion or exclusion of a variable stock of labor. Mass links both cycles to basic production-sector policies governing employment, capital investment, and efforts to maintain desired levels of output inventory and backlogs. Moreover, when he expands the model to incorporate alternative theories of business-cycle behavior, Mass finds that the additional mechanisms are less important than basic production-sector mechanisms. He finds that variable labor efficiency and price expectations exacerbate but are not necessary for generating fluctuating behavior. He also finds that multiplier-accelerator interactions are far less important sources of business-cycle fluctuations than inventory and backlog-management policies endogenous to the firm (Mass 1975, pp. 62-92).
Mass argues that the relationships between capital investment and longer-term economic cycles have important implications for economic stabilization policy:

Many prevalent economic stabilization policies are predicated on a capital-investment theory of (short-term) business-cycle behavior, (a theory assuming that fluctuations in investment are intrinsic causes of business cycles--note inserted by author). However, if business cycles are attributable for the most part to short-term employment and inventory decisions, policies that attempt to control fixed capital investment may have relatively little leverage or may be less effective than policies directly aimed at employment and inventories. Moreover, if fixed capital investment generates cycles of fifteen to twenty years or longer in capital plant, policies designed to regulate capital investment can have significant long-term impacts on output and productivity. (Mass 1975, p. 128)

In order to tie the insights of Mass's analysis to issues of investment-function specification, it is necessary to examine if particular features of the SDNM investment function are important in generating the 18-year cycle. The behavior-mode tests required for such an analysis are quite novel to econometric practice and have rarely been carried out in a thorough and well-documented fashion in system dynamics research.
III. OBJECTIVES AND APPROACH OF THE RESEARCH

The overall substantive objective of this thesis is to determine whether the SDNM investment function is superior to Jorgenson's neoclassical investment formulation from the standpoint of understanding the causes and consequences of investment behavior in an aggregate production sector. To accomplish this objective, the SDNM investment function is first compared to the neoclassical formulation to identify differences in the two theories of investment. The comparison identifies five distinct hypotheses included in the SDNM investment function but omitted from the neoclassical investment function. 9 When the five hypotheses are eliminated from the SDNM investment function, it closely resembles the neoclassical investment function. Elimination of the SDNM investment hypotheses implies several equilibrium assumptions, such as output inventory equals desired inventory, and backlog of unfilled orders for the sector's output equals desired backlog.

Identification of the five SDNM investment hypotheses permits dividing the overall objective of the research into four component tasks. The first task is to justify the hypotheses as realistic components of investment decision making. Each hypothesis is initially

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9 Note that the term "SDNM investment hypothesis", as used in the present study, refers to particular components of the SDNM investment function, not to the entire investment function. This terminology is chosen to focus on the components as individual hypotheses requiring descriptive and empirical justification, rather than seeing the components as merely extra variables in the SDNM investment function.
justified by showing that it has a clear managerial meaning and by examining similar hypotheses which have been proposed in the literature.

The second task entails assessing statistical support for the SDNM investment hypotheses. Statistical assessment focuses on the extent to which each hypothesis improves equation performance when fit to quarterly industry data. The statistical analysis shows that inclusion of all five SDNM investment hypotheses leads to substantial improvement in equation performance over the neoclassical investment function. The statistical analysis also shows that plausible estimates can be obtained for all parameters and lag distributions in the SDNM investment function.

The third task entails analysis of whether the SDNM investment hypotheses are necessary for plausible behavior in a production-sector model. To carry out the behavior plausibility tests, the SDNM investment function is incorporated into a consumer-goods sector model based on the SDNM production sector. Each SDNM investment hypothesis is then eliminated and the effects on model response to simple test inputs is examined. The tests show that each hypothesis plays a role in ensuring plausible model behavior.

The fourth task is to determine if the SDNM investment hypotheses are important in generating the 18-year cycle identified in Mass's analysis of consumer-goods sector behavior (Mass 1975). As noted above, Mass concludes that the 18-year cycle is closely related to the long delays in acquiring and depreciating fixed capital. The
behavior-mode tests presented below extend Mass's analysis to show that three SDNM investment hypotheses are important in generating the 18-year cycle. The hypothesized delay in perceiving and responding to nonoptimal factor mixes is essential in creating long-term fluctuations in desired capital. The hypothesized influence of output-inventory and backlog discrepancies also contribute to the 18-year cycle generated by the consumer-goods sector model. Moreover, simulations with a neoclassical-type investment function (i.e., an investment function which omits all five SDNM investment hypotheses) exhibit behavioral features inconsistent with historical data for investment and capital stock.

Although the thesis focuses on substantive questions of investment-function specification, the analysis is also intended to illuminate methodological issues. In particular, the study is designed to examine the usefulness of model-behavior analysis in testing investment-function specification. The juxtaposition of statistical and model-behavior tests for a common set of specification issues reveals the usefulness of model-behavior testing as an extension of conventional statistical tests of equation specification.
IV. ORGANIZATION

Chapter 2 presents the SDNM and neoclassical investment functions as alternative theories of the determinants of capital investment. The presentation begins by overviewing the purpose and scope of the SDNM production-sector model, of which the SDNM investment function is one component. The overview establishes the role of the SDNM investment function within the larger model and general criteria by which all components of the production sector should be evaluated. Chapter 2 then presents the equations of the SDNM investment function. The key hypotheses in the formulation are defended as components of actual investment decision making. It is then shown that the neoclassical formulation for desired capital can be viewed as a special case of the SDNM formulation. The neoclassical formulation for the response of investment to changes in desired capital likewise requires simplifying the relationship between desired capital and capital ordering in the SDNM investment function. Lastly, Chapter 2 shows that differences between the two investment functions can be traced to system dynamics modeling principles. Paramount among these principles is (1) the explicit representation of real-life stocks and flows, and (2) the inclusion of only information actually available to decision makers as inputs to decision rules in a model.

Chapter 3 shows the extent to which available industry data support the SDNM investment function. Statistical support for the SDNM formulation is assessed in three stages. First, the extent to which each
SDNM investment hypothesis improves equation performance (equation fit, residual autocorrelation, and overall statistical significance) is assessed through a series of regressions in which each hypothesis is progressively incorporated into the regression. This first series of regressions is repeated for four sets of industry data. Parameters and lag distributions in the full SDNM investment function are then estimated using data for total nondurable manufacturing, the industrial aggregate which most nearly corresponds to an aggregate consumer-goods sector. The plausibility and statistical significance of parameter estimates provide a second check on statistical support for the SDNM investment function. Third, the SDNM and neoclassical investment functions are compared against the four sets of industry data.

Chapters 4 presents the first set of model-behavior test results. Chapter 4 overviews the consumer-goods sector model employed for the testing. Relative to the full SDNM production-sector model, the model employed in the present tests is simplified to include only two factors of production, labor and capital, and excludes endogenous price setting and financial flows. Despite the simplifications, the consumer-goods model provides a useful framework for examining dynamic implications of the SDNM investment hypotheses. Simulation of the model reveals the behavior produced when capital investment generated with alternative investment functions feeds back to modify capital stock, production, output inventory, delivery delay (for output), shipments, backlogs of unfilled orders for output, and future investment.
The model-behavior tests in Chapter 4 examine whether the SDNM investment hypotheses are necessary to insure plausible behavior of the consumer-goods sector model. Chapter 4 first analyzes model response with the full SDNM investment function. The analysis shows how adjustments in labor and capital, in conjunction with inventory and backlog management, can lead to overshoot and oscillation in response to a single step increase in orders for output. Chapter 4 then presents a series of simulations in which SDNM investment hypotheses are eliminated from the investment function. The simulations show that elimination of each hypothesis leads the model to behave implausibly. In each case, the causes for the implausible behavior are explained in terms which reveal why the hypothesis is necessary for plausible production-sector behavior.

Taken together, the statistical tests and the behavior-plausibility tests offer persuasive evidence for choosing the SDNM investment function over investment functions drawn from the Jorgenson neoclassical framework. The additional hypotheses included in the SDNM investment function are consistent with available data and necessary for plausible production-sector behavior. By implication, a neoclassical investment formulation is less able to account for observed movements in capital ordering (capital appropriations) and leads to implausible production-sector behavior.

The behavior-mode tests in Chapter 5 show that the SDNM investment hypotheses also illuminate possible sources of longer-term fluctuations in investment and capital stock. Chapter 5 begins by
identifying the two distinct modes of oscillatory behavior when the consumer-goods sector model including the full SDNM investment function responds to a small random component in orders for output. The technique of spectral analysis is then introduced to more precisely identify periodicities in stochastic simulations. Chapter 5 then shows that elimination of all five SDNM investment hypotheses eliminates the two distinct modes of consumer-goods sector behavior. Using spectral analysis in conjunction with analysis of deterministic simulations, Chapter 5 shows that two SDNM investment hypotheses play key roles in generating the longer-term cycle in investment and capital stock. Examination of empirical time series suggests that the two modes of oscillatory behavior are likewise present in the data, thereby increasing confidence in the significance of the SDNM investment hypotheses.

Chapter 6 summarizes the findings in Chapters 2 through 5 and considers the usefulness of model-behavior tests as an extension of statistical tests of investment-function specification. The discussion notes the usefulness of statistical analysis for measuring the consistency of alternative formulations with available data. However, only model-behavior analysis provides a basis for understanding why a hypothesis is sound or unsound, or for determining why a hypothesis may be important in understanding the source of observed patterns of economic behavior. Combining the two testing approaches should therefore enhance the capabilities of econometric and system dynamics model-builders to test alternative theories and present models for critical review.
CHAPTER 2 THE SDNM INVESTMENT FUNCTION

I. INTRODUCTION

The SDNM investment function represents a theory of the determinants of capital investment within a typical economic production sector. The investment function links order starts for capital to present capital stock, indicators of the sector's current ability to meet demand for its output, expectations of future demand, and the cost and availability of new capital. Arrivals of capital, which corresponds to investment expenditures, then responds to order starts for capital, through explicitly represented delays in planning and acquiring new capital.

The following presentation introduces the SDNM investment function and compares the formulation to the neoclassical investment function developed by Jorgenson. The comparison reveals that the SDNM formulation offers a more general theory of the determinants of investment. In particular, the SDNM formulation embodies five key hypotheses not present in the neoclassical investment function:

1. **Inventory Correction**: Desired output, and hence desired capital, responds to the discrepancy between desired and actual levels of inventory of output.

2. **Backlog Correction**: Desired output, and hence desired capital, responds to the discrepancy between desired and actual levels of the backlog of unfilled orders for capital.
(3) Supply-Line Correction: Capital ordering responds to the difference between the desired and actual levels of the "supply-line" of unfilled orders for capital (capital orders in planning and backlog of unfilled orders for capital.)

(4) Expected Growth in Shipments: Capital ordering responds to expectations of future growth in shipments, which in turn are based on perceived growth trends in shipments.

(5) Perceived Ratio of Capital Return to Cost: Desired capital responds only after a delay to departures of the current capital-output ratio from the optimal capital-output ratio. (Perceived ratio of capital return to cost is formed by exponential smoothing of ratio of capital return to cost, the marginal revenue product of capital divided by the marginal cost of capital.)

Section II reviews the purpose and scope of the SDNM production sector as a backdrop for understanding the SDNM investment function.

Section III presents the equations for the SDNM investment function and identifies the key SDNM investment hypotheses. Section IV presents the neoclassical investment function and compares it to the SDNM investment function. Section V relates the differences in the two investment functions to system dynamics modeling principles.
II. BACKGROUND: THE SDNM PRODUCTION-SECTOR MODEL

Specification of an investment function depends upon the scope and purpose of the model in which the investment function is embedded. The SDNM investment function is a component of the general production-sector model developed for the System Dynamics National Model (Mass 1977a, Forrester and Mass 1976). The SDNM production sector represents a general theory of production activity. The structure of the production-sector model is essentially the structure of a single firm in the economy. The sector acquires factors of production such as labor, capital, and energy; combines the factors to generate an output stream; maintains a backlog of unfilled orders for output, inventory in process, and final output inventory; sets prices; borrows short- and long-term; holds accounts receivable and payable; holds money; obtains financial assets; and generates a full income statement and balance sheet. In the SDNM, the standard production-sector model will be replicated many times to represent diverse production sectors. By changing parameter values, such as normal inventory coverages, normal delivery delays, and normal proportions of different factor inputs, the standard sector has been adapted to fit such diverse industries as consumer goods, capital equipment, and energy. The fully-assembled SDNM will contain approximately fifteen production sectors, each based on the standard
production-sector model.\textsuperscript{1}

To attain the generality required to represent diverse production sectors, the SDNM production-sector model attempts to capture the motivations and constraints that underlie micro-level decision making within the firm. No a priori assumptions are made that production activities are in equilibrium or that business enterprises are geared only to short-term profit maximization. Rather, the model attempts to identify the information actually available at each decision point and how that information is processed to yield decisions. The model also attempts to include all relevant stock variables, or accumulations, which give rise to disequilibrium behavior. \textsuperscript{2}

Two criteria for specifying an investment function emerge from the preceding description of the SDNM production sector. First, the investment function must provide a general theory of the determinants of investment. That is, the formulation should incorporate only those influences on investment decisions thought to prevail across a broad variety of industries. Second, the investment function should provide a

\textsuperscript{1} Current plans call for the following production sectors: capital goods, consumer durables, consumer soft goods, resources, knowledge (technological know-how), energy, transportation, residential construction, commercial construction, services, agriculture, food processing and distribution, secondary manufacturing, government services, military and defense.

\textsuperscript{2} Mass (1977a) discusses more fully the modeling principles guiding formulation of the SDNM production sector.
meaningful description of micro-level decision making. The investment function should, to the fullest extent possible, reflect the managerial objectives underlying capital planning and the actual processes involved in realizing capital acquisitions.
III. EQUATIONS FOR THE SDNM INVESTMENT FUNCTION

This section presents the equations for the SDNM investment function in three stages. First, the investment function is overviewed to identify the major elements of the formulation. Second, the details of the formulation are discussed. The detailed discussion focuses on justifying the key SDNM investment hypotheses. Third, equations are combined to express the investment function in a form suitable for statistical estimation.

III.A OVERVIEW

Figure 2-1 overviews the determinants of investment and capital acquisition as modeled in the SDNM. In the figure, rectangles symbolize stock variables such as capital and backlog of orders placed for capital. The valve symbols signify flow variables such as arrivals of capital and order starts for capital. Circles symbolize "auxiliary" variables--variables which are algebraic functions of stocks and represent inputs to equations determining rates of flow. (Auxiliary variables derive their name from the fact that all auxiliaries can be collapsed into rate equations leaving only stock and flow variables.)

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3 The investment function presented below is simplified in several ways from the full set of equations determining investment in the SDNM production sector. The simplifications include eliminating several nonlinearities which restrict capital ordering under extreme conditions and omitting determinants of investment which have not been fully explored in simulations of the production-sector mode. Appendix A itemizes the simplifications.
FIGURE 2-1
Determinants of Investment
and the Capital Accumulation Process in the SDMM
The figure shows that most of the influences on investment come from within the production sector; only two, delivery delay for capital and cost of capital services, are determined outside the sector.⁴

The key decision point in the investment process as conceptualized in the SDNM is the rate of order starts for capital. Figure 2-1 shows that order starts for capital is a function of three components, expansion orders EO, replacement orders RO, and orders for the supply line OSL:

\[
OSC_t = EO_t + RO_t + OSL_t
\]  

Expansion orders EO reflect desires to expand capital stock. Replacement orders RO reflect desires to replace all or a portion of the capital currently being lost due to physical wear out or discard. Orders for the supply-line OSL represent an adjustment in order starts for capital due to discrepancies between the desired and actual levels of the supply line of unfilled orders for capital.

Expansion Orders EO and Replacement Orders RO. Both expansion orders and replacement orders depend on the current stock of capital \( CAP \) and the

⁴ In the full SDNM, delivery delay for capital is determined in the capital-producing sector; the cost of capital services depends on variables determined in the capital-producing sector (price of capital) and the financial sector (interest rate).
desired stock of capital DCAP. Replacement orders are determined as follows:

\[ RO_t = CAP_t \cdot NLC + \min (CCAP_t, 0) \]  

(2-2)

where NLC equals the normal loss of capital (a constant) and correction in capital CCAP equals the discrepancy between desired capital and current capital, divided by the time to correct the stock of capital TCSC (a constant):

\[ CCAP_t = \frac{DCAP_t - CAP_t}{TCSC} \]  

(2-3)

The first component of replacement orders corresponds to the normal rate of discard of worn-out or obsolete capital stock. The second component depresses replacement investment below the normal discard rate when desired capital is below actual capital. Recent empirical research has shown that the ratio of replacement investment to current capital fluctuates considerably over time (see Feldstein and Foot 1971 and Eisner 1972). The SDNM formulation allows the ratio of replacement investment to current capital to vary as a function of the correction in capital CCAP. Replacement investment will be a fixed proportion of current capital only when desired capital DCAP exceeds current capital CAP.
Expansion orders are determined by the correction in stock of capital CCAP, expected growth in sales EGS, and capital CAP:

\[ EO_t = \max (CCAP_t, 0) + CAP_t \cdot EGS_t \]  

(2-4)

Expected growth in sales EGS represents the perceived long-term growth trend in sales; EGS is measured as a fraction per year. Multiplication of EGS and CAP represents the growth in capital needed to prepare for the expected growth in shipments.

Orders for Supply-Line. The supply-line for capital SLC in the SDNM refers to the total volume of unfilled orders for capital. Figure 2-1 shows that the model distinguishes two categories of unfilled orders for capital: orders in planning for capital OPC and the backlog of unfilled orders for capital BC. Orders in planning subsumes the stages in the investment process from the inception of a proposed capital project to time when an order is placed for the desired capital acquisition. The parameter time for orders in planning TOP represents the average duration of the planning stages. Once an order is placed, it enters the backlog of unfilled orders for capital BC. Delivery delay for capital DDC represents the average duration between the time when an order is placed and the time when the ordered capital arrives.
Orders for supply-line depend on the desired supply-line for capital DSLS, the current supply-line for capital SLC, and the (constant) time to correct supply-line for capital TCSLC:

\[
O_{SL_t} = \frac{DSLC_t - SLC_t}{TCSLC_t} \tag{2-5}
\]

Equation (2-5) states that when the supply-line for capital SLC is below the desired supply line for capital DSLS, additional order starts are generated to adjust the supply line. As will be described below, one circumstance in which additional order starts increase to adjust the supply line for capital occurs when rising delays in acquiring capital force producers to order "further ahead" to achieve the desired rate of capital expansion. Conversely, SLC in excess of DSLS depresses order starts for capital to reduce the supply line for capital.

III. B DETAILS OF THE FORMULATION

Desired Capital. Desired capital in the SDNM investment function responds to two sets of pressures to adjust current capital stock--pressures to adjust capital to adjust output and pressures to adjust the capital-output ratio. The equation for desired capital DCAP is given below:

\[
DCAP_t = CAP_t \cdot PR_t \cdot PRCRC_t \tag{2-6}
\]
where PR is the production ratio and PRCRC is the perceived ratio of capital return to cost.

The production ratio PR represents pressures to adjust capital to adjust output. PR equals the ratio of desired output DOUT and potential production PP:

\[
PR_t = \frac{DOUT_t}{PP_t} \tag{2-7}
\]

when desired output DOUT exceeds potential production PP, PR rises above unity, creating pressure to expand capital. When DOUT is less than PP, PR is below unity, creating a pressure to contract capital.

Desired output in the SDNM depends upon average shipments ASHIP, the discrepancy between desired and actual inventory of output, and the discrepancy between desired and actual backlog of unfilled orders for output. The complete formulation for desired output is given by the following set of equations:

\[
DOUT_t = ASHIP_t + CI_t + CB_t \tag{2-8}
\]

\[
ASHIP_t = \text{smooth} (SHIP_t) \tag{2-9}
\]

\[
CI_t = (DIO_t - IO_t) / TCI \tag{2-10}
\]

\[
CB_t = (B_t - DB_t) / TCB \tag{2-11}
\]

\[
DIO_t = ASHIP_t \cdot DIC \tag{2-12}
\]

\[
DB_t = ASHIP_t \cdot DBC \tag{2-13}
\]
Equation (2-8) states that desired output DOUT equals the sum of average shipments ASHIP, the correction in inventory CI, and the correction in backlog CB. ASHIP is formed by exponentially smoothing shipments SHIP. \(^5\) CI equals the discrepancy between the desired inventory of output DIO and the inventory of output IO (i.e., desired and actual inventories of finished goods), divided by the time to correct inventory TCI (a constant.) CB equals the discrepancy between the backlog of unfilled orders for output B and the desired backlog of unfilled orders for output DB, divided by the time to correct backlog TCB (a constant.) To understand the desired output formulation, consider what happens when backlog B always equals desired backlog DB. If inventory IO now falls below desired inventory DIO, CI will be positive and desired output DOUT will rise above average shipments ASHIP to replenish inventory. If IO rises above DIO, DOUT will fall below ASHIP to allow the excess inventory to deplete. Similarly, if inventory always equals desired inventory, a surplus backlog (CB positive) causes DOUT to exceed ASHIP. Such a response is intended to raise inventory and shipments and thereby lower backlog towards its desired level.

\(^5\) ASHIP is the first of several smoothed or delayed variables in the SDNM formulation. In the SDNM, each delayed variable is formed by first-order exponential smoothing. Statistical support for this smoothing pattern, which corresponds to a geometrically declining lag distribution, will be examined in Chapter 3.
The desired inventory of output DIO and desired backlog of unfilled orders for output DB each depend on average shipments ASHIP (Equations 2-12, 2-13.) DIO equals the product of ASHIP and desired inventory coverage DIC (a constant.) DIC signifies the desired level of inventory measured as a fraction of ASHIP (DIC has the dimension of time—e.g., months or years.) DB equals the product of ASHIP and desired backlog coverage DBC. Equation (2-12) states that DIO rises with rising ASHIP; a higher volume of shipments requires a higher stock of inventory to insure smooth operation. Similarly, a higher volume of shipments increases DB, reflecting producer's desires to have a larger stock of unfilled orders to offset the higher rate at which orders are being filled. (Note that DBC corresponds to a desired delivery delay.)

The inventory and backlog corrections described above represent two key hypotheses in the SDNM investment function. The importance of output-inventory and backlog conditions has long been recognized in the micro-economic fields of production and employment planning, and inventory investment. For example, the well-known production-planning text by Holt et al. (1960) relates desired production to desired and actual levels of "net inventory," the number of units of inventory minus the number of units on back order. By explicit consideration of the costs of holding output inventories and order backlogs, they establish that the desired level of net inventory (desired levels of inventory and
backlog) depends on the rate of orders for output. When net inventory departs from its desired level, the firm incurs additional costs: 6

From (production) lot-size formulas it is shown that the optimal batch size and the optimal safety stock increase roughly as the square root of the order rate of the individual item. Thus the optimal aggregate inventory must increase with increased aggregate order rate... The total expected back orders corresponding to any given size of inventory must also increase with an increased aggregate order rate...

When actual net inventory deviates from the optimal net inventory, costs rise... The rise in costs as net inventory declines (below optimal net inventory) can be estimated by costing the increased number of machine setups, the increased back orders, and the decreased inventory. A similar cost calculation can be made for the situation in which net inventory is above the optimal level. 7 (Holt et. al. 1960, pp. 56-57)

In the analysis of Holt et. al., the motive of cost minimization leads firms to adjust production in response to departures of net inventory from desired net inventory:

If net inventory at the end of the previous month is large (relative to the optimum),...production will be decreased in order to lower inventory. Similarly, if initial net inventory is small,...an increase in production will be called for. (Holt et.al. 1960, pp. 61)

6 For additional treatments of the reasons for holding inventories and backlogs and the costs of deviating from desired levels of inventories and backlogs, see Childs (1967), Belsley (1969) and Mack (1967).

7 The square-root relation between desired net inventory and order rate suggests that desired inventory coverage DIC and desired backlog coverage DBC in the SDNM formulation (Equations 2-12 and 2-13) should be functions of the levels of output inventory and backlog. This possible revision in the formulation has not been explored to date.
More recent studies of industry production behavior likewise accord central roles to output-inventory and backlog. For example, Belsley (1969) argues that the cost minimizing concerns of the firm justify explicitly incorporating output-inventory and backlog terms into equations for planned production for aggregate industries. Similarly, Lovell (1961) and Courchene (1966) both include backlogs of unfilled orders as influences on inventory investment at the aggregate industry level.

The SDNM investment function extends the production-planning motives cited above to longer-term decisions of capital acquisition. Within the SDNM production sector, pressures to adjust output to correct inventory or backlog imbalances simultaneously affect capacity utilization and acquisition of all factors of production. The hypothesized effect of inventory and backlog corrections on desired capital represents the readiness of individual entrepreneurs to adjust capital if adjustments in capacity utilization and labor prove inadequate to accomplish desired levels of output inventory and backlog. When viewed from the standpoint of an aggregate production sector, persistent low inventories or high order backlogs provide real-life indicators for potential new firms of unmet demand. Because the creation of new firms

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8 In the model, the time to correct labor is much shorter than the time to correct stock of capital TC SL (Equation 2-3), implying that hiring and firing responds more rapidly than investment to CI and CB.
usually entails capital investment, inventory and backlog corrections seem particularly important influences on investment in an aggregate production sector. 9

Equation (2-6) states that DCAP in the SDNM formulation responds to the production ratio PR, the ratio of DOUT and potential production PP (Equation 2-7). Potential production PP equals the production rate which could be generated if all factors of production were normally utilized. In the full SDNM production sector, potential production is determined by a Cobb-Douglas production function involving the maximum stocks of all productive factors available to generate output. For example, if labor L and capital CAP were the only factors of production, potential production would be determined as follows:

$$PP_t = NPROD \cdot (L_t/\text{NL})^{EL} \cdot (\text{CAP_t/NCAP})^{EC} \quad (2-14)$$

Note that CI and CB can alternatively be interpreted as pressures to maintain desired inventory and backlog coverages. For example, CB is equivalent to a pressure to adjust capital due to imbalances between the actual and desired delivery delay for output, as can be seen by rewriting Equation (2-11) as follows:

$$CB_t = \frac{\text{ASHIP}_t \cdot (BC_t - DBC)}{\text{TCB}}$$

where backlog coverage -- $BC_t = \frac{B_t}{\text{ASHIP}_t}$ -- is approximately equivalent to delivery delay ( $DD_t = \frac{B_t}{\text{SHIP}_t}$ ) and DBC corresponds to a desired delivery delay. Hence, the above equation implies that a delivery delay longer than the desired delivery delay creates pressure to expand capital.
where NPROD equals normal production—the rate of production achieved when labor equals normal labor NL and capital equals normal capital NCAP—and EL and EC are the exponents for labor and capital in the Cobb-Douglas production function.

To see the implications of determining the production ratio PR as a function of potential production PP, consider an alternative formulation of PR as a ratio of desired output DOUT to production PROD (the following section will show that such a formulation is implicit in the neoclassical investment function):

\[ PR' = \frac{DOUT}{PROD} \]  

(2-15)

Assume DOUT initially equals PROD, then rises above PROD. If the increased DOUT is met by increased capacity utilization as well as increased desired stocks of productive factors, PR' may quickly readjust downward due to increased utilization. Hence, Equation (2-15) implies that increased capacity utilization will immediately reduce desired capital. Exactly the opposite reaction has been found in investment functions which explicitly incorporate capacity utilization (For example, see Meyer and Glauber 1964). By contrast, in the SDNM formulation for the production ratio PR (Equation 2-7), increases in production due to increased capacity utilization will not immediately
reduce desired capital.\textsuperscript{10}

The second set of pressures to which desired capital DCAP responds in the SDNM investment function are pressures to adjust the capital-output ratio. The perceived ratio of capital return to cost PR\textsubscript{CRC} represents pressures to adjust capital to adjust the capital-output ratio. PR\textsubscript{CRC} is formed as an exponentially-smoothed value of the ratio of capital return to cost RC\textsubscript{RC}:

\[
\text{PR\textsubscript{CRC}} = \text{smooth (RC\textsubscript{RC})}
\]

The ratio of capital return to cost RC\textsubscript{RC} provides a measure of the extent to which capital should be expanded or contracted to obtain the optimal (cost-minimizing) capital-output ratio. When RC\textsubscript{RC} exceeds unity, production costs can be reduced by increasing the capital-output ratio. When RC\textsubscript{RC} is below unity, production costs can be reduced by decreasing the capital-output ratio. RC\textsubscript{RC} equals the marginal revenue product of capital divided by the marginal cost of capital:

\textsuperscript{10} One can interpret the SDNM formulation for PR as implicitly including capacity utilization as a determinant of DCAP by replacing PP by \( \text{PROD}_t/(U_t/\text{NU}) \) in Equation (2-7), where \( U_t \) represents actual capacity utilization (measured as a fraction; --1.00 equals full utilization) and NU represents normal capacity utilization. If this were done, DCAP would vary directly with U and inversely with PROD and increases in PROD due to increases in U would not alter DCAP.
\[ RCRC_t = \left( \frac{\partial^{\text{PROD}}}{\partial^{\text{CAP}}} \right) \cdot MR_t / CCS_t \]  

(2-17)

The numerator in Equation (2-17), the marginal product of capital \( \frac{\partial^{\text{PROD}}}{\partial^{\text{CAP}}} \) times the marginal revenue MR, represents the dollar value of additional output derived from adding a unit of capital. The denominator in Equation (2-17), the cost of capital services CCS, represents the cost of acquiring an additional unit of capital. For the Cobb-Douglas production function assumed in the SDNM, the marginal product of capital can be expressed as a function of the current stock of capital CAP, the current production PROD, and the exponent for capital in the production function EC (the elasticity of output with respect to capital):

\[ \frac{\partial^{\text{PROD}}}{\partial^{\text{CAP}}} = \frac{EC \cdot PROD_t}{CAP_t} \]  

(2-18)

For the present study, the cost of capital services, often termed the rental price of capital, is given by the following equation:

\[ CCS_t = PCAP \cdot (NLC + r) \]  

(2-19)

where PCAP is the price of capital, NLC is the normal loss of capital (see Equation 2-2), and r is an interest rate appropriate for measuring
the "opportunity cost" of investing in capital stock.\textsuperscript{11}

The delay in forming perceived ratio of capital return to cost
PRCRC represents the third key hypothesis embodied in the SDNM investment
function. The delay in forming PRCRC reflects the imperfect information
upon which decisions to adjust capital-output ratio must be made.
Producers rarely if ever know the optimal mix of productive factors with
certainty. Uncertainty about future relative prices makes the future
optimal factor mix still more uncertain. In general, managers must rely
on diverse indicators--such as trends in relative prices, work stoppages,
overtime shifts, lower production costs operating with different factor
intensities on a limited scale, or competitors' factor mixes--to
ascertain that current factor proportions should be shifted in a
particular direction. Moreover, such indicators may arise only after

\textsuperscript{11} Equation (2-19) simplifies the more complex formula for the rental
price of capital derived by Hall and Jorgenson (1967):
\[ CCS = \frac{1 - k - uz}{1 - u} \cdot q \cdot (r + \delta) \]

where q is an investment goods price deflator, $\delta$ is the rate of
replacement of capital stock, r is the opportunity cost of capital, u is
the corporate tax rate, z is the discounted value of depreciation
allowances allowed for tax purposes, and k is the investment tax credit.
The present study employs the simplified formula for CCS for estimation
and simulation because no provisions exist for generating k, u, and z in
the SDNM. The effects of expected changes in the price of capital are
also omitted in the present study, although they will probably be
included in future versions of the SDNM investment function.
nonoptimal conditions have existed for some time and may have to recur before managers begin to believe that a change in current factor proportions is warranted. Once a perception develops that current factor proportions should be shifted in a particular direction, producers may still delay in doing so. Substantial shifts in capital-output ratio usually entail new types of capital equipment. Producers may delay in acquiring new types of capital, both due to possible disruptions in current production activities and caution in making a long-term commitment to new production technologies.

The SDNM investment function attempts to capture the perception and reaction delays in responding to nonoptimal factor proportions by the delay in forming PRCRC. The investment functions developed by Bischoff (1968, 1969, 1971a, b) and Ando et. al. (1974) embody a similar delay. For example, Bischoff distinguishes the response of investment to a change in desired output (which is equivalent to a change in output in his formulation) from the response to changes in optimal capital-output ratio (represented by changes in the ratio of price of output to the rental price of capital c):

A rise in output sets off a temporary boom in investment which then tapers off. No such temporary boom occurs in response to a change in any of the variables captures in the p/c term...(Bischoff 1971b, p. 23)

He argues that investment responds more slowly to incentives to adjust the capital-output ratio because firms
...respond to a change in output prices relative to the rental price of capital by changing the capital intensity not of the entire (capital) stock but only of new net or replacement capacity put into place. This model is derived from an assumption about technology: Factor proportions are assumed to be variable only up to the point that new capacity is put into place\(^{12}\) ...(Bischoff 1971b, p. 22-23)

Expected Growth in Shipments. Equation (2-4) shows that expansion orders \(EO\) in the SDNM investment function respond to expected growth in shipments \(EGS\), as well as to the (positive) discrepancies between desired capital and capital. In the SDNM, \(EGS\) represents expected fractional growth in shipments. \(EGS\) is determined as a function of two exponential averages, short-term average shipments \(STASHIP\) and long-term average shipments \(LTASHIP\), and a parameter, the time for long-term averaging of shipments \(TLTAS\):

\[
EGS_t = \frac{STASHIP_t - LTASHIP_t}{TLTAS\cdot LTASHIP_t} \quad (2-20)
\]

\(STASHIP\) is formed by exponentially smoothing shipment \(SHIP\); \(LTASHIP\) is formed by exponentially smoothing \(STASHIP\). The averaging time (time constant) in forming \(STASHIP\) is much shorter than the averaging time in forming \(LTASHIP\) (a priori values of .5 and 4.5 years, respectively); the

\(^{12}\) The type of investment function described by Bischoff is frequently termed a "putty-clay" investment function because it assumes that factor proportions are freely variable—like "putty"—before new capital equipment is installed, but fixed—like "clay"—once capital is in place.
time for long-term averaging of shipments TLTAS equals the averaging time in forming LTASHIP. Equation (2-20) measures the trend in shipments as follows. The numerator in Equation (2-20) gives the total rise or fall in STASHIP relative to LTASHIP. Division by LTASHIP converts the change in STASHIP into a fractional change. Division by TLTAS converts the fractional change into a fractional rate of change—that is, a growth trend.\textsuperscript{13}

The hypothesized effect of expected growth in shipments EGS on investment represents the fourth SDNM investment hypothesis. The hypothesis seems to be justified on several grounds. For the individual firm, historic trends in sales growth represent important inputs to capacity planning. If a firm ignores information on historic growth trends, it will likely find itself in a position of perpetually inadequate productive capacity (see Chapter 4.) Similar reasoning leads Holt et al. to view trend detection as a central element in production planning (see Holt, et. al. 1960, pp. 131, 132, 134-8), and lead to the incorporation of sales or order expectations in most production planning models (for example, see Belsley 1969). In an aggregate sector, perceived growth opportunities may be a primary condition for new firms

\textsuperscript{13} Note that EGS as formulated in Equation (2-20) is designed to detect exponential trends in shipments. Detection of other types of trends in shipments—such as cyclic trends—would require alternative formulations.
entering an industry, or for established firms expanding into a new market.

A second subtler set of pressures associated with growth expectations concern the propagation of optimism or pessimism in an aggregate production sector. Wesley Mitchell (1927, 1941) hypothesizes that "emotional influences" have played an important part in responding to and shaping expected growth rates. He describes the cumulative rise of optimism as follows:

Once started, a revival of activity spreads rapidly over a large part, if not all, of the field of business. For, even when the first impulse toward expansion is sharply confined to a single industry or a single locality, its effects in the restricted field stimulate activity elsewhere...

The diffusion of activity is not confined to these definite lines of interconnection among business enterprises. It proceeds also by engendering an optimistic bias in the calculations of all persons concerned with the active direction of business enterprises and with providing loans.

Virtually all business problems involve elements that are not precisely known, but must be approximately estimated even for the present, and forecast still more roughly for the future. Probabilities take the place of certainties, both among the data upon which reasoning proceeds and among the conclusions at which it arrives. This fact gives hopeful or despondent moods a large share in shaping business decisions...

Therefore, when the first beneficiaries of a trade revival develop a cheerful frame of mind about the business outlook, they become centers of infection, and start an epidemic of optimism. Perhaps the buoyancy of a grocer gives a lumber dealer no adequate reason for altering his conservative attitude toward the business projects upon which he must pass. Yet, in despite of logic, he will be the readier to buy if his acquaintances in any line of trade have become aggressively confident of the future. The fundamental conditions affecting his own business may remain the same; but his conduct is altered because he sees the old facts in a new emotional perspective.

As it spreads, the epidemic of optimism helps to produce conditions that both justify and intensify it. The mere fact that a growing number of businessmen are gaining confidence in the outlook becomes a valid reason why each member of the group
and outsiders also should feel confident. For the hopeful mood means greater readiness to made new purchases, enter into new contracts, etc.—in fine, means that the incipient revival of activity will be supported and extended. There is the stronger reason for relying upon the feeling in that its growth—like the growth in the volume of goods ordered—is cumulative. (Mitchell 1941, pp. 3–6)

The SDNM investment function attempts to capture the effects of waves of optimism and pessimism by explicit inclusion of the expected growth in shipments, changes in which appear instrumental in stimulating such waves.\(^4\)

**Desired Supply Line for Capital.** Equation (2–1) shows that order starts for capital OSL in the SDNM investment function includes orders for the supply line OSL. Orders for the supply line OSL stem from discrepancies between the desired supply line for capital DSLC and the supply line for capital SLC (Equation 2–5.) Desired supply line for capital DSLC depends on the order reference for the supply line for capital ORSLC and the perceived delay in the supply line for capital PDSL.

\(^4\) It should be noted that other types of expectations may also be important in understanding movements in capital investment. In particular, expectations of changes in relative factor prices and technological advance may be significant during certain historical periods. Such expectations might interact with expected growth in shipments in future versions of the SDNM incorporating endogenous technological progress (see Forrester, Mass and Ryan 1976). Ando et. al. (1974) formulate an investment function incorporating such expectations, but do not consider expected growth in sales. Jorgenson (1977) gives a contemporary illustration of the possible importance of expected trends in relative prices by suggesting that rising energy prices may reduce future capital intensity.
\[ \text{DSLC}_t = \text{ORSLC}_t \cdot \text{PDSLQ}_t \]  

(2-21)

Order reference for supply line for capital ORSLC reflects the rate at which the sector wants to acquire capital on a continuing basis. The continuing rate of capital acquisition is represented by the sum of replacement orders for capital, NLC·CAP, plus the capital acquisition needed to prepare for expected growth in shipments EGS:

\[ \text{ORSLC}_t = \text{NLC} \cdot \text{CAP}_t + \text{CAP} \cdot \text{EGS}_t \]  

(2-22)

Equation (2-22) implies that ORSLC does not respond to the components of capital ordering intended to correct the stock of capital and the supply line for capital. (Note that ORSLC equals OSC \( - \) CCAP \( - \) OSL). To see why ORSLC does not respond to ordering to correct the stock or supply line for capital, consider the response of the SDNM formulation to a step increase in DCAP. Assume that DCAP initially equals CAP and DSLC initially equals SLC. When DCAP increases, OSC rises. As the additional order starts flow into the level of orders in planning for capital, the resulting increase in the supply line for capital SLC leads to a reduction in OSC (Equation 2-5). This reduction, or negative supply line correction, corresponds to that portion of the desired capital expansion already in planning. No further order starts need be generated.
for new capital already in planning. However, if ORSLC increased with
the increase in DCAP, DSLC would increase (Equation 2-21), and the sector
would not reduce OSC to compensate for capital already in planning. If
ORSLC responded to changes in DSLC, a positive feedback loop would exist
in which an increase in DSLC would lead to increase in ORSLC and further
increase in DSLC. Such behavior is unrealistic because it implies that,
for every capital plan generated in response to increase in DCAP or DSLC,
producers generate additional plans, even if the perceived delay in
acquiring capital remains constant. The unrealism of such behavior
suggests that ORSLC does not respond to capital ordering to correct
discrepancies in the stock or supply-line of capital.

The perceived delay in the supply line for capital PDSLc equals
the sum of the perceived delivery delay for capital PDDC and the time for
orders in planning TOP (a constant):

\[ PDSLc_t = PDDC_t + TOP \]  

(Equation 2-23)

Equation (2-23) indicates that, as PDSLc lengthens, desired supply line
for capital DSLC increases. That is, when the delays involved in
acquiring new capital lengthen, the desired supply line for capital DSLC
increases to reflect the need to order "further ahead" to achieve the
desired rate of capital acquisition (ORSLC). Perceived delivery delay
for capital PDDC equals an exponential smoothing of past values of
delivery delay for capital DDC:
\[ PDDC_t = \text{smooth} \ (DDC_t) \]  

The supply-line correction represents the fifth key hypothesis embodied in the SDNM investment function. The supply line correction reflects two aspects of investment planning not captured elsewhere in the investment function. First is the knowledge of capital projects already in planning or on order. Investors know that capital acquisitions take time to realize. They are aware of current projects in planning and on order and take this information into account in generating new order starts. If no such awareness existed, investors would continue to generate plans for factories already under construction, or appropriate funds for equipment already financed and on order.

The second aspect of investment planning reflected in the supply line correction is a response to changes in the delivery delay for capital. When the perceived delivery delay for capital lengthens, producers are assumed to order capital "further ahead"—that is, to increase their desired volume of capital in planning and on order to compensate for the longer lead time in acquiring capital. Conversely, if delays in acquiring capital decline, producers are assumed to cut-back ordering to ensure that capital arrivals do not exceed the desired rate of capital acquisition. Therefore, the hypothesized influence of perceived delay in the supply line for capital PDSL on the desired supply line DSLC and capital ordering stems from the assumption that
producers have a desired rate of capital acquisition and adjust the supply line for capital to ensure receiving capital at the desired rate.

Though the hypothesis of a supply line correction appears novel to investment function specification, several writers have described supply line management in different contexts. For example, Thomas Mitchell described the following response of retailers to a rise in delivery delay as follows:

Retailers find that there is a shortage of merchandise at their sources of supply. Manufacturers inform them that it is with great regret that they are able to fill their orders only to the extent of 80 percent;...retailers, having been disappointed in deliveries and lost 20 percent or more of their possible profits thereby, are not going to be caught that way again. During the season they have tried with little success to obtain supplies from other sources. But next season, it they want 90 units of an article, they order 100, so as to be sure, each, of getting the 90 in the pro rata share delivered. Hence they increase the margins of their orders over what they desire. in order that their pro rata shares shall be for each the full 100 per cent that he really wants. Furthermore, to make doubly sure, each merchant spreads his orders over more sources of supply. (Mitchell 1923, pp. 645)

Similarly, Belsley notes a similar response of the customers for an industry's output:

...as the economy in general or the relevant industry in particular approaches full employment or capacity limitations, the resulting lengthening of delivery time would presumably result in multiple ordering by the buying firms. (Belsley 1969, p. 47n)

Recently many other writers in the production-planning and inventory investment fields have identified similar supply line management practices (for example, see Childs 1967, Mack 1967).
The supply line correction incorporated into the SDNM investment function assumes the practice of supply line management for firms ordering capital equipment. Producers placing orders for new capital face a problem analogous to the problem faced by any firm placing orders for an inventory. Producers cannot directly control the rate at which they acquire capital; they can only adjust the rate at which they place orders for new capital. The need to adjust ordering to attain a desired rate of capital acquisition requires that producers manage the supply line of unfilled orders for capital as well as the capital stock.
III.C. EXPRESSING THE SDNM FORMULATION FOR ESTIMATION.

For statistical estimation, it is useful to combine the above equations to express order starts for capital OSC as a function of measurable variables:

$$\text{OSC}_t = \text{EO}_t + \text{RO}_t + \text{OSL}_t$$

Equation 2-1 (repeated)

$$\frac{\text{DCAP}_t - \text{CAP}_t}{\text{TCSC}} + \text{CAP}_t \cdot \text{EGS}_t + \text{CAP}_t \cdot \text{NLC}_t + \frac{\text{DSLC}_t - \text{SLC}_t}{\text{TCSLC}}$$

$$= \frac{1}{\text{TCSC}} \left( \text{CAP}_t \cdot \text{PR}_t \cdot \text{PRCRC}_t \right) + \left( \text{NLC}_t - \frac{1}{\text{TCSC}} \right) \cdot \text{CAP}_t + \text{CAP}_t \cdot \text{EGS}_t$$

$$+ \frac{1}{\text{TCSLC}} \cdot \left( \text{ORSL}_t \cdot \text{PDSL}_t - \text{SLC}_t \right)$$

$$\text{OSC}_t = \frac{1}{\text{TCSC}} \cdot \left( 1 + \frac{\text{DIC} - \text{DBC}}{\text{TCIB}} \right) \cdot \text{CAP}_t \cdot \left( \frac{\text{ASHIP}_t}{\text{PP}_t} \right) \cdot \text{PRCRC}_t$$

$$+ \frac{1}{\text{TCSC}} \cdot \frac{1}{\text{TCIB}} \cdot \text{CAP}_t \cdot \left( \frac{\text{B}_t - \text{IO}_t}{\text{PP}_t} \right) \cdot \text{PRCRC}_t$$

$$+ \left( \text{NLC}_t - \frac{1}{\text{TCSC}} \right) \cdot \text{CAP}_t + \text{CAP}_t \cdot \text{EGS}_t$$

$$+ \frac{1}{\text{TCSLC}} \cdot \left( \text{CAP}_t \cdot \left( \text{NLC} + \text{EGS}_t \right) \cdot \text{PDSL}_t - \text{SLC}_t \right)$$

(2-26)

where

$$\text{ASHIP}_t = \text{smooth} \left( \text{SHIP}_t \right)$$

$$\text{PRCRC}_t = \text{smooth} \left( \text{RCRC}_t \right)$$

$$\text{STASHIP} = \text{LTASHIP} - \text{LTASHIP}$$

$$\text{EGS}_t = \frac{\text{STASHIP}}{\text{TLTAS} \cdot \text{LTASHIP}_t}$$

$$\text{STASHIP} = \text{smooth} \left( \text{SHIP} \right)$$

$$\text{LTASHIP} = \text{smooth} \left( \text{STASHIP} \right)$$
\[ PDSL C_t = PDDC_t + TOP. \]
\[ PDDC_t = \text{smooth} (DDC_t) \]

Equation (2-26) represents the full SDNM investment function for the present study.\(^{15}\) For estimation, the nonlinear combinations of parameters appearing in Equation (2-26) will be replaced by coefficients to be estimated; the "delayed variables," such as average shipments ASHIP, are replaced by distributed lags of the respective underlying variable, such as shipment SHIP.\(^{16}\) When the investment function is simulated, it is represented by Equations (2-1) through (2-24), and all delayed variables are formed by exponential smoothing.

\(^{15}\) Note that, in Equation (2-26), the parameters TCI and TCB are replaced by the parameter time to correct inventory and backlog TCIB. TCIB replaces TCI and TCB to facilitate statistical estimation by reducing the number of parameters to be estimated. (In general, data for inventory of output and backlog of unfilled orders for output are too poor to permit separate estimates of TCI and TCB.) The change is equivalent to assuming that TCI and TCB are equal—an assumption which has negligible impact on behavior of the consumer-goods sector model in the present analysis.

\(^{16}\) That is, \( ASHIP_t = \sum_i w_i SHIP_{t-i} \), where \( \sum_i w_i = 1 \).
IV. THE NEOCLASSICAL INVESTMENT FUNCTION

The preceding section has presented the equations for the SDNM investment function and identified the central hypotheses in the formulation. This section presents the equations for the neoclassical investment function and compares the two investment functions. The presentation shows that the neoclassical formulation for desired capital can be derived from the SDNM formulation for desired capital by omitting three SDNM investment hypotheses and by making additional simplifying assumption. The neoclassical formulation for the relation between desired capital and investment expenditures likewise omits two hypotheses included in the SDNM formulation.

IV.A DESIRED CAPITAL

The neoclassical investment function treats desired capital DCAP as a function of output OUT, price of output $p$, rental price of capital services $c$, and the (assumed constant) elasticity of output with respect to capital $\alpha$:

$$DCAP_t = \alpha \cdot \frac{p \cdot OUT_t}{c_t}$$  \hspace{1cm} (2-27)

The above formulation for desired capital can be derived by maximizing the firm's discounted present value subject to the constraints that (1) the rate of change of capital equals investment less depreciation (assumed to be a constant proportion of current capital), and (2) the
production function has constant output elasticities with respect to factors of production (see Jorgenson 1963).

The neoclassical formulation for desired capital can be derived from the SDNM formulation for desired capital by assuming that:

1. inventory of output equals desired inventory,
2. backlog of unfilled orders for output equals desired backlog,
3. average shipments equals output,
4. potential production equals production (constant capacity utilization), and
5. delay in forming the perceived ratio of capital return to cost PRCRC can be ignored.

This can be shown by combining Equations (2-6), (2-7), (2-8), (2-10), (2-11), (2-17), and (2-18):

\[
\text{DCAP} = \text{CAP}_t \cdot \text{PR}_t \cdot \text{PRCRC}_t
\]

\[
= \text{CAP}_t \cdot \left( \text{ASHIP}_t + \frac{(\text{DIO}_t - \text{IO}_t)}{\text{TCl}_t} - \frac{(B_t - DB_t)}{\text{TCB}_t} \right)/\text{PP}_t \cdot \text{PRCRC}_t \quad (2-28)
\]

\[
= \text{CAP}_t \cdot \left( \text{ASHIP}_t/\text{PROD}_t \right) \cdot \frac{\text{EC} \cdot \text{PROD}_t \cdot \text{MR}}{\text{CAP}_t \cdot \text{CCS}_t} \quad (2-29)
\]

\[
= \text{OUT}_t \cdot \frac{\text{EC} \cdot \text{MR}_t}{\text{CCS}_t} \quad (2-30)
\]
Equation (2-30) matches the neoclassical formulation for DCAP in Equation (2-27). The output elasticity $a$ in the neoclassical formulation equals the exponent for capital EC in the Cobb-Douglas production function used in the SDNM. Marginal revenue MR in the SDNM equals the price of output $p$. Lastly, Jorgenson's rental price of capital services $c$ corresponds to the cost of capital services CCS employed in the SDNM formulation, though the present study employs a simplified definition of the rental price for each investment function (see footnote 11 above). Equation (2-30) is derived from Equation (2-28) in two steps. Equation (2-29) omits the backlog and inventory corrections and the delay in forming perceived ratio of capital return to cost PRCRC. Equation (2-30) replaces output for average shipments.

IV.B RELATION BETWEEN DESIRED STOCK OF CAPITAL AND INVESTMENT ACTIVITY.

The neoclassical investment function expresses investment expenditures $I_t$ as a distributed lag function of changes in desired capital DCAP:

$$(I_t - \delta \cdot \text{CAP}_t) = \mu(\theta) \cdot (\text{DCAP}_t - \text{DCAP}_{t-1}) \quad (2-31)$$

where $\delta$ equals the fractional discard rate of capital (assumed constant) and $\mu(\theta)$ is a power function of the lag operator $\theta$.\textsuperscript{17} Jorgenson

\textsuperscript{17} $\theta^i \cdot x_t = x_{t-i}$
derives the above formulation by taking first differences of both sides of the equation

\[ \text{CAP}_t = \mu(\Theta) \cdot \text{DCAP}_t \]  \hspace{1cm} (2-32)

and noting that

\[ \Delta \text{CAP}_t = I - \delta \cdot \text{CAP}_t \]  \hspace{1cm} (2-33)

Prior to Jorgenson's work, investment functions which had been fitted to historical data (e.g., see Chenery 1952 and Koyck 1954) had often assumed \( \mu(\Theta) \) to be a geometrically-declining series. Jorgenson proposed a more general lag distribution, the rational lag \( \mu_R(\Theta) \), and estimated the following form of Equation (2-31):

\[ \mu_R(\Theta) = \frac{\gamma(\Theta)}{\omega(\Theta)} \]  \hspace{1cm} (2-34)

\[ \omega(\Theta) \cdot (I_t - \delta \cdot \text{CAP}_t) = \gamma(\Theta) \cdot (\text{DCAP}_t - \text{DCAP}_{t-1}) \]  \hspace{1cm} (2-35)
Before the neoclassical and SDNM formulations for the relation between desired capital and investment activity can be contrasted, both must be expressed with the same dependent variable. The SDNM formulation (Equation 2-26) explains movements in order starts for capital OSC; the neoclassical formulation explains movements in expenditures I. Several considerations suggest that order starts is the appropriate dependent variable. First, the order starts or appropriations decision corresponds more closely to the key decision point in the investment process. The order starts decision represents the point at which a commitment is made to an investment project. After this point, plans can still be cancelled if management decides against a project or financing becomes unavailable; but cancellations are relatively infrequent.\textsuperscript{18}

Use of order starts as the dependent variable also facilitates identification of the separate perception and reaction delays underlying investment decision making. When expenditures are taken as the dependent variable, the perception and reaction delays influencing order starts tend to be lumped together with the delays in planning and obtaining new plant and equipment. Such compression of conceptually distinguishable delays reduces a priori understanding of the formulation and limits the

\textsuperscript{18}The Conference Board's capital appropriations data employed in Chapter 3 suggest that, on the average, less than 2\% of unspent appropriations are cancelled each quarter.
Interpretability of estimation results.\textsuperscript{19}

Equally important is the misspecification implied by treating investment expenditures as a time-invariant distributed lag of changes in DCAP. The neoclassical lag distribution is inherently misspecified because it subsumes the delivery delay for capital. Examination of industry data suggests that the average delays in obtaining new capital can vary by as much as 50\% to 75\% over a business cycle.\textsuperscript{20} Such variation suggests significantly time varying weights for the expenditures lag distribution in the neoclassical investment function.\textsuperscript{21}

\textsuperscript{19}Recent investment studies concerned with the multiple delays underlying investment decisions have likewise focused on order starts or appropriations as the dependent variable. For example, see Ando, et. al. 1974.

\textsuperscript{20}Data for the delay in filling capital appropriations for total durable manufacturing, constructed along lines described in Appendix C.

\textsuperscript{21}Similar problems arise for the many econometric models which treat expenditures as a time-invariant lag distribution of past appropriations (e.g., see Almon 1965). Ando et. al. (1974) compensate for variation in the delivery delay for capital by making the lag weights in the expenditures lag distribution explicit functions of the delivery delay for capital. In the SDNM, arrivals of capital is treated explicitly as a function of backlog of unfilled orders for capital and the delivery delay for capital; hence, the SDNM makes no assumptions of a constant delivery delay for capital.
To compare the SDNM and neoclassical formulations for the relation between desired stock of capital and investment activity, it is convenient to recast the neoclassical investment function with order starts for capital as the dependent variable. Empirical results with the neoclassical formulation expressed in Equation (2-35) suggest that a neoclassical formulation for order starts can be cast in the simple stock adjustment mold: 22

$$OS_{t} = k(\text{DCAP}_{t} - \text{CAP}_{t}) + \delta \cdot \text{CAP}_{t}$$ (2-36)

Equation (2-36) can be derived from the SDNM formulation for the relation between desired capital and order starts (Equation 2-25) by assuming that:

(1) The supply line of unfilled orders for capital equals the desired supply line, and

(2) expected growth in sales equals zero.

The above discussion has shown that the neoclassical formulation for the relation between DCAP and investment activity can be viewed as a

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22 Jorgenson and Stephenson (1967b) show that the lag between changes in desired capital and changes in capital is consistently "bell-shaped" for a wide variety of industries. Because such a lag shape arises from the convolution of two or more geometrically declining lags (see Griliches 1967 or Forrester 1961, Appendix H), the simple stock adjustment formulation, together with the delays embodied in orders in planning and backlog of unfilled orders for capital, gives behavior consistent with Jorgenson and Stephenson's empirical results.
special case of the SDNM formulation if the neoclassical formulation is recast with order starts for capital as the dependent variable. Moreover, the discussion illuminated several reasons why order starts is a superior dependent variable for studying investment-function specification.

IV.C SUMMARY OF DIFFERENCES IN SDNM AND NEOCLASSICAL INVESTMENT FUNCTIONS

The above analysis has shown that the SDNM investment function provides a more general theory of the determinants of capital investment than is provided by the neoclassical investment function. The neoclassical formulation for desired capital DCAP can be derived from the SDNM formulation for DCAP by omitting the hypothesized inventory correction, backlog correction, and delay in forming perceived ratio of capital return to cost in the SDNM, and by replacing potential production and average shipments by actual production. If the neoclassical formulation for the response of capital investment to changes in desired capital is expressed with order starts for capital as the dependent variable, the resulting equation for order starts can be derived from the corresponding SDNM formulation by omitting the hypothesized supply-line correction and effect of expected growth in shipments included in the SDNM.
V. THE INFLUENCE OF SYSTEM DYNAMICS MODELING PRINCIPLES ON INVESTMENT-FUNCTION SPECIFICATION

The preceding section has shown that the SDNM investment function provides a more general theory of the determinants of capital investment. Before examining the benefits of the more general SDNM formulation for accounting for observed investment activity and understanding investment dynamics, it is useful to understand why the SDNM and neoclassical formulations differ. The answer lies in modeling principles embodied in the System Dynamics methodology (see Forrester 1961). This section briefly traces how two system dynamics modeling principles give rise to the features of the SDNM investment function that distinguish it from the neoclassical investment function.

V.A. EXPlicit REPRESENTATION OF REAL-LIFE STOCKS AND FLOWS

A key principle in system dynamics is that dynamic behavior arises out of the accumulation of flows in stock or level variables. Because of their importance in understanding the source of dynamic behavior, system dynamics models strive to include all relevant stock and flow variables and to preserve real-life relations between stocks and flows. So, for example, orders in planning for capital, backlog of unfilled orders for capital, and capital stock, along with the flows which interconnect these stocks receive explicit treatment in the SDNM. Specification of the policies controlling flow rates then becomes a
primary focus of the modeling process. Against this backdrop of explicit
stocks and flows one quickly recognizes key flow variables. For example,
in the process of capital ordering, order starts is the first of a series
of flows in the ordering stream (the succeeding flows in the SDNM are
orders placed, and arrivals of capital.) As the first flow in the
stream, order starts, not orders placed or arrivals of capital (or
investment expenditures) represents the key decision point in acquiring
new capital.

Explicit representation of system stocks also leads one to
recognize discrepancies between desired and actual levels of stock
variables which may influence decisions. Recognition of the possible
influence of output-inventory and backlog imbalances on capital ordering,
as well as the need to maintain a desired supply line of unfilled orders
for capital, follows from explicit representation of stock and flow
variables.\textsuperscript{23}

\textbf{V.B. FLOW-RATE INPUTS MUST BE INFORMATION ACTUALLY AVAILABLE TO DECISION
MAKERS}

In a system dynamics model, an available-information principle
guides formulation of equations intended to portray real policies. In
constructing a system dynamics model, one examines each variable
hypothesized to determine a flow rate from the standpoint of whether or

\textsuperscript{23}Mass 1976b discusses in detail implications of explicit treatment of
stock variables in understanding economic dynamics.
not the information represented by the variable is actually available to decision makers at that point in the system. For example, output-inventory and backlog discrepancies provide real-life measures of relative supply and demand. That is, inventory and backlog discrepancies correspond to information actually available to decision makers. By contrast economic models often assume perfect knowledge of flow measures of supply and demand which cannot be known with certainty by decision makers.

The principle that decision-points in a model can only have as inputs information available to decision makers also leads to the many individual perception delays included in the SDNM investment function. In particular, the principle leads to the hypothesis that desired capital responds only gradually to departures from the optimal mix of productive factors. As discussed in Section III.B, the delay in forming perceived ratio of capital return to cost PRCRC reflects the diverse and highly uncertain indicators which influence decisions to alter capital-output ratios. By contrast, the neoclassical formulation for desired capital implies that producers have perfect knowledge of the optimal cost-minimizing factor mix (ie., the delay in forming perceived ratio of capital return to cost is negligible.)\textsuperscript{24}

\textsuperscript{24} In the literature, one often finds desired capital in the neoclassical formulation interpreted as an implicit goal toward which capital gradually adjusts. Such a view of desired capital would not be acceptable in a system dynamics model because it violates the principle that inputs to decision points in a model must be information actually available to decision makers.
IV.C SUMMARY

The distinctions in underlying approach for the SDNM and neoclassical investment functions can be summarized by the relative emphasis on representing the actual processes by which investment behavior arises. In the SDNM, the available information principle leads to explicit representation of perception and reaction delays and thereby aids in describing how information on system conditions is eventually converted into investment decisions. Explicit representation of stocks and flows aids in describing how investment decision eventually lead to capital acquisition. The absence of explicit stocks and flows and decision-making delays leads to a more artificial description investment decision making in the neoclassical investment function. The neoclassical formulation for desired capital cannot be related to an explicit management goal because it rests on information--such as the optimal capital-output ratio--which can never by known with certainty by managers. The neoclassical lag distribution between changes in desired capital and investment expenditures likewise corresponds to no recognizable real process because it aggregates incommensurable sources of delay in decision-making, planning, and realizing capital acquisitions.
CHAPTER 3 STATISTICAL ESTIMATION AND TESTING

I. INTRODUCTION AND PREVIEW OF RESULTS

This chapter presents the results of fitting the SDNM and neoclassical investment functions to quarterly industry data. The parameter estimates and goodness of fit measures serve three purposes in the present study. First, measures of goodness of fit provide one means for testing the SDNM and neoclassical investment functions. The comparative fits and residual autocorrelation of the two investment functions measure the overall ability of each formulation to account for observed investment behavior. Secondly, statistical estimation of parameters in the SDNM formulation yields parameter estimates which will be used when alternative investment functions are simulated within a consumer-goods sector model in Chapters 4 and 5. Thirdly, statistical estimation and testing contributes to the methodological objectives of the present study by providing a concrete set of statistical-test results against which subsequent model-behavior-test results will be compared in Chapter 6.

Section II shows that the nonlinear combinations of delayed variables in the SDNM investment function preclude direct estimation of all parameters and lag distributions by conventional econometric techniques. Fortunately, problems in estimating the SDNM investment function can be overcome by relatively minor simplifications in the
expected growth in shipments lag distribution and in the way the order reference for the supply line is measured. Section III presents estimation and test results for the SDNM investment function. The results show that inclusion of each SDNM investment hypothesis leads to an improvement in fit and a reduction in residual autocorrelation in regressions using four sets of industry data. Section III also shows that plausible, statistically significant parameter estimates can be obtained for the SDNM formulation.

Section IV compares the performance of the SDNM and neoclassical investment functions for the four sets of industry data. The results show that the SDNM function consistently outperforms the neoclassical function when the lag distributions in each formulation are replaced by single-lagged variables and when they are estimated as polynomial-distributed (Almon) lags. Results are inconclusive when both investment functions are estimated with the rational-distributed lags employed originally by Jorgenson. Results are inconclusive due to the lagged dependent variables introduced into both investment functions by the rational-distributed lag.

Section V summarizes the statistical results.
II. SIMPLIFYING THE SDNM INVESTMENT FUNCTION FOR STATISTICAL ANALYSIS

II.A ESTIMATION PROBLEMS POSED BY THE SDNM FORMULATION\(^1\)

The major difficulties for estimation posed by the SDNM investment function stem from the complex delay structure through which the determinants of investment influence order starts for capital. The SDNM formulation separates out several perception and reaction delays that affect investment decision. Though conceptually desirable, separate treatment of information delays leads to difficult estimation problems.

The full SDNM investment function as expressed in Equation 2-26 can be expressed for estimation by grouping the "structural" parameters such as TCSC and TCIB as coefficients K1, K2, K3 and K4:

\[
OSC_t = K1 \cdot CAP_t \cdot (ASHIP_t / PP_t) \cdot PRCRC_t + K2 \cdot CAP_t \cdot (B_t - IO_t) / PP_t \cdot PRCRC_t \\
+ K3 \cdot CAP_t \cdot EGSt + K4 \cdot (CAP_t \cdot (NLG + EGSt) \cdot PDSLC_t - SLC_t) + \epsilon_t
\]  

(3-1)

where \(\epsilon_t\) represents a stochastic error process. Equation (3-1) includes five separate delayed variables: average shipments ASHIP, perceived ratio of capital return to cost PRCRC, perceived delay in the supply line for capital PDSLC, and two averages of shipments in expected

\(^1\)The following discussion touches only briefly on the estimation problems posed by the SDNM investment function. The interested reader is referred to Appendix D for a more thorough discussion of the estimation problems posed by the delay structure of typical system dynamics models and the applicability of common econometric techniques to estimate such formulations.
growth in shipments EGS (short-term average shipments STASHIP and long-term average shipments LTASHIP -- see Equation 2-20).

Ideally, one would like to perform a single estimation to obtain estimates for the lag distribution associated with each delayed variable and the structural parameters which enter the coefficients K1, K2, K3, and K4. Fortunately, estimates of the structural parameters can be derived from the coefficient estimates coupled with analysis of available data (see Appendix A of the present chapter). However, the products and ratios of lag distributions in the SDNM investment function still create a difficult nonlinear estimation problem. For example, the "coterm" for the coefficient K1 includes the product of two delayed variables, average shipments ASHIP and perceived ratio of capital return to cost PRCRC. Direct estimation of the lag distribution associated with each delayed variable requires a nonlinear estimator:

\[
\text{ASHIP}_t \cdot \text{PRCRC}_t = \sum_{i=0}^{M} w_i \cdot \text{SHIP}_{t-i} \cdot \sum_{i=0}^{N} w_i \cdot \text{RCRC}_{t-i}
\]

2That is, the full SDNM investment function is "nonlinear in the parameters," not just nonlinear in the variables. An equation which is nonlinear-in-the-variables can still be estimated by a linear estimator provided all parameters to be estimated enter linearly (i.e., enter as coefficients.) Such is not the case for an equation which is nonlinear in the parameters.

3The term "coterm" is the combination of variables which multiplies a coefficient to be estimated. For example, the coterm for the coefficient K1 in Equation (3-1) is \( \text{CAP}_t \cdot (\text{ASHIP}_t/\text{PP}_t) \cdot \text{PRCRC}_t \).
Similarly, expected growth in shipments EGS includes a ratio of two lag distributions, one associated with short-term average shipments STASHIP and one associated with long-term average shipments LTASHIP (see Equation 2-20.) While nonlinear estimation of lag distributions is in principle possible, attempts to estimate all five lag distributions in the SDNM investment function by nonlinear estimation have failed.4

II.B SIMPLIFYING THE SDNM DELAY STRUCTURE

To overcome the difficulties for statistical estimation posed by the SDNM investment function, two simplifications are made in the SDNM formulation. The simplifications eliminate two nonlinear combinations of lag distributions, thereby facilitating application of linear estimators to estimate parameters and examine fit to available data. First, the SDNM formulation for expected growth in shipments EGS is replaced by an alternative formulation which involves only one lag distribution. The revised formulation is given by the following equation (the prime "'" indicates a revised formulation):

4Nonlinear estimation of Equation (3-1) entails linearization about an initial set of parameter estimates, calculation of the least squares estimates for the linearized equation, then relinearization about the new estimates and reestimation (see Marquardt 1963 or Pindyck and Eisner 1973). The process continues until convergence of parameter estimates on successive iterations. To date, attempts to apply nonlinear estimation to the full SDNM investment function have resulted in divergence.
\[ \text{EGS}_t = \frac{\Delta \text{SHIP}_t}{\Delta \text{SHIP}_{t-(i+1)}} \]

\[ \Delta \text{SHIP}_t = \text{SHIP}_t - \text{SHIP}_{t-1} \]  

Equation (3-2) determines expected growth in shipments as an average of past rates of growth in shipments. Given quarterly data, Equation (3-2) represents an average quarterly growth rate in shipments, measured as a fraction per quarter. The original SDNM formulation for EGS likewise provides a measure of the fractional growth rate in shipments (Equation 2-5.) Moreover, given proper choice of the lag weights \( w_i \), the two formulations give qualitatively similar dynamic responses of expected growth to changes in shipments (see Appendix A of the present chapter.) Equation (3-2) is convenient for estimation purposes because it eliminates the ratio of lag distributions implicit in the original formulation for EGS.

The second simplification for purposes of estimation involves measurement of the order reference for supply for capital ORSLC. In the SDNM production-sector model, ORSLC equals the rate of normal replacement orders for capital, NL\(C\cdot \text{CAP}_t \), plus expansion orders for growth, \( \text{CAP}_t \). EGS\( _t \) (Equation 2-22). As explained in Chapter 2, ORSLC represents the rate at which the production sector wants to acquire capital on a
continuing basis. In the following regressions, order reference for supply line for capital ORSLC is measured as the linear trend in order starts for capital OSC:

\[ ORSLC_t^i = \text{trend} (OSC_t) \] (3-3)

That is, data for ORSLC equal the values along a straight line fit through data for OSC; ORSLC ignores all variation in OSC away from the linear trend line.

Two considerations motivate measuring ORSLC as the trend in order starts for capital. First, Equation (3-3) eliminates the EGS lag distribution implicit in the original formulation for ORSLC, thereby eliminating the product of the EGS and PDSL lag distributions in the original formulation. Second, the revised formulation eliminates capital stock as a determinant of ORSLC. Of all the data employed in the following regressions, data for capital stock is probably the poorest. Hence, the trend in OSC may be viewed as an instrumental variable necessitated by errors in measuring capital stock. (Section III discusses other steps to compensate for the poor quality of capital data.)

As a consequence of the two simplifications described above, the full SDNM investment function is expressed for estimation as follows:
\[ \text{OSC}_t = K_1 \cdot \text{CAP}_t \cdot (\text{ASHIP}_t/\text{PP}_t) \cdot \text{PRCRC}_t + K_2 \cdot \text{CAP}_t \left( \frac{(B - \text{IO})_t}{\text{PP}_t} \right) \cdot \text{PRCRC}_t \\
+ K_3 \cdot \text{CAP}_t \cdot \text{EGS}'_t + K_4 \cdot (\text{ORSLC}'_t \cdot \text{PDSL}_t - \text{SLC}_t) + \epsilon_t \]  

(3-4)

where

\[ \text{ASHIP}_t = \sum_{i} w_1 \cdot \text{SHIP}_{t-i} \quad (\sum_{i} w_1 = 1) \]

\[ \text{PRCRC}_t = \sum_{i} w_2 \cdot \text{RCRC}_{t-i} \quad (\sum_{i} w_2 = 1) \]

\[ \text{EGS}'_t = \sum_{i} w_3 \cdot \frac{\Delta \text{SHIP}_{t-i}}{\text{SHIP}_{t-i-1}} \]

\[ \text{PDSL}_t = \sum_{i} w_4 \cdot \text{DYSLC}_{t-i} \quad (\sum_{i} w_4 = 1) \]

\[ \text{ORSLC}'_t = \text{trend} \left( \text{OSC}_t \right) \]

Equation (3-4) includes four lag distributions to be estimated. Equation (3-4) also includes one product of lag distributions, which occurs due to the product of ASHIP and PRCRC in the K1 coterm. Section III discusses the procedure employed to estimate Equation (3-4).
III. STATISTICAL ESTIMATION AND TESTING OF THE SDNM INVESTMENT FUNCTION

This section examines statistical support for the SDNM investment function and derives estimates for the parameters and lag distributions in the SDNM formulation. Statistical support is assessed by a series of regressions that begin with a "neoclassical-type" equation for capital ordering, and then progressively incorporate each SDNM investment hypothesis. The regressions show the degree to which SDNM investment hypotheses improve equation performance for four sets of industry data. Estimates of parameters and lag distributions in the full SDNM investment function are then compared to a priori estimates used in past simulations of the SDNM consumer-goods sector.

III.A DATA

Because the SDNM investment function is intended to portray the determinants of capital ordering within typical producing sectors, industry data are employed for the following estimations. Data for four different industrial aggregates are employed: total durable manufacturing, total nondurable manufacturing, electrical machinery and equipment, and textile mill products. The data represent two distinct
levels of aggregation. Total durables and total nondurables constitute the two major subdivisions of manufacturing industries. Electrical machinery and textile products are "2-digit" industry groups respectively subsumed within total durable and total nondurable manufacturing. Using data from different levels of aggregation provides some indication of whether the SDNM investment function can be applied equally appropriately for aggregate as well as disaggregate producing sectors.

Appendix C describes in detail the data base employed for the following regressions. Data for order starts for capital, the supply-line of unfilled orders for capital and the delay in the supply line for capital are constructed from the Conference Board's quarterly survey of capital appropriations for the 1000 largest manufacturing corporations. Data for capital stock, output inventory and output backlog, shipments of output come from Bureau of Economic Analysis and Bureau of Census data. All data are deflated to 1972 prices and measured on a quarterly basis. The data begin in 1953 and run until the second quarter of 1975.

III.B ESTIMATION PROCEDURE

Table 3-1 summarizes the series of regressions performed to assess statistical support for the SDNM investment function. The table indicates the determinants of capital ordering (order starts for capital) included in each regression and how the lags associated with each delayed variable are specified for estimation. The table indicates three
Table 3-1
Regressions with Alternative Investment-Function Specifications

Full SDNH Investment Function*: \( OS_{c_t} = k_1 \cdot CAP_{c_t} \cdot \left( ASHIP_{c_t}/PP_{c_t} \right) \cdot PRC_{c_t} + k_2 \cdot CAP_{c_t} \cdot \left( B_{t-1} - IO_{c_t-1} \right)/PP_{c_t} \cdot PRC_{c_t} \cdot K_3 \cdot CAP_{c_t} + CAP_{c_t} \cdot EGS'_{c_t} + k_4 \cdot (ORS_{c_t} \cdot PSDSC_{c_t} - SK_{c_t-1}) + \epsilon_t \)

<table>
<thead>
<tr>
<th>Regression Conditions</th>
<th>Determinants of Capital Ordering</th>
<th>Specification of Lag Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression no.</td>
<td>Variables Affecting Capital Ordering</td>
<td>Variable Lagged One Period</td>
</tr>
<tr>
<td>1</td>
<td>( K_2 = K_4 = 0 ) ( PP = PROD ) ( EGS' = 0 )</td>
<td>CAP, ASHIP, PROD, ( PRC_{c_t} ) ( \text{(neoclassical-type formulation)} )</td>
</tr>
<tr>
<td>2</td>
<td>( K_2 = K_4 = 0 ) ( EGS' = 0 )</td>
<td>same as #1 except ( PP ) replaces ( PROD ) in ( K_1 )-coterm (Assume Variable Utilization)</td>
</tr>
<tr>
<td>3</td>
<td>( K_4 = 0 ) ( EGS' = 0 )</td>
<td>same as #2 plus Inventory and Backlog Corrections Affect Desired Capital</td>
</tr>
<tr>
<td>4</td>
<td>( EGS' = 0 )</td>
<td>same as #3 plus Supply-Line Correction Affects Capital Ordering</td>
</tr>
<tr>
<td>5</td>
<td>( EGS' = 0 )</td>
<td>same as #4 plus Expected Growth in Shipments Affects Capital Ordering</td>
</tr>
<tr>
<td>6</td>
<td>( K_2 = K_4 = 0 ) ( EGS' = 0 )</td>
<td>same as #5</td>
</tr>
<tr>
<td>7</td>
<td>( EGS' = 0 )</td>
<td>same as #5</td>
</tr>
<tr>
<td>8</td>
<td>( EGS' = 0 )</td>
<td>same as #5</td>
</tr>
</tbody>
</table>

* B, IO, and SKC are lagged one period because data for these variables represent end-of-period stocks.
approaches to lag specification—representing the delayed variable by a single lagged variable (e.g., ASHIP = SHIP$_{t-1}$), by a distributed lag formed prior to estimation, and by an estimated distributed lag.

The regressions in Table 3-1 can be divided into two groups. Regressions 1 through 5 progressively incorporate each of the hypothesized determinants of capital ordering in the SDNM formulation. Regressions (6) through (8) incorporate features of the SDNM lag structure. Regression (1) includes only four determinants of capital ordering—capital CAP, average shipments ASHIP, production PROD, and perceived ratio of capital return to cost PRCRC. The capital ordering formulation in Regression (1) is a "neoclassical-type" formulation in the sense that all five SDNM investment hypotheses identified in Chapter 2 are omitted from the formulation. The equation estimated in Regression (1) can be derived from Equation (3-4) by setting the coefficients K2 and K4 to zero, by replacing potential production PP by production PROD, and by setting expected growth in shipments EGS to zero. Table 3-1 also shows that regression (1) replaces the delayed variables ASHIP and PRCRC by variables lagged one period—i.e., SHIP$_{t-1}$ and RCRC$_{t-1}$. Hence, the equation estimated in Regression (1) is as follows:

$$\text{OSC}_t = K1 \cdot \text{CAP}_t \cdot \left(\text{SHIP}_{t-1}/\text{PROD}_t\right) \cdot \text{RCRC}_{t-1} + K3 \cdot \text{CAP}_t \quad (3-5)$$
Regression (2) replaces potential PP for production PROD in Equation (3-5). As discussed in Chapter 2, the SDNM investment function implicitly assumes variable utilization when PROD is replaced by PP in Equation (3-5):  

\[ \text{OSC}_t = K1 \cdot \text{CAP}_t \cdot (\text{SHIP}_{t-1}/\text{PP}_t) \cdot \text{RCRC}_{t-1} + K2 \cdot \text{CAP}_t \]  

(3-6)

Regressions (3) through (5) successively incorporate the hypothesized inventory- and backlog-corrections, supply-line correction, and effect of expected growth in shipments included in the SDNM investment function. Regression (5) represents the first regression involving distributed lag estimation. Incorporating expected growth in shipments requires estimating the associated lag distribution because growth expectations are based on perceptions of the historical growth trend in shipments. (EGS is expressed as in Equation 3-2.) The EGS' lag distribution, and all subsequent estimated lag distributions, is estimated by the polynomial-distributed (Almon) lag technique (hitherto called PDL).

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5 Data for potential production are constructed using the Federal Reserve Board index for capacity utilization $u$ ($u=1.0$ implies full utilization):

\[ \text{PP}_t = \frac{\text{PROD}_t}{u_t} \]

See Appendix C for details.
In Regressions (6) and (7), the lag structure of the estimated equations approaches the lag structure in the full SDNM investment function. Regression (6) estimates the distributed lag associated with average shipments ASHIP, as well as the EGS' lag distribution. Regression (7) also estimates the distributed lag associated with the perceived delay in the supply line for capital PDSL. Regression (7) comes the closest to estimating the full SDNM investment function. The regression estimates three of the four SDNM lag distributions. The fourth lag distribution, the lag distribution associated with PRRC, must be estimated separately from the ASHIP lag distribution because the two combine multiplicatively.

Regression (8) provides a test for the fifth SDNM investment hypothesis—the hypothesized delay in forming perceived ratio of capital return to cost PRRC. The test derives from an approximation for estimating the product of two lag distributions proposed by Bischoff (1971a). Regression (8) approximates the product of the ASHIP and PRRC lag distributions by estimating two lag distributions involving products of the underlying variables, SHIP and RCRC:

\[ \sum_{i} w_i \cdot \text{SHIP}_{t-i} \cdot \sum_{j} v_j \cdot \text{RCRC}_{t-j} \approx \sum_{i} w_i' \cdot \text{SHIP}_{t-i} \cdot \text{RCRC}_{t-i} + \sum_{j} v_j' \cdot \text{SHIP}_{t-(j-1)} \cdot \text{RCRC}_{t-j} \]

(3-7)
If the hypothesis of separate lag distributions for ASHIP and PRCRC is incorrect, and capital ordering actually responds to a single lag distribution of the product SHIP•RCRC, then the lag weights $v_j$ should equal zero. Therefore, statistically significant estimates for the weights $v_j$ allows one to reject the hypothesis that capital ordering responds to a single distributed lag of past values of SHIP•RCRC.\(^6\)

In addition to presenting summary measures of equation performance for each of the eight regressions described above, the following section also presents coefficient estimates and estimated lag distributions for the SDNM investment function. These estimates are arrived at by an iterative procedure described below.

### III.C ESTIMATION RESULTS

**Summary Statistics for Regressions (1) through (8).** Table 3-2 shows the results of conducting the first 7 regressions described above. (Results for Regression 8 are presented in Table 3-3.) Each regression is performed with ordinary least squares estimation OLS. The series of regressions is repeated for each of the four sets of industry data. For

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\(^6\)Note that Table 3-1 states that the PDSL lag distribution and PRCRC lag distribution in the K2 coterm are replaced by single lags in Regression 8. Also, the ECS lag distribution is formed prior to estimation using a priori time constants for STASHIP and LTASHIP. These simplifications are made to reduce the number of lag distributions to be estimated and thereby reduce collinearity and increase the degrees of freedom.
<table>
<thead>
<tr>
<th>Data Regression no.</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \bar{R}^2 = 0.565 )</td>
<td>( \bar{R}^2 = 0.580 )</td>
<td>( \bar{R}^2 = -0.169 )</td>
<td>( \bar{R}^2 = 0.561 )</td>
</tr>
<tr>
<td></td>
<td>SER = 0.904</td>
<td>SER = 0.929</td>
<td>SER = 0.138</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 0.47</td>
<td>DW = 0.30</td>
<td>DW = 0.49</td>
<td>DW = 0.58</td>
</tr>
<tr>
<td>2</td>
<td>( \bar{R}^2 = 0.594 )</td>
<td>( \bar{R}^2 = 0.703 )</td>
<td>( \bar{R}^2 = -0.169 )</td>
<td>( \bar{R}^2 = 0.586 )</td>
</tr>
<tr>
<td></td>
<td>SER = 0.876</td>
<td>SER = 0.741</td>
<td>SER = 0.134</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 0.49</td>
<td>DW = 0.43</td>
<td>DW = 0.49</td>
<td>DW = 0.62</td>
</tr>
<tr>
<td>3</td>
<td>( \bar{R}^2 = 0.789 )</td>
<td>( \bar{R}^2 = 0.823 )</td>
<td>( \bar{R}^2 = -0.169 )</td>
<td>( \bar{R}^2 = 0.584 )</td>
</tr>
<tr>
<td></td>
<td>SER = 0.632</td>
<td>SER = 0.603</td>
<td>SER = 0.134</td>
<td></td>
</tr>
<tr>
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<td>F(1/85) = 80.1*</td>
<td>F(1/85) = 44.8*</td>
<td>F(1/85) = 22.8*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 0.90</td>
<td>DW = 0.83</td>
<td>DW = 0.74</td>
<td>DW = 0.62</td>
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<tr>
<td>4</td>
<td>( \bar{R}^2 = 0.789 )</td>
<td>( \bar{R}^2 = 0.864 )</td>
<td>( \bar{R}^2 = 0.241 )</td>
<td>( \bar{R}^2 = 0.699 )</td>
</tr>
<tr>
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<td>SER = 0.102</td>
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</tr>
<tr>
<td></td>
<td>F(1/84) = 2.1</td>
<td>F(1/84) = 27.0*</td>
<td>F(1/84) = 33.6*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 0.42</td>
<td>DW = 1.00</td>
<td>DW = 1.42</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>( \bar{R}^2 = 0.841 )</td>
<td>( \bar{R}^2 = 0.888 )</td>
<td>( \bar{R}^2 = 0.555 )</td>
<td>( \bar{R}^2 = 0.740 )</td>
</tr>
<tr>
<td></td>
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<td>SER = 0.460</td>
<td>SER = 0.099</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F(3/81) = 9.8*</td>
<td>F(3/81) = 6.9*</td>
<td>F(3/81) = 9.3*</td>
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</tr>
<tr>
<td></td>
<td>DW = 1.23</td>
<td>DW = 1.03</td>
<td>DW = 1.08</td>
<td>DW = 1.56</td>
</tr>
<tr>
<td>6</td>
<td>( \bar{R}^2 = 0.844 )</td>
<td>( \bar{R}^2 = 0.890 )</td>
<td>( \bar{R}^2 = 0.406 )</td>
<td>( \bar{R}^2 = 0.770 )</td>
</tr>
<tr>
<td></td>
<td>SER = 0.548</td>
<td>SER = 0.446</td>
<td>SER = 0.099</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F(1/80) = 2.3</td>
<td>F(1/80) = 2.3</td>
<td>F(1/80) = 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 1.20</td>
<td>DW = 1.00</td>
<td>DW = 1.59</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>( \bar{R}^2 = 0.931 )</td>
<td>( \bar{R}^2 = 0.912 )</td>
<td>( \bar{R}^2 = 0.447 )</td>
<td>( \bar{R}^2 = 0.812 )</td>
</tr>
<tr>
<td></td>
<td>SER = 0.858</td>
<td>SER = 0.422</td>
<td>SER = 0.090</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F(3/42) = 33.1*</td>
<td>F(3/42) = 75.5*</td>
<td>F(2/44) = 9.3*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DW = 1.96</td>
<td>DW = 1.53</td>
<td>DW = 1.11</td>
<td>DW = 1.32</td>
</tr>
</tbody>
</table>

* Significant at 0.99 level
† Significant at 0.95 level
each regression Table 3-2 presents the adjusted coefficient of multiple determination $\bar{R}^2$, the standard error of regression SER, an F-statistic F, and the Durbin-Watson statistic DW. The first two statistics, $\bar{R}^2$ and SER, measure the degree to which the investment equation in question "accounts for" observed movements in order starts for capital (capital appropriations.) SER measures the standard deviation of the residuals of the regression, the sequence of discrepancies between observed and predicted values of order starts for capital. Because the residuals represent unaccounted for movements in order starts, SER is often termed a measure of "unexplained variation." $\bar{R}^2$ compares the unexplained variation to the observed variation in order starts as a measure of overall equation fit. ($\bar{R}^2 = 1$ implies zero unexplained variation.)\(^7\) The F statistic presented in Table 3-2 measures the extent to which the additional variable or variables added in the regression have a statistically significant effect on equation fit. The value of the F-statistic for each regression depends on the

\(^7\)Note that values of $\bar{R}^2$ are generally lower and values of SER are generally higher for the more disaggregate data. Poorer fits are especially apparent with textile data. The general cause for poorer fit with disaggregate data is the greater impact of omitted variables on individual industries than on large industrial aggregates (see Theil 1971, p. 181). Changes in legislation, weather, or competition from foreign-produced goods tend to affect some industries more than others. Hence, the ability of a general model to account for investment in disaggregate industry groups is typically poorer than for more aggregate industrial groupings.
value of the (unadjusted) coefficient of multiple determination $R^2$ for the regression compared to the $R^2$ for the immediately preceding regression. The fourth statistic presented in Table 3-2, DW, measures the degree of first-order autocorrelation in the residuals. When DW equals 2.0, successive values of the residuals are completely uncorrelated. When DW is below 2.0, successive values are positively correlated; when DW is above 2.0, successive values are negatively correlated.

Results for regressions 2 through 5 measure the impact of the additional variables included in the SDNM investment function; results for Regressions (6) and (7) measure the impact of the ASHIP- and PDSL C lag distributions. Results for Regression 2 show that replacing production PROD by potential production PP in the KI coterm leads to improvement in fit and reduction in residual autocorrelation for 3 of the

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8 The F-statistic presented in Table 3-2 is computed according to the following equation:

$$F = \frac{(R^2_k - R^2_r)/(k-r)}{(1-R^2)/(n-k)}$$

where $R^2_k$ and $R^2_r$ are the respective coefficients of multiple determination for the regressions with and without the variable(s) being tested, $(k-r)$ equals the number of additional parameters estimated when the additional variable(s) are included in the regression, and $n$ equals the number of observations available (see Johnston 1972, pp. 143-147).
4 data sets. For example, results for total nondurable manufacturing in Regression (1), with the neoclassical-type equation for capital ordering, show \( R^2 \) equals 0.565, SER equals 0.907, and DW equals 0.46. When variable utilization is assumed in Regression (2), \( R^2 \) increases to 0.594, SER falls to 0.876, and DW rises to 0.49\(^9\). Assuming variable utilization has the greatest effect on results for total durables; \( R^2 \) improves from 0.58 to 0.733, SER declines from 0.929 to 0.741 (a 20% reduction in unexplained variability) and DW rises from 0.30 to 0.43. On the other hand, assuming variable utilization has negligible impact on equation performance for textile mill data. The greater effect of assuming that durable manufacturing producers take account of capacity utilization rates when generating capital orders apparently reflects the greater variation in capacity utilization rates for durable manufacturing.\(^{10}\)

\(^9\)Note that no F-statistic is reported for Regression (2) because PP enters nonlinearly into the regression. The linear statistical theory underlying the F-tests for Regressions (3) through (7) can be applied exactly only when the variables tested enter as individual coterms in the regression.

\(^{10}\)The standard deviation for capacity utilization for total durables equals about 8.7% of the mean capacity utilization. By contrast, the standard deviation for the capacity utilization data used for textile mill products equals about 4.5% of the mean utilization. The negligible effect of assuming variable utilization for capital ordering in the textile industries also stems from the poor utilization data available for textile mill products. As discussed in Appendix C, utilization data for textile mill products span less than half the sample period; nondurable data are used for the balance of the sample period.
Regression (3) tests the effect of including inventory- and backlog corrections in capital ordering. Table 3-2 shows that inclusion of inventory- and backlog corrections leads to significant improvement for 3 of 4 data sets. For total nondurables, $R^2$ rises to 0.789, SER falls to 0.632 and DW rises to 0.90. The F-statistic for Regression (3) equals 80.1, which is significant at the 0.99 level. (For an F distribution with (1, 85) degrees of freedom, the 0.01 critical point equals 6.98.) Hence, inventory and backlog corrections have a highly significant effect on equation fit and residual autocorrelation for total nondurables. Comparable improvement in fit is seen when inventory- and backlog corrections are included in Regression (3) for total durable manufacturing and textile mill products.

The hypothesized inventory and backlog corrections in capital ordering have negligible impact when Regression (3) is performed using electrical machinery and equipment data. The low F-statistic (0.6) shows that inventory and backlog corrections do not have a statistically significant effect in accounting for observed movements in capital ordering for electrical machinery and equipment industries. Similarly, including the hypotheses leaves D-W unchanged from Regression (2). The statistical insignificance of inventory- and backlog corrections in capital ordering for electrical machinery and equipment stems from one of two possible causes. Either the variables do in fact have little influence on producers' decisions to order capital in these industries,
or the influence is not discernable in the available data for electrical machinery and equipment producers. Given the highly significant effects of inventory and backlog corrections in accounting for movements in capital ordering for the three other sets of industry data, data limitations seem the more probable cause of the insignificant effect.\textsuperscript{11}

Regression (4) incorporates the hypothesized supply-line correction in capital ordering. In Regression (4), the supply-line correction is simplified by replacing the lag distribution for perceived delay in the supply line for capital PDSL\textsubscript{C} by a single lagged value of the delay in the supply line for capital DYS\textsubscript{LC}. (The PDSL\textsubscript{C} lag distribution is estimated in Regression 7.) Hence, Regression (4) tends to underestimate the impact of the supply-line correction on regression performance.

Nonetheless, Table 3-2 shows that including the simplified supply-line correction significantly improves equation fit and reduces residual autocorrelation for 3 of 4 data sets. F-statistics for Regression (4) are statistically significant at the 0.99 level for total durables, textile mill products, and electrical equipment, and

\textsuperscript{11}Actual influences may be undetectable in available data for several reasons: errors in measuring variables such as output inventory, collinearity (high correlation over the sample period between inventory and backlog data and other explanatory variables such as shipments), or lack of movement in an explanatory variable (in this case, the difference between inventory and backlog) over the sample period. Inspection of the electrical machinery and equipment data suggests that collinearity or lack of movement in the data are not the cause of the statistical insignificance. This leaves measurement error as the most probable cause.
machinery. DW statistics also improve substantially in each of the three regressions. Including the simplified supply-line correction has negligible impact when Regression (4) is computed for total nondurable manufacturing data. However, when the supply-line correction including the PDSL lag distribution is tested for total nondurables, the result is statistically significant. Estimating the PDSL lag distribution in Regression (7) leads to a statistically significant improvement in fit (F=33.1) and almost zero residual autocorrelation (DW=1.96) for total nondurables. Therefore, the supply-line correction leads to significant improvement in regression performance for all four sets of industry data.

Regression (5) incorporates the hypothesized effect of expected growth in shipments EGS into the investment function. Polynomial distributed lag (PDL) estimation is used to estimate the EGS lag distribution. The lag weights are assumed to lie along a third-order polynomial; the lag length is determined by experimentation to maximize $R^2$. Table 3-2 shows that inclusion of the EGS' lag distribution in Regression (5) leads to a statistically significant improvement in fit for all four sets of industry data. Residual autocorrelation similarly declines for all data sets, although the increase in DW is small for total durables.

Regressions (6), (7), and (8) show the consequences of incorporating additional SDNM lag distributions into the investment function. All lag distributions are estimated by the PDL technique. Table 3-2 shows the results for Regressions (6) and (7). Estimating the
distributed lag associated with average shipments ASHIP in Regression (6) leads to negligible improvement in equation performance, except in the regression using textile data. The cause for the negligible improvement in Regression (6) apparently stems from the short length of the ASHIP lag distribution. Results for the ASHIP lag distribution will be discussed further below. On the other hand, Regression (7), which estimates the distributed lag associated with perceived delay in the supply line for capital PDSLc as well as the ASHIP and EGS (expected growth in shipments) lag distributions, leads to substantial improvement in equation fit and residual autocorrelation for all four sets of industry data. Three of four F-statistics are significant at the 0.99 and the fourth, F = 2.70 for textile mill products, is only slightly below the 0.05 critical point (F = 2.75). DW statistics improve in three of the four versions of Regression (7).

As discussed in the preceding section, it is not possible to expand Regression (7) further to also estimate the distributed lag associated with the perceived ratio of capital return to cost PRCRC. Rather, Regression (8) tests the hypothesized delay in forming PRCRC by examining the statistical significance of the hypothesis that ASHIP and PRCRC affect order starts for capital through separate lag distributions (see Equation 3-7.). Table 3-3 displays the estimated lag weights and the standard errors of the estimated lag weights (in parentheses) for the two lag distributions in Regression (8). As discussed in the preceding
section, statistically significant lag weights for the \( \text{SHIP}_{t+1} \)
\( \text{RCRC}_t \) lag distribution\(-v_j'\) in Table 3-3--allows one to reject the
hypothesis that SHIP and RCRC enter the investment function with the same
distributed lag.

The results in Table 3-3 show that the estimates of the
\( \text{SHIP}_{t+1} \) \( \text{RCRC}_t \) lag distribution are statistically significant in three
of four sets of industry data. For example, all but the first two
estimates lag weights \( \hat{v}_j' \) for total nondurables are statistically
significant at the 0.99 level. (Note carrots "\(^\wedge\)" indicate estimated
values.) Similarly, all estimated lag weights \( \hat{v}_j' \) for total durables
are statistically significant at the 0.99 level. Standard deviations for
the estimated sums of the lag weights \( \sum\hat{v}_j' \) are likewise small relative
to the sums themselves for total nondurables and total durables.
Statistically significant estimates for \( v_j' \) are also obtained using
data for electrical machinery and equipment. Although textile mill
estimates for \( v_j' \) are not significant at the 0.95 level, the standard
deviations for most \( \hat{v}_j' \) are equal to or smaller than the respective
estimates \( \hat{v}_j' \); the standard deviation for the sum \( \sum\hat{v}_j' \) is likewise
smaller than the estimated sum of the lag weights. Overall, the results
in Table 3-3 strongly support rejecting the hypothesis that SHIP and RCRC
enter the investment function with the same lag distribution.

**Estimated Parameter Values and Lag Distributions.** The summary statistics
presented in Table 3-2 provide only a partial assessment of the extent to
which the SDNM investment function is consistent with available data. To
### Table 3-3

**Estimated Lag Weights for Regression 8**

Standard errors of lag weights in parentheses

\[
\begin{align*}
\text{OSC}_t &= \text{CAP}_{t-1}(1/PP_{t-1}) (C_{t-1} - \text{DUR}_{t-1}) + \text{CAP}_{t-2}(1/PP_{t-2}) (C_{t-2} - \text{DUR}_{t-2}) \\
&+ \text{K}_{t-1}(1/PP_{t-1}) (C_{t-1} - \text{DUR}_{t-1})
\end{align*}
\]

<table>
<thead>
<tr>
<th>Data</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_1$</td>
<td>-0.0024 (0.0034)</td>
<td>-0.0029 (0.0034)</td>
<td>-0.0045 (0.0034)</td>
<td>-0.0045 (0.0034)</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>-0.0032 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
<td>-0.0045 (0.0034)</td>
<td>-0.0045 (0.0034)</td>
</tr>
<tr>
<td>$\omega_3$</td>
<td>-0.0054 (0.0034)</td>
<td>-0.0044 (0.0034)</td>
<td>-0.0019 (0.0034)</td>
<td>-0.0032 (0.0034)</td>
</tr>
<tr>
<td>$\omega_4$</td>
<td>-0.0085 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
<td>-0.0014 (0.0034)</td>
<td>-0.0032 (0.0034)</td>
</tr>
<tr>
<td>$\omega_5$</td>
<td>-0.0105 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
<td>-0.0016 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
</tr>
<tr>
<td>$\omega_6$</td>
<td>-0.0128 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
<td>-0.0016 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
</tr>
<tr>
<td>$\omega_7$</td>
<td>-0.0154 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0016 (0.0034)</td>
<td>-0.0040 (0.0034)</td>
</tr>
<tr>
<td>$\omega_8$</td>
<td>-0.0145 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_9$</td>
<td>-0.0145 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{10}$</td>
<td>-0.0185 (0.0034)</td>
<td>-0.0026 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{11}$</td>
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<td>-0.0026 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{12}$</td>
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<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{13}$</td>
<td>-0.0145 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{14}$</td>
<td>-0.0154 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
<tr>
<td>$\omega_{15}$</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0039 (0.0034)</td>
<td>-0.0013 (0.0034)</td>
<td>-0.0020 (0.0034)</td>
</tr>
</tbody>
</table>

\[ \sum \omega_i = -0.157 (0.034) - 0.038 (0.0068) - 0.017 (0.013) - 0.018 (0.004) \]

**In specifying the lag distribution, I follow Bischoff's procedure of starting each distribution with a lag of 2 quarters (1=1-2). The lengths of each lag distribution were arrived at by experimentation to find lengths which maximized the statistical significance of lag weight estimates.**
complete the assessment, it is necessary to assess the plausibility and statistical significance of parameter estimates and estimated lag distributions.

Table 3-4 presents estimation results using data for total nondurable manufacturing.\textsuperscript{12} Table 3-4a presents results for a slightly modified version of Regression (7). The estimated equation in Table 3-4a is given below:

\[
OSC_t = \text{CAP}_t \cdot \left(\sum_{i} \text{SHIP}_{t-i}/\text{PP}_t\right) \cdot \text{PRCRC}_t + K1 \cdot \text{CAP}_t \cdot \left(\text{B}_t - \text{IO}_t/\text{PP}_t\right) \cdot \text{PRCRC}_t
\]
\[
+ K3 \cdot \text{CAP}_t + \text{CAP}_t \cdot \sum_{i} \text{w}_{2i} \cdot \frac{\triangle \text{SHIP}_t-i}{\text{SHIP}_{t-(i+1)}} + \text{ORSLC}_t \cdot \sum_{i} \text{w}_{3i} \cdot \text{DYSLC}_t-i
\]
\[
- K4 \cdot \text{SLC}_t + \epsilon_t
\]

(3-8)

Equation (3-8) is identical to the equation estimated in Regression (7) except that it employs data formed prior to estimation for perceived ratio of capital return to cost PRCRC. (Regression (7) replaced PRCRC by RRCRC lagged one period.) Estimating Equation (3-8) yields estimates for three of the four lag distributions in the SDNM investment function—

\textsuperscript{12}Data for total nondurables are used to derive estimates of the parameters and lag distributions in the SDNM investment function because, of the four sets of industry data, total nondurables corresponds most nearly to the aggregate consumer-goods sector model used in Chapters 4 and 5.
lag distributions associated with average shipments ASHIP, expected growth in shipments EGS', and the perceived delay in the supply line for capital PDSLSC. Table 3-4b presents results for a version of the SDNM investment function which permits estimation of the fourth SDNM lag distribution—the lag distribution associated with perceived ratio of capital return to cost PRCRC. The estimated equation in Table 3-4b is given below:

$$\text{OSC}_t = \text{CAP}_t \cdot \left( \frac{\text{ASHIP}_t}{\text{PP}_t} \right) \cdot \sum_{i} \cdot \text{RCRC}_t \cdot i + K_2 \cdot \text{CAP}_t \cdot \left( \frac{B_t - IO_t}{\text{PP}_t} \right) \cdot \text{PRCRC}_t$$

$$+ K_3 \cdot \text{CAP}_t \cdot \text{EGS}_t' + K_4 \cdot \left( \text{ORSLC}_t' \cdot \text{PDSLSC}_t - \text{SLC}_t \right) + \epsilon_t$$

(3-9)

Estimating Equation (3-9) requires data formed prior to estimation for the ASHIP, PRCRC, EGS', and PDSLSC lag distributions.

The estimation results in Table 3-4 are arrived at by an iterative procedure. The procedure, shown diagrammatically in Figure 3-1, has five steps. Step 1 entails creating data for PRCRC. PRCRC data are formed by first-order exponential smoothing of data for ratio of capital return to cost RCRC. In Step 2, Equation (3-8) is estimated using the PRCRC data. Estimating Equation (3-8) yields estimates of the ASHIP,

\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.\[\text{PRCRC}_t = (1-\lambda) \cdot \text{PRCRC}_{t-1} + \lambda \cdot \text{RCRC}_t\]

\[\text{PRCRC}_{t0} = \text{RCRC}_{t0}\]

where $\lambda$ is the "smoothing constant." The a priori value chosen for $\lambda$ equals $1/8$.
**Table 3-4**

**Estimation Results for S0NH Investment Function**

**Total Nondurable Manufacturing**

Table 3-4a: Equation (3-8) -- IV Estimation

\[ \text{OSC}_t = \text{CAP}_t \cdot (\frac{\sum w_{1i} \cdot \text{SHIP}}{\text{PP}_t}) \cdot \text{PRCRC}_t + K2 \cdot \text{CAP}_t \cdot (\text{B}_{t-1} - \text{IO}_{t-1}) / \text{PP}_t \cdot \text{PRCRC}_t + K3 \cdot \text{CAP}_t + \text{CAP}_t \cdot \frac{\sum w_{2i} \cdot (\Delta \text{SHIP}_{t-1} - \text{SH}_{t-1})}{\text{SH}_{t-1}} + \text{ORSCE}_t \cdot \sum_{i=0}^{\infty} w_{3i} \cdot D Y \cdot \text{SC}_{t-i} - K4 \cdot \text{SLC}_t - 1 \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( w_{1i} )</th>
<th>( K2 )</th>
<th>( K3 )</th>
<th>( w_{2i} )</th>
<th>( w_{3i} )</th>
<th>( K4 )</th>
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<tr>
<td><strong>Estimate(s)</strong></td>
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<tr>
<td><strong>(Standard Errors in parentheses)</strong></td>
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<td></td>
<td></td>
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<td></td>
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<td>0.0147 (0.0032)*</td>
<td>-0.0442 (0.0143)*</td>
<td>0.0369 (0.0148)*</td>
<td>0.0364 (0.0148)*</td>
<td>0.331 (0.096)*</td>
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<td></td>
<td></td>
<td></td>
<td>0.0149 (0.0032)*</td>
<td>0.0547 (0.0134)*</td>
</tr>
<tr>
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<td></td>
<td></td>
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<td>0.0519 (0.0152)*</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>4</td>
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<td></td>
<td></td>
<td></td>
<td>0.1970 (0.0385)*</td>
<td>0.0455 (0.0221)*</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2301 (0.0362)*</td>
<td>0.0433 (0.0203)*</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2572 (0.0415)*</td>
<td>0.0412 (0.0156)*</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2781 (0.0383)*</td>
<td>0.0387 (0.0137)*</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2831 (0.0499)*</td>
<td>0.0351 (0.0135)*</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2783 (0.0483)*</td>
<td>0.0300 (0.0143)*</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2590 (0.0458)*</td>
<td>0.0228 (0.0165)*</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.2333 (0.0408)*</td>
<td>0.0130 (0.0102)*</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1692 (0.0383)*</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0943 (0.0439)*</td>
<td></td>
</tr>
</tbody>
</table>

\[ \sum w_{1i} = 0.00922 \]

\[ \text{Mean lag} = 0.535 (14.5) \]

\[ \sum w_{2i} = 2.46 (0.44) \]

\[ \sum w_{3i} = 0.491 (0.042) \]

\[ \text{Mean lag} = 2.25 (1.17) \]

\[ \text{Mean lag} = 4.26 (0.96) \]

\[ R^2 = 0.923 \quad SER = 0.387 \quad F(10, 63) = 89.0 \quad DW = 1.43 \]

*Significant at 0.99 level

†Significant at 0.975 level
Table 3.4 (Cont.)

Table 3.4 b: Equation (3-9) -- IV - GHS Estimation

\[
\text{OSC}_t = \frac{\text{CAP}_t \cdot (\text{ASHIP}_t / \text{PP}_t)}{\sum \omega_i \cdot \text{RCR}_{t-1} + K_2 \cdot \text{CAP}_t \cdot (B_{t-1} - IO_{t-1}) / \text{OP}_t} \cdot \text{PRCE}_t \\
+ K_3 \cdot \text{CAP}_t + K_4 \cdot \text{ECS}_{t-1}^t + K_4 \cdot \text{(ORSLC}^t \cdot \text{PDSSL}_t - \text{SLC}_{t-1}^t) 
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(-\omega_i)</th>
<th>(K_2)</th>
<th>K3</th>
<th>K4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimate(s) (Standard errors in parentheses)</td>
<td>(0.00334 (0.00087)*)</td>
<td>(0.0255 (0.0053)*)</td>
<td>(-0.0187 (0.0137))</td>
<td>(0.391 (0.083)*)</td>
</tr>
<tr>
<td>Log 0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>0.00225 (0.00038)*</td>
<td>0.00156 (0.00032)*</td>
<td>0.00161 (0.00037)*</td>
<td>0.00099 (0.00033)*</td>
<td>0.00096 (0.00036)*</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>0.00099 (0.00032)*</td>
<td>0.00099 (0.00032)*</td>
<td>0.00099 (0.00032)*</td>
<td>0.00099 (0.00032)*</td>
<td>0.00099 (0.00032)*</td>
</tr>
<tr>
<td>(\sum \omega = 0.014 (0.002))</td>
<td>(\text{Neq} \cdot \text{Leq} = 3.12 (0.32))</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[R^2 = 0.503 \quad \text{SER} = 0.461 \quad F(5/71) = 16.4 \quad DW = 2.03\]

\[p_1 = 0.67 \quad p_2 = 0.08\]

* significant at the 0.99 level  † significant at the 0.978 level
EGS', and PDSLCLag distributions. In Step 3, the estimated ASHIP, EGS', and PDSLCLag distributions are then used to form data for ASHIP, EGS', and PDSLCLag. For example, ASHIP data are formed from data for shipments ASHIP according to the following equation:

$$\text{ASHIP}_t = \sum_i w_i \text{SHIP}_{t-1}$$  \hspace{1cm} (3-10)

where $w_i$ are the estimated lag weights for the ASHIP lag distribution. In Step 4, the data for ASHIP, EGS', and PDSLCLag are used, along with the original PRCRC data, to estimate Equation (3-9).

Estimating Equation (3-9) yields estimates for the PRCRC lag distribution. Step 5 tests for convergence of the iterative procedure. If the PRCRC-lag distribution estimated in Step 4 deviates from the lag distribution assumed when PRCRC data was formed in Step 1, new data are formed for PRCRC and the procedure is repeated until estimated and assumed PRCRC lag distributing converge.\(^4\)

---

\(^4\)In checking for convergence of estimated and assumed PRCRC lag distributions, both the shape and mean lag of the distributions are compared. As can be seen from Table 3-4b, the estimated PRCRC-lag distribution has steadily declining lag weights. Such an estimated lag pattern approximately matches the shape of the geometrically-declining lag used to form PRCRC data. In such a case, the estimated mean lag can be compared directly to the smoothing constant used in forming PRCRC data. (See appendix A of the present chapter.) The convergence criterion for estimated and assumed mean lags for PRCRC in the present analysis was 10%. With this criteria, convergence occured after only a four iterations. In each iteration, the estimated PRCRC lag distribution declined continuously and, therefore, new PRCRC data were formed by first-order exponential smoothing.
Due to the poor quality of capital stock data, instrumental variable IV estimators were used to obtain the estimates in Table 3-4. Past research has shown that OLS estimates for a system dynamics model can be quite sensitive to measurement errors (Senge 1977) and that IV estimation can considerably reduce measurement error bias in such models (Morecroft 1977). The results in Table 3-4a are obtained by projecting the K3 coterm, CAP, onto past values of capital.  

Note that only the K3 coterm is projected onto the instruments, even though CAP appears in the K1 and K2 coterms as well. Projecting the K1- and K2 coterms onto instruments had little effect on results, apparently because errors in capital tend to cancel out in the first two coterms. (Note that capital appears in the denominator of RCRC.)
Table 3-4b are obtained by combining IV and generalized least squares GLS estimation. ¹⁶ (The DW obtained for the IV estimation of Equation 3-9 equals 0.94.)

The results in Table 3-4 show that statistically significant estimates can be obtained for all coefficients and lag distributions in the SDNM investment function. As in Table 3-3, Table 3-4 presents parameter estimates and standard errors for each estimate (in parentheses). The table shows that only 4 of 45 estimates in the two regressions are not statistically significant at the 0.975 level; most estimates are significant at the 0.99 level. Likewise, the sums of the lag weights are highly significant for each of the four SDNM lag distributions.

The plausibility of estimation results can be judged partly by inspection of the parameter estimates in Table 3-4. All estimated lag weights are positive as expected. All other parameter estimates likewise have the correct sign (K², K⁴ positive; K³ negative -- see Appendix A of the present chapter). The shapes of the estimated lag distributions conform with prior expectations in the sense that the ASHIP, PDSL, and PRCRC lag distributions were expected to decline continuously, while the

¹⁶The GLS estimator assumes a second-order autoregressive model for the error process and iterates over a series of IV estimations to find the GLS parameters which minimize the sum of squared residuals. This approach to combining IV and GLS estimation is described in Eisner and Pindyck (1973).
EGS' lag distribution was expected to be "bell-shaped." Lag lengths also conform to prior expectations. EGS', PDSL, and PRCRC were expected to have relatively long distributed lags; a priori mean lags for these lag distributions were 6, 7, and 7 quarters respectively. On the other hand, ASHIP was expected to have a short lag; the a priori mean lag was 1 quarter.

The plausibility of parameter estimates can be judged further by comparing estimated and a priori values for the structural parameters and "delay times" (the time constants for delayed variables) in the SDNM formulation. Table 3-5 summarizes these estimates, which are derived from estimates in Table 3-4 and from examination of nondurable data. The table presents estimated and a priori values for the ten structural parameters and delay times in the SDNM investment function. The a priori values are those used in past simulations of the SDNM consumer-goods sector model. They should be viewed as educated guesses based on first-hand observation of corporate decision-making. The

---

17 In the SDNM production-sector model, ASHIP, PDSL, and PRCRC are formed by first-order (continuous) exponential smoothing and therefore have continuously declining lag distributions. On the other hand, EGS depends on the ratio of two exponential averages of shipments (Equation 2-20) and therefore exhibits a bell-shaped response to changes in shipments. (See Appendix A of the present chapter.)

18 A priori parameter estimates may be found in data sets PS10, PF12, and PFS17 of the System Dynamics National Project and have been used for simulations for a year or longer prior to the present study.
### TABLE 3-5

**Estimated Delay Times for SDNM Lag Distribution and Estimates of SDNM Structural Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated Parameter Value</th>
<th>a priori Parameter Value</th>
<th>Estimated Standard Deviation of Estimate</th>
<th>Estimation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 TASSIP Time to Average Shipments</td>
<td>2.13 qtrs</td>
<td>2 qtrs</td>
<td>1.88 qtrs</td>
<td>Ratio of first two IV-PDL estimates in ASHIP lag distribution (Table 3-4a)</td>
</tr>
<tr>
<td>2 TPRCRC Time to Perceive Ratio of Capital Return to Cost</td>
<td>4.12 qtrs</td>
<td>8 qtrs</td>
<td>0.32 qtrs</td>
<td>Derived from mean lag for IV-PDL estimates of PRCRC lag distribution (Table 3-4b)</td>
</tr>
<tr>
<td>3 TPOSIC Time to Perceive Delay in Supply Line for Capital</td>
<td>5.36 qtrs</td>
<td>8 qtrs</td>
<td>0.96 qtrs</td>
<td>Derived from mean lag for IV-PDL estimates of POSIC lag distribution (Table 3-4c)</td>
</tr>
<tr>
<td>4 NI 66 Mean lag for Expected Growth in Shipments</td>
<td>7.25 qtrs</td>
<td>6.1 qtrs</td>
<td>1.14 qtrs</td>
<td>IV-PDL estimation of Eq3 lag distribution (Table 3-4d)</td>
</tr>
<tr>
<td>5 NLC Normal Loss of Capital</td>
<td>0.0004 qtr</td>
<td>0.0156 qtr</td>
<td>0.00431 qtr</td>
<td>Estimated directly from data</td>
</tr>
<tr>
<td>6 TESC Time to Correct Supply Line for Capital</td>
<td>3.02 qtrs</td>
<td>10 qtrs</td>
<td>0.86 qtrs</td>
<td>Derived from IV estimate of K4 (Table 3-4a)</td>
</tr>
<tr>
<td>7 TESC Time to Correct Stock of Capital</td>
<td>12.1 qtrs</td>
<td>10 qtrs</td>
<td>2.18 qtrs</td>
<td>Derived from IV estimate of K5 (Table 3-4a)</td>
</tr>
<tr>
<td>8 TEB Time to Correct (Output) Inventory and Backlog</td>
<td>1.43 qtrs</td>
<td>3 qtrs</td>
<td>0.34 qtrs</td>
<td>Derived from IV estimate of K2 (Table 3-4a), TESC and EC</td>
</tr>
<tr>
<td>9 DEC - DBC Desired Inventory Coverage minus Desired Backlog Coverage</td>
<td>-1.18 qtrs</td>
<td>0</td>
<td>0.34 qtrs</td>
<td>Derived from IV estimate of sum of PDL lags weights in ASHIP distribution (Table 3-4a), TSC, TBE, and EC</td>
</tr>
<tr>
<td>10 DEC Desired Inventory Coverage</td>
<td>0.472 qtrs</td>
<td>1.33 qtrs</td>
<td>0.033 qtrs</td>
<td>Estimated directly from data</td>
</tr>
<tr>
<td>11 DEC Desired Backlog Coverage</td>
<td>1.65 qtrs</td>
<td>1.33 qtrs</td>
<td>0.34 qtrs</td>
<td>Estimate in Row 10 minus Estimate in Row 9</td>
</tr>
</tbody>
</table>
parameter estimates and standard deviations in Table 3-4 are derived in Appendix A of the present chapter. The appendix also explains the estimation method for each parameter in more detail.

Table 3-5 shows that the coefficient estimates and estimated lag distributions in Table 3-4 lead to plausible estimates for all SDNM parameters. Six of ten estimated parameter values fall within a factor of two of a priori parameter values. For example, TASHIP, the time constant in forming ASHIP, has an estimated value of 2.13 quarters; the a priori value for this parameter is 2 quarters. Similarly, TPRCRC, TPDSLC, MLEGS, TCSC, and TCIB fall within a factor of two of a priori estimates. Of the four parameter estimates which do not fall within a factor of two of a priori values, NLC, DIC, and (DIC - DBC) appear to deviate due to known data errors or to known inconsistencies between the industry data and definitions of variables in the SDNM consumer goods sector model. For example, shipments data measure the sum of all shipments by nondurable manufacturers. The flow of all shipments by nondurable manufacturers considerably exceeds the flow of shipments of nondurable goods to consumers. The inflated shipments data (relative to the definition of shipments in the SDNM consumer-goods sector model) cause the estimated value of DIC (which depends inversely on SHIP) to fall short of the a priori DIC. Causes for deviation of estimates of NLC and (DIC - DBC) are discussed in the Appendix to the present chapter.
The fourth deviant estimate is the estimated time to correct the supply line for capital TCSLC. TCSLC is shorter by a factor of three than the a priori estimate for TCSLC. Since no systematic bias in this estimate is known, the estimate cannot be rejected. Appendix A discusses further implications of the estimated value of TCSLC.

The results in Table 3-5 also show that estimated standard deviations for most of the parameter estimates are fairly small relative to the estimates themselves. Only one standard deviation, that for TASHIP, is larger than one-half of the respective estimate.

The results presented in Table 3-5 underscore the consistency of the SDNM formulation with available data. No parameter estimates deviate drastically from a priori values (for example, have the wrong sign) and most fall within reasonable ranges of uncertainty from a priori values. (Appendix A of the present chapter explains why some estimates in Table 3-5 are unsuitable for subsequent simulations and presents the full set of parameters used in the simulations.)

IV. COMPARISON OF FITS OF SDNM AND NEOCLASSICAL INVESTMENT FUNCTIONS

Estimation results in the preceding section provided considerable support for the SDNM investment hypotheses. Beginning with a neoclassical-type equation for capital ordering, equation fits and residual autocorrelation consistently improved as the SDNM investment
hypotheses were incorporated into the estimations. The results in Section III suggest that the SDNM investment function accounts for observed investment behavior better than the neoclassical investment function. However, such a conclusion would be premature because the neoclassical-type investment function examined in Section III had an extremely simple lag structure. This section compares performance for the two investment functions with more realistic lag distributions.

IV.A ESTIMATION PROCEDURE

General Approach. The chief problem in comparing the two investment functions lies in their disparate specifications of delays underlying the investment process. The neoclassical investment function views current capital stock as a distributed lag of past values of desired capital and, by implication, investment as a distributed lag of past changes in desired capital. Jorgenson assumes a rational-distributed lag when he estimates the response of investment to changes in desired capital. (See Section IV of Chapter 2.) The SDNM investment function distinguishes a larger variety of delays in the investment process—delays in perceiving and reacting to information, delays in adjusting current levels (of output inventory, backlog of unfilled orders for output, capital stock, and the supply-line of unfilled orders for capital) towards desired levels, and physical delays, such as the delay in receiving new capital once an order is placed. Only the information delays enter the SDNM
equations for capital ordering as lag distributions. These lag
distributions were estimated by the PDL (Almon) technique in Section III.

In order to successfully compare the two investment functions to
a common set of data, the delay structures of each formulation must be
specified for estimation in a way that preserves their essential
conceptual distinctions noted above but gives each formulation equal
"flexibility" in fitting the data.19 One approach is to eliminate all
lag distributions from each formulation, replacing distributed lags by a
single contemporaneous or lagged variable. Replacing a lag distribution
by a single variable completely constrains the shape of lag distribution
by setting all lag weights save one to zero. A second approach is to
estimate all lag distributions by a common distributed lag estimation
technique. For example, Bischoff (1971b) uses polynomial-distributed lag
PDL estimation for all lag distributions in his comparison of alternative
investment functions (including the neoclassical investment function).

The present study uses both approaches to compare the SDNM and
neoclassical investment functions. In tests similar to ones presented in
Section III, the present comparison begins by examining equation
performance when each formulation is estimated with no lag

19By flexibility, I mean degree of constraint placed prior to
estimation on the shape of a lag distribution. Unless the theories
underlying two investment functions suggest particular shapes for lag
distributions, fair comparison of the two functions requires that the lag
distributions in each be equally constrained.
distributions. The investment functions are then compared with all
lag distributions estimated by PDL estimation. Lastly, both formulations
are estimated with the rational-distributed lag approach used by
Jorgenson.

**Specification of Equations for Estimation.** Before presenting the
estimation results, a brief discussion of the estimated equations is in
order. When the lag distributions in each investment function are
replaced by single lagged variables, the two equations estimated are as
follows. (Note that elimination of all lag distributions forces omission
of expected growth in shipments from the SDNM investment function,
leaving Equation 3-10 identical to Regression 4 in the preceding section).

**SDNM:**

\[
OSC_t = K_1 \cdot CAP_t \cdot \left( \frac{SHIP_{t-1}}{PP_t} \right) \cdot RCRC_{t-1} + K_2 \cdot CAP_t \cdot \left( \frac{(B_t - IO_t)}{PP_t} \right) \cdot RCRC_{t-1} \\
+ K_3 \cdot CAP_t + K_4 \cdot \left( ORSLC_t \cdot DSLC_{t-1} - SLC_t \right) \tag{3-10}
\]

**NEOCLASSICAL:**

\[
OSC_t = K_1 \cdot (MR_{t-1} \cdot \frac{OUT_{t-1}}{CGS_{t-1}}) + K_2 \cdot CAP_t \tag{3-11}
\]

To enhance comparability of results, order starts for capital OSC becomes
the dependent variable for the neoclassical formulation in Equation
(3-11). The above specification of the neoclassical investment function
can be interpreted within the stock adjustment framework described in Section IV of Chapter 2 (see Equation 2-36).²⁰

PDL estimation for the neoclassical formulation follows directly from Equation (3-11) above by replacing the first term by a lag distribution. PDL estimation of the SDNM formulation treats average shipments ASHIP, expected growth in shipments EGS, and perceived delay in supply line for capital PDSLC as distributed lags. Equation (3-12) replaces the PRCRC lag distribution RCRCT₋₁. Equation (3-12) matches Regression (7) in Section III.

**SDNM:**

\[
OSC_t = \text{CAP}_{t} \cdot (\sum_{i} w_{i} \cdot \text{SHIP}_{t-i/PP_{t}}) \cdot RCRCT₋₁ + K2 \cdot \text{CAP}_{t} \cdot ((B_{t} - IO_{t})/PP_{t}) \cdot RCRCT₋₁
\]

\[
+ K3 \cdot \text{CAP}_{t} + \text{CAP}_{t} \cdot \sum_{i} w_{i} \cdot \Delta \text{SHIP}_{t-i} \cdot \text{ORSLC}_{t} \cdot \sum_{i} w_{i} \cdot \text{DYSLC}_{t-i}
\]

\[
+ K4 \cdot \text{SLC}_{t}
\]

(3-12)

**NEOClassICAL:**

\[
OSC_t = \sum_{i} w_{i} \cdot \left(\frac{MR_{i} \cdot \text{OUT}_{t}}{CCS_{t}}\right)_{t-i} + K2 \cdot \text{CAP}_{t}
\]

(3-13)

²⁰Recall that EC \cdot MR \cdot OUT \cdot CCST equals DCAP in the neoclassical formulation — Equation 2-30.
PDL estimation permits the most informative comparison of the two investment functions. Equation (3-12) embodies all five SDNM investment hypotheses, though the lag distribution underlying perceived ratio of capital return to cost PRCRC is replaced by a single lagged variable \( RCR_{t-1} \).21 Equation (3-13) can be derived from Equation (3-12) by eliminating all five SDNM investment hypotheses, by substituting output OUT for SHIP and production for potential production in the first coterm in Equation (3-12), and by treating the entire first coterm in Equation (3-12) as a single distributed lag. (See Section IV.A of Chapter 2.)

Rational-distributed lag estimation imposes different restrictions than PDL estimation in specifying the SDNM investment function. Recall that application of the rational-distributed lag begins with the assumption that current capital equals a distributed lag of past values of desired capital:

\[
CAP_t = \mu(\Theta) DCAP_t
\]

Equation 2-32 (repeated)

Taking first differences and assuming that the lag distribution \( \mu(\Theta) \) can be expressed as the ratio of two lag distributions, \( \psi(\Theta) \) and \( \omega(\Theta) \) gives

21PRCRC is replaced by a single lagged value of RCR to avoid performing the iterative procedure described above for estimating the PRCRC lag distribution for each set of industry data.
the basic form for a rational-distributed lag investment function:

$$\omega(\Theta)(I_t - \text{CAP}_t) = \gamma(\Theta)(\text{DCAP}_t - \text{DCAP}_{t-1})$$

Equation 2-27 (repeated)

Three modifications are required to cast the SDNM investment function in the form of Equation 2-35. First, investment expenditures must replace order starts for capital as the dependent variable. Second, the effect of growth expectations must be incorporated into desired capital. The modified SDNM formulation for desired capital DCAP' then becomes:

$$\text{DCAP'}_t = \text{CAP}_t \cdot (\text{PR}_t \cdot \text{PRRC}_t + \text{EGS}_t \cdot \text{TCSC})$$

(3-14)

where PR equals the production ratio (ratio of desired output to potential production) and TCSC equals the time to correct the stock of capital (a parameter). Equation (3-14) can be interpreted as

The parameter TCSC in Equation (3-14) represents the planning horizon over which the expected growth trend is extrapolated to determine the level of capital required for expected growth. An alternative formulation for DCAP' would replace TCSC by PDSL as a measure of the planning horizon, as is done by Mass (see Mass 1975, p. 105-106). PDSL is not used because the PDSL lag distribution would then appear with every lagged value of DCAP in the rational distributed lag (Equation 2-27 above). The multiple occurrences of the PDSL lag distribution would greatly increase collinearity.
follows. The desired stock of capital equals the current stock adjusted to meet perceived need for more or less output and for a greater or smaller capital-output ratio, and also adjusted to reflect expected growth over the time required to adjust capital. Finally, the supply-line correction is eliminated. The hypothesized supply-line correction is eliminated because the hypothesis cannot plausibly be incorporated as a determinant of desired capital.23

Therefore, estimation of the SDNM and neoclassical investment functions using rational-distributed lags is accomplished by expressing both investment functions in the form given in Equation (2-35). The investment functions differ only in how they determine desired capital DCAP:

SDNM:

\[ \text{DCAP}'_t = K1 \cdot \text{CAP}_t \cdot (\text{SHIP}_{t-1}/\text{PP}_t) \cdot \text{RCRC}_{t-1} + K2 \cdot \text{CAP}_t \cdot ((B_t - IO_t)/\text{PP}_t) \cdot \text{RCRC}_{t-1} \]
\[ + K3 \cdot \text{CAP}_t \cdot \text{EGS}_t \]  \hspace{1cm} (3-15)

NEOCLASSICAL:

\[ \text{DCAP}_t = MP_t \cdot \text{OUT}_t/\text{CCS}_t \]  \hspace{1cm} (3-16)

23 The supply-line correction has no role in an investment function in which the desired rate of capital acquisition affects expenditures directly. If new capital automatically arrives at the desired rate, there is no motivation to manage the supply-line for capital to assure that capital arrives at the desired rate.
Note that Equation (3-15) approximates the separate delays in ASHIP and PRCRC hypothesized in the SDNM formulation by replacing each lag distribution by a single lagged variable (i.e., \(\text{SHIP}_{t-1}\) and \(\text{RCRC}_{t-1}\)). The EGS lag distribution is formed prior to estimation as in Regression B in Section III.

All estimations in Section IV are performed by ordinary least squares. OLS is used for the rational distributed lag estimations, despite the presence of lagged dependent variables, for consistency with Jorgenson's published results.

IV.B ESTIMATION RESULTS

Tables 3-6, 3-7, and 3-8 respectively summarize regression results with the three different distributed-lag estimation approaches. The tables show that the SDNM investment function consistently improves upon the performance of the neoclassical investment function with lag distributions replaced by single lagged variables and with polynomial-distributed lags.\(^{24}\) For example, when both investment

\(^{24}\)Note that the F-statistics presented in Tables 3-6, 3-7 and 3-8 are for the standard regression F-test of the hypothesis that all coefficients are zero:

\[
F = \frac{R^2/(k-1)}{(1-R^2)/(n-k)}
\]

where \(k\) is number of explanatory variables (coterms) and \(n\) is the number of observations (see Johnston 1972, p. 143).
formulations are estimated with lag distributions replaced by variables lagged one period (Table 3-6), results for total nondurable manufacturing show that $\bar{R}^2$ equals 0.657 with the neoclassical formulation and 0.791 with the SDNM. The improvement in $\bar{R}^2$ corresponds to a substantial reduction in unexplained variability (SER falls 22%, from 0.805 to 0.628). Residual autocorrelation likewise improves sharply with the SDNM formulation: DW equals 0.60 with the neoclassical formulation and 0.92 with the SDNM formulation. The $F$-statistic falls for the SDNM investment function because the SDNM formulation has more explanatory variables than the neoclassical formulation (see Footnote 24). However, the $F$-statistic for the SDNM formulation is significant at the 0.99 level for total nondurables. Table 3-6 shows similar improvement in performance for the three other sets of industry data, although the degree of improvement is smaller for the more disaggregate industry groups.

When both investment functions are estimated with polynomial distributed lags (Table 3-7), $\bar{R}^2$ equals 0.691 with the neoclassical formulation and 0.931 with the SDNM formulation for total nondurables. Unexplained variability falls even further than in the regressions with

25Note that fits obtained with the neoclassical-type investment functions are depressed below fits obtainable with such formulations due to the simplified data for the cost of capital services (see Equation 2-19 and footnote 11 in Chapter 2). Nonetheless, Tables 3-6, 3-7, and 3-8 present valid measures of the relative fits of each investment function because the cost of capital services is determined identically for the SDNM and neoclassical formulations.
### Table 3-6

**Goodness of Fit Measures for SDNM and Neoclassical Investment Functions --**

**Lag Distributions Replaced by Single Lagged Variables**

<table>
<thead>
<tr>
<th>Data</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNM</td>
<td>$R^2 = 0.491$</td>
<td>$R^2 = 0.844$</td>
<td>$R^2 = 0.819$</td>
<td>$R^2 = 0.699$</td>
</tr>
<tr>
<td></td>
<td>SER = 0.628</td>
<td>SER = 0.521</td>
<td>SER = 0.662</td>
<td>SER = 0.102</td>
</tr>
<tr>
<td></td>
<td>F(3</td>
<td>184) = 110.9*</td>
<td>F(3</td>
<td>184) = 185.3*</td>
</tr>
<tr>
<td></td>
<td>DW = 0.92</td>
<td>DW = 1.00</td>
<td>DW = 0.81</td>
<td>DW = 1.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoclassical</td>
<td>$R^2 = 0.657$</td>
<td>$R^2 = 0.674$</td>
<td>$R^2 = -0.167$</td>
<td>$R^2 = 0.561$</td>
</tr>
<tr>
<td></td>
<td>SER = 0.805</td>
<td>SER = 0.619</td>
<td>SER = 0.766</td>
<td>SER = 0.415</td>
</tr>
<tr>
<td></td>
<td>F(1</td>
<td>186) = 164.5*</td>
<td>F(1</td>
<td>186) = 182.7*</td>
</tr>
<tr>
<td></td>
<td>DW = 0.60</td>
<td>DW = 0.39</td>
<td>DW = 0.49</td>
<td>DW = 0.58</td>
</tr>
</tbody>
</table>

* Significant at the 0.99 level

### Table 3-7

**Goodness of Fit Measures for SDNM and Neoclassical Investment Functions --**

**Polynomial Distributed Lags**

<table>
<thead>
<tr>
<th>Data</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNM</td>
<td>$R^2 = 0.931$</td>
<td>$R^2 = 0.912$</td>
<td>$R^2 = 0.447$</td>
<td>$R^2 = 0.812$</td>
</tr>
<tr>
<td></td>
<td>SER = 0.358</td>
<td>SER = 0.412</td>
<td>SER = 0.055</td>
<td>SER = 0.090</td>
</tr>
<tr>
<td></td>
<td>F(10</td>
<td>13) = 112.8*</td>
<td>F(10</td>
<td>13) = 86.8*</td>
</tr>
<tr>
<td></td>
<td>DW = 1.96</td>
<td>DW = 1.53</td>
<td>DW = 1.11</td>
<td>DW = 1.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoclassical</td>
<td>$R^2 = 0.691$</td>
<td>$R^2 = 0.762$</td>
<td>$R^2 = 0.036$</td>
<td>$R^2 = 0.583$</td>
</tr>
<tr>
<td></td>
<td>SER = 0.774</td>
<td>SER = 0.797</td>
<td>SER = 0.072</td>
<td>SER = 0.134</td>
</tr>
<tr>
<td></td>
<td>F(14</td>
<td>11) = 42.8*</td>
<td>F(14</td>
<td>69) = 59.4*</td>
</tr>
<tr>
<td></td>
<td>DW = 0.68</td>
<td>DW = 0.41</td>
<td>DW = 0.63</td>
<td>DW = 0.59</td>
</tr>
</tbody>
</table>

†All lag weights lie along third order polynomials. Lag lengths are determined by experimenting to find the lag length for each investment function which minimizes SER. (In most cases, the lag lengths for the investment functions differ.)

* Significant at the 0.99 level
**Table 3-8**

Goodness of Fit Measures for SDNM and Neoclassical Investment Functions—Rationally Distributed Lags*

<table>
<thead>
<tr>
<th></th>
<th>Total Nondurable Manufacturing</th>
<th>Total Durable Manufacturing</th>
<th>Textile Mill Products</th>
<th>Electrical Machinery &amp; Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SDNM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.983</td>
<td>$R^2 = 0.983$</td>
<td>$R^2 = 0.985$</td>
<td>$R^2 = 0.943$</td>
</tr>
<tr>
<td>$SER$</td>
<td>0.120</td>
<td>$SER = 0.134$</td>
<td>$SER = 0.055$</td>
<td>$SER = 0.0270$</td>
</tr>
<tr>
<td>$F(13/67)$</td>
<td>$356.6$</td>
<td>$F(13/67) = 362.6$</td>
<td>$F(13/69) = 49.4$</td>
<td>$F(13/68) = 229.8$</td>
</tr>
<tr>
<td>$DW$</td>
<td>2.01</td>
<td>$DW = 2.13$</td>
<td>$DW = 2.04$</td>
<td>$DW = 2.01$</td>
</tr>
<tr>
<td><strong>Neoclassical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.980</td>
<td>$R^2 = 0.934$</td>
<td>$R^2 = 0.883$</td>
<td>$R^2 = 0.960$</td>
</tr>
<tr>
<td>$SER$</td>
<td>0.130</td>
<td>$SER = 0.130$</td>
<td>$SER = 0.0155$</td>
<td>$SER = 0.0805$</td>
</tr>
<tr>
<td>$F(5/76)$</td>
<td>$74.91$</td>
<td>$F(5/76) = 105.1$</td>
<td>$F(5/78) = 126.0$</td>
<td>$F(5/77) = 472.4$</td>
</tr>
<tr>
<td>$DW$</td>
<td>2.03</td>
<td>$DW = 2.12$</td>
<td>$DW = 2.06$</td>
<td>$DW = 2.01$</td>
</tr>
</tbody>
</table>

*The number of lags for DCAP and $(1 - \delta \cdot \Delta CAP)$ in Equation (2-35) are determined by the number of lags for the respective industry group in Jorgenson and Stephenson (1967a). Values for $\delta$, which must be supplied prior to estimation, are computed from capital stock and expenditures data by the following formula:

$$\delta = \text{mean} \left( \frac{I_t - \Delta \text{CAP}_t - 1}{\text{CAP}_{t-1}} \right)$$

Single lagged variables. SER declines 54% from 0.774 to SER = 0.358 and residual autocorrelation again improves sharply (from DW = 0.68 to DW = 1.96) with the SDNM formulation. Table 3-7 shows that the SDNM formulation leads to comparable improvement in fit for all four sets of industry data.

Inconclusive results are obtained when both investment functions are estimated with rational-distributed lags. Table 3-8 shows that the SDNM investment function obtains a better $R^2$ for 3 of 4 sets of industry data. However, the improvement in fit is small (eg., $R^2$ increases only from 0.980 to 0.983 for total nondurables), and the SDNM
formulation fails to improve upon the fit obtained with the neoclassical formulation for total durable manufacturing. Both formulations show little residual autocorrelation. Because it involves fewer explanatory variables, the neoclassical formulation has a consistently higher F-statistic than the SDNM formulation when both are estimated with the rational-distributed lag.

There appear to be two reasons for the failure of the SDNM formulation to improve upon the neoclassical formulation when both are estimated with rational-distributed lags. The first is omission of the supply-line correction when the SDNM formulation is estimated with a rational-distributed lag. The second and probably more important cause of the relatively similar fits in Table 3-8 is the rational-distributed lag itself. As can be seen from Equation (2-35), the rational-distributed lag leads to the inclusion of lagged-dependent variables in each investment function. Due to the high degree of autocorrelation in investment expenditures, lagged values of expenditures account for almost all movement in current expenditures in the rational-distributed lag estimations. In most of the regressions in Table 3-8, coefficients of the lagged dependent variables are the only statistically significant estimates. Because the lagged dependent variables leave little leeway for explanatory variables to account for movements in expenditures, the rational-distributed lag provides a poor approach for comparing fits of alternative investment functions.
V. SUMMARY

This chapter has analyzed the consistency of the SDNM investment function with available industry data. The analysis has revealed statistical evidence for specific SDNM investment hypotheses and indicated broad support for choosing the SDNM over the neoclassical investment function.

Before the analysis could be carried out, two simplifications of the SDNM formulation had to be made to facilitate statistical estimation. By eliminating the ratio of lag distributions in forming expected growth in shipments and the product of lag distributions in the supply-line correction, the SDNM investment function was made amenable to linear estimation techniques with little cost to the realism of the formulation.

The first attempt to assess statistical support for the SDNM investment hypotheses involved a series of regressions in which the hypotheses were successively incorporated into the investment function. Results for the series of regressions showed that inclusion of the hypothesized inventory and backlog corrections, supply-line corrections and expected growth in shipments significantly improved fit and reduced residual autocorrelation for four sets of industry data (Regressions 3, 4, and 5 of Table 3-2). Improved equation performance occurred even though the inventory, backlog, and supply-line corrections were estimated without associated lag distributions. Equation performance
improved further when the perceived delay in supply line for capital
PDLSC lag distribution was incorporated into the regression (Regression
7, Table 3-2). Estimating the ASHIP lag distribution (see Regression 6)
had a negligible impact on equation performance due to the short length
of the lag distribution (see Table 3-4a).

Statistical support for the hypothesized delay in forming
perceived ratio of capital return to cost PRCRC was assessed via a formal
statistical test of the hypothesis of no delay. The SDNM investment
function hypothesizes that desired capital responds to a product of two
lag distributions, a distributed lag of shipments SHIP and a distributed
lag of ratio of capital return to cost RCRC. The neoclassical framework
implies that desired capital responds to a single distributed lag of the
product SHIP RCRC. It was found that the hypothesis of a single
distributed lag of the product SHIP·RCRC could be rejected at the 0.99
level for 3 of 4 sets of industry data (Table 3-3).

Examination of parameter estimates and estimates lag
distributions provided further evidence of consistency with available
data. Table 3-4 showed that plausible statistically significant
estimates could be obtained for the SDNM investment function. Estimated
lag distributions had the expected length and shape, and all parameter
estimates had the correct sign. When values for the ten structural
parameters and delay times were derived from the statistical estimates,
most were within a factor of two of a priori values (Table 3-5), thereby
further showing the plausibility of estimation results.
Lastly, the SDNM and neoclassical investment functions were compared using different distributed lag estimation techniques. The polynomial distributed lag (PDL) technique was clearly the best technique for comparing the alternative formulations because it was flexible (i.e., imposed few constraints on lag shape) yet avoided the lagged dependent variables which inflate measures of fit with rational-distributed lags. When both investment functions were estimated with polynomial distributed lags, the SDNM formulation substantially improved upon the fit, residual autocorrelation, and statistical significance (F-test) of the neoclassical formulation for each set of industry data (Table 3-7).
APPENDIX A OF CHAPTER 3. DERIVATION OF STRUCTURAL PARAMETERS AND DELAY TIMES

This appendix derives estimates and standard errors for the structural parameters and delay times in the SDNM investment function based on estimation results in Table 3-4. The analysis also determines parameter values for use in subsequent simulations involving the SDNM investment function.

Structural Parameters. The SDNM investment function includes six structural parameters:

- **TCSLC**  Time to correct the supply line for capital
- **NLC**  Normal loss of capital
- **TCSC**  Time to correct the stock of capital
- **TCIB**  Time to correct (output) inventory and backlog
- **DIC**  Desired inventory coverage
- **DBC**  Desired backlog coverage

The structural parameters are related to the estimated coefficients $K_1$ through $K_4$ in Equation (3-4), according to the following relationships...
(see Equation (2-26)).

\[ \begin{align*}
K_1 &= \left( \frac{EC}{TCSC} \right) \left( \frac{1 + (DIC - DBC)}{TCIB} \right) \quad (A-1) \\
K_2 &= \left( \frac{EC}{TCSC} \right) \left( \frac{1}{TCIB} \right) \quad (A-2) \\
K_3 &= NLC - \left( \frac{1}{TCSC} \right) \quad (A-3) \\
K_4 &= \frac{1}{TCSLC} \quad (A-4)
\end{align*} \]

Given only estimates for the four coefficients \( K_1, K_2, K_3, \) and \( K_4 \), it is not possible to derive unique estimates of the six structural parameters plus the exponent for capital (in the production function) \( EC \). However, given estimates of \( EC \) and \( NLC \), estimates of three of the remaining five structural parameters can be obtained by the sequence of Equations (A-5) through (A-7). Equation (A-8) yields an estimate of

\[ \delta_t \]

\[ \Delta \text{CAP}_t = \text{I}_t - \delta_t \cdot \text{CAP}_{t-1} \]

For total non-durables, the above relationship yields an estimated value of \( NLC \) of \( 0.0384 \text{ qtr.}^{-1} \pm 0.0156 \text{ qtr.}^{-1} \) (the standard deviation of \( \delta_t \)).

\[ 26 \text{ Note that the exponent for capital } EC \text{ appears in Equations (A-1) and (A-2) but not in Equation (2-26) because it was subsumed in the perceived ratio of capital return to cost PRCRC in the earlier equation. Because } EC \text{ was not used in forming data for PRCRC, it is subsumed into the coefficients } K_1 \text{ and } K_2 \text{ when Equation (3-4) is estimated.} \]

\[ 27 \text{ Estimates for } EC \text{ are available from past production function studies; the following derivations assume } EC \text{ equals } 0.35 \text{ (see Douglas 1967). Normal loss of capital } NLC \text{ is estimated directly from capital-stock and investment-expenditure data using the following relation } \text{(NLC = mean of } \delta_t)\text{.} \]
the difference (DIC-DBC), which can then be combined with an estimate of DIC derived directly from nondurable data to yield an estimate of DBC.

\[
\hat{TC}_{SLC} = \frac{1}{\hat{K}_4} \quad \text{(A-5)}
\]

\[
\hat{TC}_{SC} = \frac{1}{\hat{NL}_C - \hat{K}_3} \quad \text{(A-6)}
\]

\[
\hat{TC}_{IB} = \frac{\hat{EC}}{(\hat{K}_2 \cdot \hat{TC}_{SC})} \quad \text{(A-7)}
\]

\[
\hat{DIC} - \hat{DBC} = (\hat{TC}_{SC} \cdot \hat{K}_1 / \hat{EC} - 1) \cdot \hat{TC}_{IB} \quad \text{(A-8)}
\]

Proceeding through Equations (A-5) through (A-8) leads to the parameter estimates in rows 6 through 9 in Table 3-5. Estimates for \( K_1, K_2, K_3, \) and \( K_4 \) are taken from Table 3-4a. DIC is estimated as the mean value of the quarterly ratios of inventory of output to shipments for total nondurable manufacturers:

\[
\hat{DIC} = \text{mean} \left( \frac{IO_t}{SHIP_t} \right)
\]

Delay Times. Estimates of the delay times, the time constants for the exponentially delayed variables in the SDNM investment function, are derived from the estimated lag distributions in Table 3-4. The five delay times to be estimated are:

\[\text{Note that } \hat{K}_1 = \sum w_i \text{ due to the constraint that the sum of the lag weights for the ASHIP lag distribution equals unity.}\]
TASHIP  Time to average shipments
TPRCRC  Time to perceive ratio of capital return to cost
TPDASLC Time to perceive the delay in the supply line for capital
TSTAS   Time for short-term averaging of shipments
TLTAS   Time for long-term averaging of shipments

The first three delay times are respectively estimated from the ASHIP, PRCRC, and PDSLC lag distributions in Table 3-4. The last two delay times are involved in forming the short- and long-term averages of shipments required for expected growth in shipments EGS (see Equation 2-20). These delay times must be chosen from examining the EGS' lag distribution in Table 3-4a.

To estimate the delay times TASHIP, TPRCRC, and TPDSLC, first note that the all three respective estimated lag distributions in Table 3-4 have almost continuously declining lag weights: $w_{1i}$ and $w_{3i}$ in Table 3-4a decline continuously, $w_{1i}$ in Table 3-4b decline continuously except for $w_6$ which increases slightly relative to $w_5$. The continuously declining pattern of lag weights for the ASHIP, PRCRC and PDSLC lag distributions makes it possible to generate each delayed variable by first-order exponential smoothing when the SDNM investment function is simulated in Chapters 4 and 5. The variables were generated by first-order exponential smoothing in previous simulations of the SDNM investment functions (see Forrester and Mass 1976); hence, the estimation results are consistent with prior specification of the three delays.
The time constants for the first-order exponential smoothing for PDSL C and PR CRC can be estimated from the estimated mean lags for the respective lag distributions. For example, assume that the PR CRC lag distribution is generated by first-order exponential smoothing of the ratio of capital return to cost RC RC:

\[
\frac{d}{dt} \text{PR CRC}_t = \frac{1}{\text{TPR CRC}} \left( \text{RC RC}_t - \text{PR CRC}_t \right)
\]  \hspace{1cm} (A-9)

The discrete version to Equation (A-9),

\[
\text{PR CRC}_t = \left( \frac{1}{\text{TPR CRC}} \right) \text{RC RC}_t + \left( 1 - \frac{1}{\text{TPR CRC}} \right) \text{PR CRC}_{t-1}
\]  \hspace{1cm} (A-10)

can be solved to give PR CRC as a distributed lag of past values of RC RC:

\[
\text{PR CRC}_t = \left( \frac{1}{\text{TPR CRC}} \right) \sum_{i=0}^{\infty} \left( 1 - \frac{1}{\text{TPR CRC}} \right)^i \text{RC RC}_{t-i}
\]  \hspace{1cm} (A-11)

The mean lag for the geometrically-declining lag distribution in Equation (A-11) \( \text{ML}_{\text{PR CRC}} \) is related to the exponential smoothing time constant TPR CRC by the following equation:\(^{29}\)

\(^{29}\)See Johnston 1972, p. 299.
where $M_{PRCRC}$ and $TPCRC$ are expressed in quarters because the data used for estimation are quarterly. The mean lag for the PDSLCl lag distribution is related to $TPDSLCl$ by a similar equation:

\[ M_{PDSLCl} = TPDSLCl - 1 \]  

(A-13)

The values for $TPCRC$ and $TPDSLCl$ in Table 3-5 are derived from the respective mean lags in Table 3-4 using equations (A-12) and (A-13).

A slightly different procedure is used to derive an estimate of TASHIP from the estimated ASHIP lag distribution. The short length of the ASHIP lag distribution makes the estimated mean lag an unreliable basis for estimating TASHIP.\(^{30}\) An alternative estimate for TASHIP can

---

\(^{30}\)The mean lag computed from the three estimated lag weights $\hat{w}_1$, $\hat{w}_1$, $\hat{w}_0$ has an extremely large standard deviation, owing to $\hat{w}_1$ in Table 3-4a has an extremely large standard deviation, owing to $\hat{w}_2$ the large standard deviation for $\hat{w}_1$. Conversely, if $\hat{w}_1$ is neglected in computing the mean lag, the resulting mean lag probably underestimates the true mean lag.
be derived by assuming that the first two estimated lag weights in the
ASHIP lag distribution (the only statistically significant estimates) lie
along a geometrically-declining lag distribution—ie.,

\[ w_{11} = (\lambda) \cdot (1 - \lambda)^i \]  \hspace{1cm} (A-14)

If \( \hat{w}_{10} \) and \( \hat{w}_{11} \) lie along such a lag distribution, then the ratio
of the two estimated lag weights provides an estimate of the geometric
distribution constant \( \lambda \):

\[ \frac{\hat{w}_{11}}{\hat{w}_{10}} = (1 - \lambda) \]  \hspace{1cm} (A-15)

or,

\[ \hat{\lambda} = 1 - \frac{\hat{w}_{11}}{\hat{w}_{10}} \]  \hspace{1cm} (A-16)

Comparison of equations (A-11) and (A-14) shows that the geometric
distribution constant \( \lambda \) equals the inverse of the time constant for
first-order exponential smoothing (TPRCRC in Equation A-11). Hence,

\[ \frac{\hat{\lambda}}{\hat{\lambda}} = \left(1 - \frac{\hat{w}_{11}}{\hat{w}_{10}}\right)^{-1} \]  \hspace{1cm} (A-17)
The estimate of TASHIP in Table 3-5 is derived using Equation A-17 and the values for $\hat{\omega}_{0}$ and $\hat{\omega}_{1}$ in Table 3-4a.

Estimating the two delay times involved in forming expected growth in shipments EGS, TSTAS and TLTAS is complicated by the simplification of the EGS lag distribution required for estimation. Recall that the original SDNM formulation for EGS,

$$\text{EGS} = \frac{\text{STASHIP}_t - \text{LTASHIP}_t}{\text{LTAS}\cdot\text{LTASHIP}_t}$$

(Equation 2-20, repeated)

is approximated for estimation by a distributed lag of fractional changes in shipments SHIP:

$$\text{EGS'} = \sum_{i} w_i \cdot \frac{\Delta\text{SHIP}_{t-1}}{\text{SHIP}_{t-(i+1)}}$$

(Equation 3-2, repeated)

The first step in relating the estimated lag weights for the EGS' lag distribution to values for TSTAS and TLTAS involves examining the general pattern of EGS response to a change in shipments SHIP. Figure 3A-1 shows the response of STASHIP, LTASHIP, and EGS to a step increase in SHIP. Note that STASHIP and LTASHIP initially equal SHIP. When SHIP increases at time $t_0$, both delayed variables begin to adjust toward the new value of SHIP, although the pattern of response for STASHIP and LTASHIP differ. The rate of increase of STASHIP declines continuously as
it approaches SHIP. LTASHIP accelerates initially, as the difference between STASHIP and LTASHIP increases. Beyond time $t_1$, when the difference between STASHIP and LTASHIP is a maximum, the rate of increase in LTASHIP gradually falls as it approaches SHIP.\textsuperscript{31}

Figure 3A-1 shows that the response of STASHIP and LTASHIP to the step increase in SHIP leads to a "bell-shaped" response of expected growth in shipments. EGS rises as the difference between STASHIP and LTASHIP increases, reaching a peak slightly before time $t_1$. EGS

\[ EGS_t = \frac{STASHIP_t - LTASHIP_t}{TLTAS \cdot LTASHIP_t} \]

\textbf{FIGURE 3A-1}

Response of STASHIP, LTASHIP, and EGS to a step increase in SHIP

\textsuperscript{31} For a general discussion of the response of first- and second-order exponentially smoothed variables, see Forrester (1961), Chapter 9.
gradually falls back toward zero after the peak as LTASHIP gradually adjusts toward STASHIP.

The "bell-shaped" response of EGS in Figure 3A-1 matches the estimated EGS' lag distribution in Table 3-4a and provides a possible explanation for the estimated lag pattern. Table 3-4a shows that estimated EGS' lag weights increase from \( \hat{w}_{20} \) to \( \hat{w}_{28} \); the lag weights decline from \( \hat{w}_{29} \) to \( \hat{w}_{13} \). The estimated bell-shaped lag distribution implies that investment responds more strongly to quarterly growth rates lagged several quarters than to recent changes in shipments. The underlying theoretical structure describing the formation of trend perceptions in the SDNM suggests that such a response occurs for two reasons. First, producers' perceptions of shipment rates during recent history, represented by STASHIP, adjust only gradually to changes in SHIP. If STASHIP responded immediately to changes in SHIP, EGS would rise immediately to a maximum and then decline in Figure 3A-1. Second, producers' perception of the long-term historical rate of shipments against which recent history is compared, represented by LTASHIP, adjusts over a much longer period to changes in SHIP. The long-term adjustment of LTASHIP causes the difference between STASHIP and LTASHIP eventually

---

32 The shape of the EGS response in Figure 3A-1 can be compared directly to the shape of the EGS' lag distribution because the step increase in SHIP in Figure 3A-1 is equivalent to an "impulse" change in \( \Delta \text{SHIP}_t / \text{SHIP}_{t-1} \). A lag distribution can always be viewed as the response to an impulse in the lagged variable (see Griliches 1967).
LTASHIP eventually to decline toward zero. Therefore, the trend-perception mechanism hypothesized in the SDNM causes EGS to respond to a change in SHIP in a manner consistent with the estimated EGS' lag distribution, and thereby provides a possible explanation for the estimated lag distribution.

The consistency of the theoretical and estimated response response of EGS allows one to choose values for TSTAS and TLTAS based on the estimated EGS' lag distribution. The a priori values for the two delay times, TSTAS = .5 years and TLTAS = 4.5 years, lead EGS to respond somewhat more rapidly than implied by the estimated EGS' lag distribution.\textsuperscript{33} With the a priori values for TSTAS and TLTAS, EGS rises to a peak value three quarters after a step increase in SHIP and the mean lag for the first thirteen quarters equals 6.1 quarters.\textsuperscript{34} By

\textsuperscript{33}The a priori times for TSTAS and TLTAS are implicit in parameter values in the PSIO and MACR8 data sets of the System Dynamics National Project.

\textsuperscript{34}The response of EGS is obtained by computing STASHIP, LTASHIP, and EGS (using Equation 2-20) in response to a step increase in SHIP. The "mean lag" for the response of EGS is computed analogously to the computation of a mean lag for a lag distribution (note that prior to $t_0$, EGS = 0):

$$ML = \frac{\sum_{t=t_0}^{t_0+13} EGS_t \cdot (t - t_0)}{\sum_{t=t_0}^{t_0+13} EGS_t}.$$ 

The computation only subsumes the first 13 quarters of the EGS response because the estimated EGS' lag distribution does not extend beyond a 13-quarter lag.
contrast, the estimated EGS' lag distribution rises to a peak 8 quarters after a change in SHIP and has a mean lag after 13 quarters of 7.25 quarters. After experimenting with different combinations of values for TSTAS and TLTAS, the following were chosen for use in subsequent simulation:

TSTAS = 4 qtr.
TLTAS = 16 qtr.

With the above values, EGS rises to a peak value 5 quarters after a step increase in SHIP and has a mean lag after 13 quarters of 6.72 quarters. The EGS response generated with the above values of TSTAS and TLTAS appears to fit the estimated EGS' lag distribution about as well as can be accomplished, given an a priori constraint that TLTAS must be considerably longer than TSTAS.35

Standard Deviations of Estimates. Standard deviations for estimates of structural parameters are derived from Equations (A-5) through (A-8) using estimated standard deviations and covariances for $\hat{K}_1$, $\hat{K}_2$, $\hat{K}_3$, and

35This constraint stems from the notion that STASHIP represents average shipments during recent history, while LTASHIP represents average shipments during much more distant historical periods. If one relaxes this constraint, it may be possible to find values of TSTAS and TLTAS (eg., TSTAS = 3 years, TLTAS = 1 year) which generate an EGS response somewhat closer to the estimated EGS' lag distribution.
K4. Nonlinear relations between structural parameters and estimated coefficients are approximated by Taylor series expansions.

To illustrate how standard deviations are estimated, consider the estimate of TCSLC. Equation (A-5) shows that \( \hat{K4} \) equals the inverse of \( \hat{K4} \). To estimate the standard deviation of TCSLC, Equation (A-5) must be linearized.\(^{36}\) To linearize Equation (A-5), the nonlinear relationship for TCSLC can be approximated by a first-order Taylor series expansion about the estimate \( \hat{K4} \):\(^{37}\)

\(^{36}\)The equation must be linearized because expectation is commutative only for linear relationships:

\[ E(f(\bar{x})) = f(E(\bar{x})) \]

only if \( f(\cdot) \) is a linear function \((\bar{x} \) is a random variable).

\(^{37}\)The general formula for the Taylor series expansion of \( f(\bar{x}) \), where \( \bar{x} \) is a vector, about a point \( \bar{x}_0 \) is:

\[ f(\bar{x}) = f(\bar{x}_0) + \sum \frac{\partial f(\bar{x}_0)}{\partial \bar{x}^i} \cdot (\bar{x} - \bar{x}_0) + \frac{1}{2!} \sum \frac{\partial^2 f(\bar{x}_0)}{\partial \bar{x}^i \partial \bar{x}^j} \cdot (\bar{x} - \bar{x}_0)^2 \]

\[ + \frac{1}{3!} \sum \frac{\partial^3 f(\bar{x}_0)}{\partial \bar{x}^i \partial \bar{x}^j \partial \bar{x}^k} \cdot (\bar{x} - \bar{x}_0)^3 + \ldots \]

where \( \frac{\partial f(\bar{x}_0)}{\partial \bar{x}} = \left( \begin{array}{c} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \end{array} \right) \)

\( \bar{x} = \bar{x}_0 \)

and \( 2! = 2 \cdot 1, 3! = 3 \cdot 2 \cdot 1, \ldots \)

A first-order Taylor series expansion includes only the first two terms in the full Taylor series.
\[ \tilde{\kappa}_{\text{TCSLC}} = \frac{1}{\hat{\kappa}_4} = \frac{1}{\hat{\kappa}_4} + \left. \frac{\partial (1/\hat{\kappa}_4)}{\partial \hat{\kappa}_4} \right|_{\hat{\kappa}_4} \cdot (\hat{\kappa}_4 - \hat{\kappa}_4) \]  
(A-18)

\[ \tilde{\kappa}_{\text{TCSLC}} = \frac{1}{\hat{\kappa}_4} - \frac{1}{\hat{\kappa}_4^2} \cdot (\hat{\kappa}_4 - \hat{\kappa}_4) \]  
(A-19)

where \( \hat{\kappa}_4 \) denotes the random variable estimate of \( \kappa_4 \) and \( \hat{\kappa}_4 \) denotes the estimated value of \( \kappa_4 \). From Equation (A-19) one can derive an expression for the standard deviation of \( \tilde{\kappa}_{\text{TCSLC}} \):

\[ \text{STD.DEV.}(\tilde{\kappa}_{\text{TCSLC}}) = \frac{1}{\hat{\kappa}_4^2} \cdot \text{STD.DEV.}(\hat{\kappa}_4) \]  
(A-20)

Using values from Table 3-4a for the estimated value and standard deviation of \( \hat{\kappa}_4 \) gives:

\[ \text{STD.DEV.}(\tilde{\kappa}_{\text{TCSLC}}) = \frac{1}{(0.331)^2} \cdot (0.094) = 0.860 \]  
(A-21)

Equations (A-22) through (A-29) show how standard deviations for the remaining structural-parameter estimates are computed. Each equation gives the variance of the respective structural-parameter estimate as a function of variances and covariances of coefficient estimates and the coefficient estimates themselves. Standard deviations are computed by taking the square root of the variance. Values of the coefficient
estimates and coefficient-estimate variances are taken from Table 3-4a; coefficient-estimate covariances are taken from the same regression. 38

The variance formulae are derived by determining the variance of the first-order Taylor series approximation for Equations (A-6) through (A-8). For $\hat{\mathcal{C}}$, and (NIC − NBC) the variance of the first-order Taylor series expansions (Equations A-23 and A-26) still involve variances and covariances of nonlinear combinations of coefficient and structural-parameter estimates. In such cases, further Taylor series expansions are required. For example, the variance of the first-order Taylor series approximation for $\hat{\mathcal{C}}$ in Equation (A-23) involves the variance of the product $\hat{\mathcal{K}}_2 \cdot \hat{\mathcal{C}}$. Approximating the product by a second Taylor series expansion leads to Equation (A-24), which involves the covariance of $\hat{\mathcal{C}}$ and $\hat{\mathcal{K}}$. Computation of COVAR ($\hat{\mathcal{C}}$, $\hat{\mathcal{K}}$) requires another Taylor series approximation because $\hat{\mathcal{C}}$ is a nonlinear function of NLC and $\hat{\mathcal{K}}_3$ (Equation A-25). In the case of (NIC − NBC), several Taylor series approximations are likewise required. (Note that Equation A-29 summarizes a lengthy derivation which is not presented.)

38 Recall that $\hat{K}_l = \sum_i \hat{\omega}_i$, where $\hat{\omega}_i$ are the lag weights for the ASHIP lag distribution. Covariances of $\hat{\mathcal{K}}_1$ and $\hat{\mathcal{K}}_2$ and of $\hat{\mathcal{K}}_1$ and $\hat{\mathcal{K}}_3$ are computed as follows:

$$\text{COVAR}(\hat{\mathcal{K}}_1, \hat{\mathcal{K}}_2) = \text{COVAR}(\hat{\omega}_0, \hat{\mathcal{K}}_2) + \text{COVAR}(\hat{\omega}_1, \hat{\mathcal{K}}_2) + \text{COVAR}(\hat{\omega}_0, \hat{\mathcal{K}}_2)$$

$$\text{COVAR}(\hat{\mathcal{K}}_1, \hat{\mathcal{K}}_3) = \text{COVAR}(\hat{\omega}_0, \hat{\mathcal{K}}_3) + \text{COVAR}(\hat{\omega}_1, \hat{\mathcal{K}}_3) + \text{COVAR}(\hat{\omega}_0, \hat{\mathcal{K}}_3)$$
\[
VAR(TCSC) \approx \frac{VAR(NLC - K3)}{(NLC - K3)^4} \\
= \frac{VAR(NLC) - VAR(K3)}{(NLC - K3)^4} 
\]
\[
VAR(TCIB) \approx \frac{EC^2}{(K2 \cdot TCSC)^4} \cdot \text{VAR}(K2 \cdot TCSC) \\
\approx \frac{EC^2}{(K2 \cdot TCSC)^4} \cdot (K2 \cdot VAR(TCSC) + TCSC^2 \cdot VAR(K2)) \\
+ 2 \cdot K2 \cdot TCSC \cdot \text{COVAR}(\tilde{\xi}, \tilde{\eta}) 
\]
where \( \text{COVAR}(TCSC, K2) = \text{COVAR}(\tilde{\xi}, \tilde{\eta}) \)
\[
\approx \frac{\text{COVAR}(K3, K2)}{(NLC - K3)^2} 
\]
\[
VAR(NIC - NBC) \approx (\frac{TCSC \cdot K1}{EC} - 1)^2 \cdot \text{VAR}(TCIB) \\
+ TCIB^2 \cdot \text{VAR}(\frac{TCSC \cdot K1}{EC} - 1) \\
+ 2 \cdot (\frac{TCSC \cdot K1}{EC} - 1) \cdot TCIB \cdot \text{COVAR}(\frac{TCSC \cdot K1}{EC} - 1, TCIB) 
\]
where \( \text{VAR}(\frac{TCSC \cdot K1}{EC} - 1) \approx \frac{1}{EC^2} \cdot (TCSC^2 \cdot \text{VAR}(K1)) \\
+ K1^2 \cdot \text{VAR}(TCSC) + 2 \cdot TCSC \cdot K1 \cdot \text{COVAR}(TCSC, K1) \) 
\[
\text{COVAR}(\tilde{\xi}, \tilde{\eta}) \approx \frac{\text{COVAR}(K3, K1)}{(NLC - K3)^2} 
\]
\[
\text{COVAR}(\frac{TCSC \cdot K1}{EC} - 1, TCIB) = \text{COVAR}(\frac{TCSC \cdot K1}{EC} - 1, K2 \cdot TCSC) 
\]
\[ \frac{1}{\text{VAR}(\hat{\text{TCSC}}) + \text{COVAR}(\hat{\text{TCSC}}, \hat{K1})} \left( \hat{\text{K1}} \cdot \hat{\text{K2}} \cdot \text{VAR}(\hat{\text{TCSC}}) + \hat{\text{TCSC}} \cdot \hat{\text{K2}} \cdot \text{COVAR}(\hat{\text{TCSC}}, \hat{K1}) ight. \\
+ \left. \hat{\text{TCSC}} \cdot \hat{\text{K1}} \cdot \text{COVAR}(\hat{\text{TCSC}}, \hat{K2}) + \hat{\text{TCSC}}^2 \cdot \text{COVAR}(\hat{\text{K1}}, \hat{K2}) \right) \]  

(A-29)

Note that two simplifying assumptions are made in deriving Equations (A-22) through (A-29). First, I assume that NLC is statistically independent of the coefficient estimates. For example, in deriving Equation (A-22), the covariance of NLC and \( \hat{\text{K3}} \) is assumed to equal zero. The assumption is justified by the different sources of the two estimates: \( \hat{\text{K3}} \) is derived from the regression presented in Table 3-4a; NLC is computed directly from data for capital stock and investment expenditures (see Footnote 27). Similarly, I assume that the covariance of NLC and \( \hat{\text{K2}} \) is zero in deriving Equation (A-25) and that the covariance of NLC and \( \hat{\text{K1}} \) is zero in deriving Equation (A-28). Second, Equations (A-23), (A-27), and (A-29) treat \( \hat{\text{EC}} \) as a constant (i.e., not as a random variable). The variance of \( \hat{\text{EC}} \) is assumed to equal zero because the estimate is not derived in the present study. A non-zero variance for \( \hat{\text{EC}} \) would tend to increase the estimated variances of TCIB and (NIC - NBC).

Standard deviations for estimated delay times \( \hat{\text{TPCRC}} \) and \( \hat{\text{TPDSLC}} \) are taken directly from Table 3-4. In both cases, the delay time equals the respective mean lag plus one (see Equations A-12 and A-13). Hence the standard deviations of \( \hat{\text{TPCRC}} \) and \( \hat{\text{TPDSLC}} \) respectively equal the estimated standard deviations for the mean lags of the PRCRC and PDSLC.
lag distributions.\textsuperscript{39}

The standard deviation for TASHIP is computed via a Taylor series approximation of Equation (A-17):

\[
\text{VAR(TASHIP)} \approx \frac{1}{\hat{\theta}_1^4} \cdot \text{VAR}(1 - \hat{\theta}_1^{-1}) (1 - \frac{\hat{\theta}_1^{-1}}{\hat{\theta}_0^{-1}})^4
\]

\[
\approx \frac{1}{\hat{\theta}_1^4} \cdot \left\{ \frac{1}{\hat{\theta}_1} \text{VAR}(\hat{\theta}_1^{-1}) + \left(\frac{\hat{\theta}_1^{-1}}{\hat{\theta}_0^{-1}}\right)^2 \text{VAR}(\hat{\theta}_0^{-1}) + \frac{2\hat{\theta}_1^{-1}}{(\hat{\theta}_1^{-1})^3} \text{COVAR}(\hat{\theta}_1^{-1}, \hat{\theta}_0^{-1}) \right\}
\quad \text{(A-31)}
\]

Values for \(\hat{\theta}_0^{-1}\) and \(\hat{\theta}_1^{-1}\) and for the variances of \(\hat{\theta}_1^{-1}\) and \(\hat{\theta}_0^{-1}\) are taken from Table 3-4a; the value of the covariance of \(\hat{\theta}_1^{-1}\) and \(\hat{\theta}_0^{-1}\) is taken.

\textsuperscript{39} The standard deviations for the estimated mean lags in Table 3-4 must be computed from a first-order Taylor series approximation for the mean lag:

\[
\text{VAR}(\hat{\theta}_1^{-1}) \approx \left(\frac{1}{\hat{\theta}_1^{-1}}\right) \cdot \text{VAR}(\hat{\theta}_1^{-1}) + \left(\frac{\hat{\theta}_1^{-1}}{\hat{\theta}_0^{-1}}\right)^2 \cdot \text{VAR}(\hat{\theta}_0^{-1}) - 2 \cdot \frac{\hat{\theta}_1^{-1}}{(\hat{\theta}_1^{-1})^3} \cdot \text{COVAR}(\hat{\theta}_1^{-1}, \hat{\theta}_2^{-1})
\]

where \(\hat{\theta}_1 = \sum i \cdot w_i \); \(\hat{\theta}_2 = \sum w_i\)
from the same regression \((\text{COVAR}(\tilde{\omega}_{10}, \tilde{\omega}_{11}) = -1.9 \times 10^{-6})\).

No standard deviations are computed for TLTAS and TSTAS because these parameter estimates are not derived by a formal procedure.

Choice of Parameter Values for Simulation. The preceding discussion has shown how the parameter estimates and standard deviations presented in Table 3-6 are derived. However, as noted in Section III above, several of the estimated parameter values are questionable. In particular, estimated values for NLC, DIC, (DIC - DBC), and TCSLC deviate from a priori estimates by more than a factor of two. These parameter estimates warrant scrutiny before they are used for simulation.

The estimated value of NLC is shorter than the a priori value and appears unrealistic. The value (0.0384) implies a 6.6-year average physical lifetime for capital stock held by nondurable manufacturers. Such a value appears to be much too short for aggregate plant and equipment. Coen (1975) finds that the average service lifetimes for plant and equipment range from 10 to 18 years for the ten two-digit nondurable industrial groups; average service lifetimes for plant range from 20 to 45 years.⁴⁰ Apparently, the source of the erroneous estimate is the capital stock data constructed for the present study. Several

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⁴⁰Coen (1975), Table 2.
alternative techniques exist for constructing capital stock data based on data for investment expenditures.\textsuperscript{41} The data constructed for the present study are based on IRS data for total depreciable assets and appear to improve upon certain weaknesses in the capital-stock data constructed by Jorgenson (see Appendix C of the present volume). Nonetheless, the data probably underestimate capital stock by a factor of two or greater and should be revised for future studies.\textsuperscript{42} For the simulations in Chapters 4 and 5 the estimated value of NLC is replaced by the a priori value of 0.016 qtr.\textsuperscript{−1}, implying a 16.7-year average lifetime for capital (plant and equipment). Such a lifetime is consistent with the range of lifetimes estimated by Coen (1975).

\(^\hat{\text{DIC}}\) and (\(^\hat{\text{DIC}}\) − \(\text{DBC}\)) appear to deviate from a priori values due to inconsistencies between data for inventory and shipments and the way these variables are defined in the SDNM consumer-goods sector mode. Data for inventory measure stocks held by manufacturers only. The SDNM consumer-goods sector aggregates stocks of finished goods throughout the production-distribution system for consumer goods. Therefore, inventory data probably underestimate total inventory in the production-distribution

\textsuperscript{41}The BEA capital stock survey (Wasson et. al. 1970) presents 8 different estimates for capital stock in total manufacturing.

\textsuperscript{42}One approach to constructing improved estimates for capital-stock data might be to impose a reasonable estimate for NLC a priori (perhaps based on Coen's 1975 study) and compute capital data by the equation in footnote 27.
Conversely, shipments data are computed as the sum of all shipments by nondurable manufacturers and hence measure a larger flow than the flow of shipments in the consumer-goods sector model. Shipments in the industry data includes shipments from producers to producers. Shipments to consumers represent only a small portion of the sum of shipments of all nondurable manufacturers.

Because inventory data tend to underestimate output inventory in the consumer-goods-sector model and shipments data overestimate shipments in the model, \(^\hat{\text{DIC}}\) (0.472 qtr. in Table 3-5) falls below a reasonable DIC for the consumer-goods-sector model. Similarly, the overestimated SHIP data tends to depress \(^\hat{\text{K1}}\) and hence \((\text{DIC} - \text{DBC})\) (see Equation A-8). The underestimate of \((\text{DIC}-\text{DBC})\) implies that DBC is overestimated. Given the biases in the estimated values \(^\hat{\text{DIC}}\) and \(^\hat{\text{DIC}-\text{DBC}}\), a priori values for DIC and DBC are used for simulation \((\text{DIC} = 0.3, \text{DBC} = 0.3)\).

Lastly, \(^\hat{\text{TCSLC}}\) is considerably shorter than the a priori value. More importantly, estimates for TCSLC and TCSC deviate sharply from the a priori equality constraint--\(^\hat{\text{TCSLC}}\) is only about one quarter of \(^\hat{\text{TCSC}}\). Such estimates imply that the production sector attempts to adjust imbalances in the capital supply line four times faster than it attempts

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43The relation of inventory data to inventory as defined in the SDNM consumer-goods sector model is somewhat unclear because the inventory data used in the present study aggregate finished inventory, in-process inventory, and inventories of parts and supplies. Inclusion of the latter variables makes inventory data larger than manufacturers' output inventory in the model and tends to offset the effect of omitting output inventories in the production-distribution system.
to adjust imbalances in capital stock. To see the implausibility of such parameters, it is helpful to first examine the reasons for the equality constraint. Consider the response of order starts for capital to a step increase in desired capital. Assume that the sector begins in equilibrium with capital CAP and the supply line for capital SLC equal to their desired levels. Consider the simplified equation for OSC:

\[
\text{OSC}_t = \frac{\text{DCAP}_t - \text{CAP}_t}{\text{TCSC}} + \frac{\text{DSLCS}_t - \text{SLC}_t}{\text{TCSLC}} + \text{CAP}_t \cdot \text{NLC}
\]  \hspace{1cm} (A-32)

If TCSC equals TCSLC, Equation (A-32) can be rewritten:

\[
\text{OSC}_t = \frac{\left(\text{DCAP}_t - \text{CAP}_t\right) + \left(\text{DSLCS}_t - \text{SLC}_t\right)}{\text{TCSC}} + \text{CAP}_t \cdot \text{NLC}
\]  \hspace{1cm} (A-33)

Equation (A-33) implies that, as order starts flow into the supply line, the sector reduces OSC by an amount commensurate with the capital already on order (or in planning). For example, if the step increase in DCAP leads to \(x\) additional order starts over a period of time \(\Delta t\), SLC increases above DSLC by \(x\) units over the same time and OSC falls by an amount equal to the reduction in OSC if capital increased by \(x\) units.\(^{44}\) In such a case, one would say that the sector considers

\(^{44}\)Note that DSLC remains constant until CAP increases and hence can be ignored over a short \(\Delta t\). Over a slightly longer \(\Delta t\), OSC falls less than \(x\) units due to rising DSLC.
"capital" in the supply-line equivalent to capital in place.

By contrast, if the parameters TCSC and TCSLC are unequal, the sector does not consider capital on order and capital in place as equivalent. If TCSLC is longer than TCSC, capital on order is "worth less" than capital in place in the following sense. If x additional order starts are generated in response to an increase in DCAP, OSC falls less than would happen if x additional capital units were received. Such behavior probably occurs in reality, especially in production sectors where volatile capital delivery delays create a climate of uncertainty with regard to the time to realize capital acquisitions. However, the behavior implied by TCSLC shorter than TCSC seems much less plausible. In such a case, capital ordering falls by a larger amount when x additional order starts flow into the supply line than when the same amount of new capital is added to capital in place. Capital on order is "worth more" than capital in place. Such relative valuing of capital and orders for capital seems unrealistic.

The cause for the discrepant TCSC and TCSLC estimates is unclear. It is unlikely that the discrepancy stems from uncertainty in the parameter estimates. The estimate of TCSLC lies some 10 standard deviations from the estimate of TCSC; the estimate of TCSC lies some 4 standard deviations from TCSLC.\(^45\) Hence, it is extremely unlikely that

\(^45\)The difference in the two estimates equals 9.08. The ratio of the difference divided by the standard deviation of TCSLC equals 9.08/.86 = 10.6; the difference divided by the standard deviation of TCSC equals 9.08/2.18 = 4.2
the two estimates have the same expected value. More likely, the
discrepancy between $\hat{\text{TCSC}}$ and $\hat{\text{TCSLC}}$ stems from data error--errors in the
capital-stock data cited above and errors in the way in which order
reference for the supply line for capital ORSLC is measured (see Section
II above). If data error is primarily responsible, the discrepancy
between $\hat{\text{TCSC}}$ and $\hat{\text{TCSLC}}$ may be eliminated by improved capital stock data.

For the simulations in Chapters 4 and 5, values for TCSC and
TCSLC are chosen which combine the statistical results and the a priori
constraint that the two parameters are equal. The estimate $\hat{\text{TCSC}}$ ($=\hat{\text{TCSLC}}$)
equals a weighted average of the two estimates $\hat{\text{TCSC}}$ and $\hat{\text{TCSLC}}$ with
weights chosen to minimize the variance of the TCSC:$^{46}$

\[ \hat{\text{TCSC}} = \hat{\text{TCSLC}} = w_1 \cdot \hat{\text{TCSC}} + w_2 \cdot \hat{\text{TCSLC}} \]  
\[ (A-34) \]

\[ w_1 = \frac{\text{VAR}(\text{TCSLC})}{\text{VAR}(\hat{\text{TCSC}}) + \text{VAR}(\text{TCSLC})} \]  
\[ (A-35) \]

\[ w_2 = \frac{\text{VAR}(\hat{\text{TCSC}})}{\text{VAR}(\hat{\text{TCSC}}) + \text{VAR}(\text{TCSLC})} \]  
\[ (A-36) \]

$^{46}$Values $w_1$ and $w_2$ are found by taking the derivative of the
following expression for VAR ($\hat{\text{TCSC}}$) with respect to $w_1$ and setting the
derivative equal to zero:

\[ \text{VAR}(\hat{\text{TCSC}}) = w_1^2 \text{VAR}(\hat{\text{TCSC}}) + (1 - w_1)^2 \text{VAR}(\text{TCSLC}) \]

\[ w_2 = 1 - w_1 \]
Using values for $\hat{\text{TCSC}}$, $\hat{\text{TCSLC}}$, and the respective variances in Table 3-5, Equations (A-34) through (A-36) yield the following estimate for TCSC and TCSLC for use in simulation:

$$\hat{\text{TCSC}} = \hat{\text{TCSLC}} = 4.29 \text{ qtr.}$$

$$\text{STD.DEV.}(\hat{\text{TCSC}}) = \text{STD.DEV.}(\hat{\text{TCSLC}}) = 0.75 \text{ qtr.}$$

$$(\omega_1 = 0.14; \omega_2 = 0.86)$$

To summarize, Table 3-9 lists the parameters used in the following simulations. The table lists the estimated parameter value and the standard deviation of the parameter estimate. (Values are expressed in quarters and years, the latter being the unit of time in the consumer-goods-sector model.) The table shows that $\hat{\text{TASHIP}}$, $\hat{\text{TPRCRC}}$, $\hat{\text{TPDSLC}}$, and $\hat{\text{TCIB}}$ are derived directly from parameter estimates in Table 3-4. (Estimates for these parameters are identical to estimates presented in Table 3-5.) The delay times involved in forming expected growth in shipments EGS, TLTAS and TSTAS, are picked so as to make the response of EGS match the estimated EGS' lag distribution. Estimates of TCSC and TCSLC are derived by imposing an a priori equality constraint between $\hat{\text{TCSC}}$ and $\hat{\text{TCSLC}}$ presented in Table 3-5. Lastly, NLC, DIC and DBC are given a priori values for simulation.
<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Estimated Parameter Value</th>
<th>Estimated Standard Deviation of Estimate</th>
<th>How Parameter Estimate is Derived</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASHIP: Time to Average Shipments</td>
<td>2.13 qtrs. (0.53 yr.)</td>
<td>1.88 qtrs. (0.47 yr.)</td>
<td>Ratio of first two IV-PDL estimates in ASHIP lag distribution (Table 3-4a)</td>
</tr>
<tr>
<td>TPRCRC: Time to Perceive Ratio of Capital Return to Cost</td>
<td>4.12 qtrs. (1.02 yr.)</td>
<td>0.32 qtr. (0.08 yr.)</td>
<td>Derived from mean lag for IV-PDL estimates of PRCRC lag distribution (Table 3-4b)</td>
</tr>
<tr>
<td>TPSLC: Time to Perceive Delay in Supply Line for Capital</td>
<td>5.36 qtrs. (1.34 yr.)</td>
<td>0.96 qtr. (0.24 yr.)</td>
<td>Derived from mean lag for IV-PDL estimates of PDSL lag distribution (Table 3-4a)</td>
</tr>
<tr>
<td>TSTAS: Time for Short-term Averaging of Shipments</td>
<td>4 qtr.s (1 yr.)</td>
<td></td>
<td>Picked to make EGS response match estimated EGS lag distribution</td>
</tr>
<tr>
<td>TLAS: Time for Long-term Averaging of Shipments</td>
<td>16 qtr.s (4 yr.)</td>
<td></td>
<td>Picked to make EGS response match estimated EGS lag distribution</td>
</tr>
<tr>
<td>TSCC; TSSL: Time to Correct Stock of Capital, Time to Correct Supply Line for Capital</td>
<td>4.29 qtrs. (1.07 yr.)</td>
<td>0.75 qtr. (0.19 yr.)</td>
<td>Derived from TSCC and TSSL in Table 3-5, plus a priori equality constraint</td>
</tr>
<tr>
<td>NLC: Normal Loss of Capital</td>
<td>0.015 qtr. (0.006 yr.)</td>
<td></td>
<td>a priori value</td>
</tr>
<tr>
<td>TCIB: Time to Correct (Outstanding) Inventory and Backlog</td>
<td>1.73 qtr.s (0.43 yr.)</td>
<td>0.37 qtr. (0.093 yr.)</td>
<td>Derived from IV estimate of K2 in Table 3-4a, TSCC and EC</td>
</tr>
<tr>
<td>DIC: Desired Inventory Coverage</td>
<td>1.2 qtr. (0.3 yr.)</td>
<td></td>
<td>a priori value</td>
</tr>
<tr>
<td>DBC: Desired Backlog Coverage</td>
<td>1.2 qtr. (0.3 yr.)</td>
<td></td>
<td>a priori value</td>
</tr>
</tbody>
</table>
CHAPTER 4  MODEL-BEHAVIOR TESTS--PART 1: BEHAVIOR PLAUSIBILITY TESTS

I. INTRODUCTION AND PREVIEW OF RESULTS

This chapter presents the first series of model-behavior tests of the SDNM investment function. The model-behavior tests extend the scope of the single-equation tests presented in Chapter 3 to examine the implications of the SDNM investment hypotheses for the behavior of a production sector of an economy. The purpose of the tests presented in Chapter 4 is to determine if the SDNM investment hypotheses are necessary for plausible behavior in a production-sector model.

To accomplish the behavior testing, the SDNM investment function is analyzed within a model of an aggregate consumer-goods sector. Section II overviews the model and explains why the model provides a useful framework for testing the SDNM investment hypotheses. The consumer-goods sector model is based on the generic SDNM production-sector model. The model describes how an aggregate consumer-goods producing sector acquires labor and capital, generates an output stream, and manages output inventory and backlog of unfilled orders for output. Simulation of alternative investment formulations within the consumer-goods sector model reveals the behavior produced when predicted investment activity feeds back to modify capital stock, output, output inventory, delivery delay, shipments, order backlog, and future investment.
Section III introduces the dynamic properties of the model by analyzing model response with the full SDNM investment function to a "step" increase in orders for output, and by contrasting the response to response of an econometric production-sector model. The analysis shows that the SDNM consumer-goods sector model captures important mechanisms underlying overshoot and oscillation not present in the econometric model.

Section IV analyzes the effects of eliminating each SDNM investment hypothesis on the plausibility of model behavior. The analysis identifies the shifts in model behavior precipitated by eliminating each hypothesis and explains causes for the shifts. In each case, the shift in behavior reveals an implausible feature of behavior without the hypothesis in question. For example, eliminating inventory and backlog corrections leaves shipments as the measure of desired output used in capital planning. As the analysis points out, shipments is a poor indicator of demand for output. Shipments fail to fully reflect increases in demand if production capacity and finished inventories are inadequate to meet demand. Therefore, eliminating inventory- and backlog corrections in capital ordering can lead to circumstances where desired capital fails to rise because current capacity is inadequate. Simulations without inventory- and backlog corrections in capital ordering show that the modified investment function allows desired capital to expand only
after production and shipments have expanded. Such behavior is implausible because it means that capital can only expand if labor (employment) expands first. If, for example, additional labor were unavailable, there would be no capital expansion.

The results of the behavior plausibility tests are summarized in Section V.
II. THE CONSUMER-GOODS SECTOR MODEL

The following model-behavior tests employ a consumer-goods sector model based on the generic SDNM production-sector model discussed in Chapter 2. This section gives a brief overview of the consumer-goods sector model and discusses why a consumer-goods sector model was chosen as the initial framework for testing investment hypotheses. (Appendix A further describes the structure of the consumer-goods sector model, provides an equation listing, and describes how parameter values are set in the model.)

II.A OVERVIEW OF MODEL STRUCTURE AND PARAMETER VALUES

Model Boundary. Figure 4-1 overviews the production-sector model showing major stocks, flows, and exogenous inputs. Variables involved in the production stream appear in the lower portion of the figure, along with backlog of unfilled orders for output. Inventory in process IP is increased by production PROD and decreased by output OUT. Inventory of output IO is increased by output OUT and decreased by shipments SHIP. Backlog of unfilled orders for output B is increased by orders for output 0 and decreased by shipments. The model includes labor and capital stock as endogenous factors of production. Ordering and accumulation of labor and capital appear respectively in the upper left- and right-hand portions of the figure.¹ Order starts for both factors enter

¹Note that the specific determinants of factor ordering such as desired factor stocks, growth expectations, and supply-line conditions are not shown in Figure 4-1.
FIGURE 4-1
THE CONSUMER-GOODS SECTOR MODEL

[Diagram showing various economic variables and flows, including marginal cost of labor, cost of capital services, orders for labor, cancellations of plans for labor, backlog of orders for labor, desired output, potential productivity, average shipments, delivery delay for labor, and inventory in process.]
respective supply lines of unfilled orders, involving orders in planning (orders in planning of labor OPL and orders in planning for capital OPC) and backlogs of unfilled orders (backlog of orders for labor BL and backlog of orders for capital BC.) Levels of labor L and capital CAP are increased by the respective arrival rates and decreased by reduction of labor RL and reduction of capital RC, respectively.

Figure 4-1 also shows the variables which are exogenous to the consumer-goods model.\(^2\) Orders for output O is an exogenous input to the backlog of unfilled orders B in the consumer-goods sector. Similarly, delivery delay for labor (the delay in filling job vacancies) and delivery delay for capital are set outside the sector and respectively determine arrivals of labor (hires) and arrivals of capital (investment.) Lastly, prices of labor and capital, and interest rate are set outside the sector and respectively influence order starts for labor and capital.

The present model excludes endogenous price-setting, borrowing, savings, and financial accounting—all of which are included in the generic SDNM production-sector model. Pricing and financial flows are omitted because the present tests focus on the influence of several real (that is, non-financial) variables omitted from the neoclassical

\(^2\)All variables exogenous to the consumer-goods sector model are determined in other sectors of the full SDNM. For example, orders for the consumer goods sector's output are generated in the household sector, delivery delay for labor is determined in the worker mobility sector (see Forrester, Mass, and Ryan 1976.)
investment function, as well as a more detailed specification of the
delays involved in ordering and acquiring capital. Findings of the
present study can be reevaluated in the future by repeating the tests
with endogenous pricing and financial flows. At that time, an expanded
version of the SDNM investment function including financial variables may
be compared to alternative investment functions incorporating financial
factors (possible candidates include the investment functions developed

Key Rate Equations. The equations governing order starts for labor have
the same general form as the SDNM ordering equations for capital
discussed in Chapter 2. Desired stock of labor depends on the current
stock of labor, the production ratio (ratio of desired output to
potential production), perceived ratio of factor return to cost for labor
(marginal revenue product for labor divided by marginal cost for labor),
and expected growth in sales. Order starts for labor includes
replacement of departed workers, as well as responses to the discrepancy
between desired labor and labor and the discrepancy between desired and
actual levels of the supply line of unfilled orders for labor.

The production rate in the full SDNM production sector is
governed by a modified Cobb-Douglas production function allowing for
variable utilization of factors. The simplified production function used
in the present production-sector model can be written as a function of
potential production PP and the multiplier from the production ratio
MPR. As described in Chapter 2, PP depends on NPROD, labor L, normal labor NL, exponent for labor EL, capital CAP, normal capital NCAP, the exponent for capital EC:

\[ \text{PROD}_t = \text{PP}_t \cdot \text{MPR}_t \]  \hspace{1cm} (4-1)

\[ \text{PP}_t = \text{NPROD} \cdot \left( \frac{L_t}{NL} \right)^{\text{EL}} \cdot \left( \frac{\text{CAP}_t}{\text{NCAP}} \right)^{\text{EC}} \]  \hspace{1cm} \text{Equation 2-14 (repeated)}

MPR reflects variation in factor utilization in the present model. MPR depends on the production ratio PR. When PR rises above unity (signifying desired output above potential production), MPR rises above unity causing PROD to exceed potential production PP. Conversely, when PR falls below unity (signifying desired output below potential production), MPR depresses PROD below PP. The effect of MPR is restricted so that PROD is never increased by more than 10% over PP in model simulation. ³

Shipments SHIP are determined as the ratio of backlog of unfilled orders for output B divided by delivery delay DD. The sector

³The present formulation of variable utilization, which takes no account of the possibility that utilization of some factors may exceed utilization of other factors, differs from the formulation of variable utilization in the full SDNM production-sector model. The full formulation, which considers changes in the length of work week for each factor as well as pressures to allocate portions of a factor stock to overhead and other nonproduction activities, is not included in the present model because many of the variables which cause such changes are not included in the model. See Forrester and Mass (1976).
determines delivery delay as the product of normal backlog coverage NBC and the multiplier for delivery delay MDD. The equations for shipments and delivery delay are

\[ \text{SHIP}_t = \frac{B_t}{DD_t} \]  \hspace{1cm} (4-2) \]
\[ DD_t = \text{NBC MDD}_t \]  \hspace{1cm} (4-3) \]

Normal backlog coverage NBC reflects the normal delay the sector attempts to maintain in filling orders. Multiplier for delivery delay MDD reflects pressures to reduce or increase delivery delay depending on output inventory and backlog conditions. For example, if B rises and inventory stays constant, MDD rises to increase delivery delay DD. If output inventory rises and B stays constant, MDD falls to reduce DD. Equations for the multiplier for delivery delay MDD and the multiplier from production ratio MPR are given in Appendix A.

Parameter Values. Most parameter values in the consumer-goods sector model are drawn from data for total nondurable manufacturing. Total nondurable estimates obtained in Chapter 3 are used for all but three parameters in the SDNM investment function, desired backlog coverage DBC, desired inventory coverage DIC, and normal loss of capital NLC (see Appendix A of Chapter 3). A priori estimates based on earlier system
dynamics studies are used for DBC, DIC and NLC. Most other model parameters are estimated from available data or from earlier empirical studies (see Appendix A at end of thesis).

II.B CHOICE OF A CONSUMER-GOODS SECTOR MODEL FOR BEHAVIOR TESTING

Two features of the consumer-goods sector model make it a useful basis for testing the implications of alternative investment functions. First, the model generates a sufficiently rich variety of dynamic behavior to couple the behavior testing to significant investment issues. As will be shown below, the consumer-goods sector model generates prolonged disequilibrium behavior when perturbed by simple deterministic inputs. The disequilibrium behavior provides ample opportunity to identify implausible features of behavior brought about by eliminating SDNM investment hypotheses. When perturbed by a stochastic input, the sector generates two modes of oscillatory behavior--a short-term fluctuation in labor and production (with about a 5 year period) and longer-term fluctuations in capital stock and investment (with an average period of about 18 years). The two periodicities appear to correspond to observed periodicities of economic behavior. Therefore, analysis of the effects of investment hypotheses on model fluctuations may illuminate important causes of economic fluctuations. (The behavior-mode analysis is presented in Chapter 5.).
The second motive for beginning testing with the consumer-goods sector model derives from the relative simplicity of the model. The consumer-goods sector model is sufficiently simple to permit relatively straightforward explanations of behavior test outcomes. When such understanding is possible, one may learn not only that a particular hypothesis is important but why it is important. Seeing that a particular hypothesis is important because it creates feedback mechanisms which appear to operate in real production sectors greatly enhances the credibility of model-behavior testing.
III. PRODUCTION SECTOR BEHAVIOR WITH THE FULL SDNM INVESTMENT FUNCTION

This section presents and analyzes behavior of the consumer-goods sector model with the full SDNM investment function. The presentation is intended to give the reader unfamiliar with the model an initial understanding of its behavior. Such understanding will be useful when model behavior without SDNM investment hypotheses is analyzed in Section IV.

III.A RESPONSE TO A STEP INCREASE IN ORDERS FOR OUTPUT

Figure 4-2 presents behavior of the production-sector model with the full SDNM investment function in response to a 10% step-increase in orders for output 0. Though highly simplified, the single step-increase in orders provides a useful starting point in understanding the behavior of the consumer-goods-sector model. By perturbing the model from its initial equilibrium, the step input shows model behavior as the model adjusts to a new equilibrium.

Model Behavior. Figure 4-2a shows the behavior of labor and associated variables. Figure 4-2b shows the behavior of capital and related variables. Figure 4-2c shows the behavior of output inventory, backlog, production, shipments, and orders. The simulation covers 10 years, each plot

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4Parameter values used to generate the simulation shown in Figure 4-2 and all subsequent simulations are given in Appendix B.
interval equals .125 years. The model starts off in equilibrium: inventory, backlog, labor, and capital stock equal desired levels; production, shipments, and orders for output all equal desired output. At time = 1 year, orders increase by 10%, thereby disturbing the equilibrium and leading to the sector response shown in the figure.

Figure 4-2 shows that labor, capital, and production respond to the 10% increase in orders for output by rising toward their new equilibrium values (1.1 times their initial values), overshooting the equilibrium values and oscillating. The period of the fluctuation for labor and production is approximately 4.5 years. The period of fluctuation for capital is considerably longer. The initial upswing of labor equals about 30% (measured from initial conditions); the initial upswing for capital equals about 15%. Variables associated with labor—such as desired labor and arrivals of labor—primarily exhibit short-term fluctuations. Variables associated with capital—such as order starts for capital and arrivals of capital—primarily exhibit longer term fluctuations. Short-term fluctuations predominate in the behavior of sector variables such as order starts for capital and arrivals of capital -- primarily exhibit longer term fluctuations. Short-term fluctuations predominate in the behavior sector variables

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5The period of capital fluctuation will be examined in detail in Chapter 5.
such as output inventory and backlog. Fluctuations in all variables continue throughout the simulation.\textsuperscript{6}

\textsuperscript{6}The behavior in Figure 4-2 shows little damping. The undamped behavior stems from several simplifications in the consumer-goods sector model. For example, if orders for output responded to rising price or delivery delay for output when the sector experienced difficulty in filling orders, damping would increase. Similarly, there are several features of the full SDNM production sector which, if activated, would increase damping (see Appendix A). Though the degree of damping in Figure 4-2 is somewhat unrealistic, it has little impact on the outcomes of the following tests.
Analysis of Step-Response.\textsuperscript{7} To establish an initial understanding of the behavior of the consumer-goods sector model, two questions need to be addressed regarding the model's response to the step-increase in orders. First, why do labor, production, output inventory and backlog oscillate with an approximate 4 1/2-year period? Second, why does capital stock exhibit a longer period of expansion and overshoot?

The short-term oscillations seen in Figure 4-2 arise from adjusting production in order to manage output inventory and backlog. To see how inventory and backlog management can lead to overshoot and oscillation, consider the following simplified plots of the behavior of inventory, backlog, desired inventory, desired backlog, production, and shipments in response to a step increase in orders for output. Figure 4-3 shows behavior up to the point where production has risen to the new higher rate of orders for output. Consider the behavior of production, shipments, and inventory. Beginning at time $t_0$, inventory falls because shipments exceed production.\textsuperscript{8} Production gradually expands in response to the increased demand for output, as measured by rising shipments and the increasing discrepancy between desired and actual inventory. At time $t_1$ production has risen to equal shipments,

\textsuperscript{7}The following analysis of model behavior borrows heavily from Mass and Senge (1975).

\textsuperscript{8}The present discussion does not distinguish production and output, since the latter follows the former with a time lag which is very short for the purposes of the present analysis.
and the decline in inventory has been arrested. However, the balance is only partial. Inventory has declined steadily from $t_0$ to $t_1$ because shipments exceeded production throughout this time. Moreover, desired inventory has increased because more inventory is needed to cover the higher rate of shipments. Therefore, even though production equals shipments to time $t_1$, inventory is below its desired level, and production must continue to expand beyond time $t_1$ in order to correct the inventory imbalance.

Figure 4-3 shows that the sector is further motivated to expand beyond time $t_1$ by an excess backlog of unfilled orders for output.

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9To simplify the analysis, shipments, production, and orders have been shown as intersecting in a common point in Figure 4-3. In the actual simulation, production first intersects shipments, then shipments, pushed by rising inventory, intersects orders (see Figure 4-2c).
Figure 4-4 shows that, by the time inventory has been restored to its desired level at time $t_2$, production exceeds shipments and orders. Once again, only a partial balance is attained—inventory equals desired inventory, but production exceeds shipments. Thus, the inventory balance is short-lived. If model behavior beyond time $t_2$ were plotted in Figure 4-4, inventory would continue to increase beyond time $t_2$ because production would exceed shipments. Surplus inventory accumulated would create pressure to contract production. However, the inventory surplus would continue to increase until production were reduced to equal

![Figure 4-4](image-url)

**Figure 4-4**

*Increase of Production Above Incoming Orders and Shipments*
shipments. By the time production equaled shipments, the accumulated inventory surplus would depress production below shipments and the fluctuations would continue.10

The oscillatory mechanisms created by inventory and backlog management can lead to oscillation of different periods, depending on the means of adjusting production. By analyzing a model similar to the present consumer-goods sector model, Nathaniel Mass shows that, when production is adjusted solely through adjustments in employment and factor utilization, inventory and backlog management can lead to oscillations in production, inventory, backlog, and employment with a period of about 4 years (Mass 1975, Chapter 3). Conversely, if employment is held constant, and adjustments in factor utilization and capital bear the full burden of adjusting production, production, inventory, backlog and capital fluctuate with about a 15-year period (Mass 1975, Chapter 4).

As Mass's analysis suggests, the short-term fluctuations in Figure 4-2 stem from adjusting labor and factor utilization in order to manage output inventory and backlog of unfilled orders for output. Adjustments in capital play little role in generating the short-term

10 Backlog management contributes to production-sector instability through mechanisms analogous to those created by inventory management. Backlog tends to rise above desired backlog at the same time that inventory falls below desired inventory. Hence, as shown in Figure 4-3, the discrepancy between desired backlog and backlog at time t creates a pressure to expand production beyond shipments, analogous to the pressure to expand production stemming from the inventory discrepancy.
fluctuation. For example, note that production expands by 21.5% from year 1 to year 2.75. Over this time interval, the multiplier from the production ratio rises 4% (signifying a 4% increase in capacity utilization) to a peak value of 1.04 at year 2.0, then declines, labor rises 28%, and capital increases by about 5%. Clearly, increases in capital have only minor influence on the initial rise in production to meet the higher rate of incoming orders and to rebalance inventory and backlog. Similarly, production begins to fall at year 3, even though capital continues to increase until about year 6. Clearly, movements in capital stock cannot account for the short-term fluctuations in production.

Causes of the longer-term expansion and overshoot in capital stock in Figure 4-2 will be examined in detail when portions of the SDNH investment formulation are inactivated in subsequent sections. The following is a brief preview of the ensuing analysis. Observe first that desired stocks of both factors begin rising at year 1.1 in response to the need for more production capacity, represented by the increasing production ratio (Figure 4-2b). Due to shorter delays in planning for and obtaining additional labor, labor expands much more rapidly than capital. For example, during the initial upswing in desired capital, the actual stock of capital typically lags behind its desired level by 1 1/2 to 3 years. By contrast, labor lags desired labor by only about 1/2 year during the initial expansion. The more rapid expansion of labor reduces the capital-labor ratio, thereby creating a second motive to expand
capital. As the perception of a nonoptimal mix of labor and capital develops, the sector orders additional capital to rebalance factor proportions. The pressure to add capital to rebalance factor mix is represented in the model by the perceived ratio of capital return to cost. Figure 4-2b shows that the perceived ratio of capital return to cost begins to rise at year 1.6 and stays above unity until year 4.9, signifying a desire to increase capital intensity throughout this period. By contrast, the production ratio for capital, which indicates pressure to expand capital in order to expand output, falls below unity by year 2.9. Therefore, pressure to add capital to rebalance factor proportions persists for two years beyond the time when further output is needed in the sector. One begins to see from this brief description how successive pressures to increase capital to increase output and to rebalance factor proportions can lead to upswings in desired capital and capital which are considerably longer than the short-term upswings in labor.

III.B COMPARISON TO BEHAVIOR OF AN ECONOMETRIC PRODUCTION-SECTOR MODEL

Further insight into the behavior of the SDNM consumer-goods sector model can be gained by comparison to the neoclassical model of demand for factors of production developed by Nadiri and Rosen (1973). Though space does not permit a detailed comparison of the two models, a brief comparison of the scope of the models and the response of each to a
step increase in demand reveals an important feature of the model employed for the present testing.

The Nadiri and Rosen model closely resembles the SDNM consumer-goods sector model in scope. The model allows for concurrent adjustments in production workers (labor), capital, inventory, and factor utilization in response to exogenous shifts in demand.\footnote{The Nadiri and Rosen model also includes adjustment of nonproduction workers, which is not included in the consumer-goods sector model, and differentiates adjustments in capacity utilization from adjustments in overtime hours for labor (the two adjustments are aggregated in the present consumer-goods sector model).} Specification of the adjustment processes resembles that of the present model to the extent that the rates of adjustment depend on the discrepancy between desired and actual levels of each variable, and to the extent that desired levels depend on rate of sales.\footnote{Sales are determined exogenously in the Nadiri and Rosen model. In the SDNM consumer-goods sector model, orders for output are determined exogenously.} Moreover, Nadiri and Rosen's estimated adjustment parameters are similar to parameter values in the consumer-goods sector models. For example, they estimate the time to adjust labor at 1.8 quarters and the time to adjust capital at about 10 quarters for total manufacturing.\footnote{The above adjustment times are computed from the first-order lagged coefficients estimated by Nadiri and Rosen (Nadiri and Rosen, p. 59). For example, the estimated adjustment time equals $1/\beta$ in an equation of the form: $Y_t - Y_{t-1} = \beta(Y^*_t - Y_{t-1}) + \text{(other variables)}$ where $Y^*$ is the desired level of $Y$ (all variables expressed as natural logarithms).} In the present
consumer-goods-sector model, the time to correct labor (to its desired level) is set at 0.3 years. The time to correct the stock of capital TCSC was estimated as 1.07 quarters in Chapter 3 (see Appendix A of Chapter 3). Hence, the SDNM parameters are slightly shorter than the parameters in the Nadiri and Rosen model.

Despite similarities in model boundary, specification, and assumed factor adjustment times, the Nadiri and Rosen model does not generate the oscillations generated by the present model. In response to a step increase in demand (sales), the number of production workers adjusts smoothly to its new equilibrium in about 4 quarters (Nadiri and Rosen, p. 76). Capital rises to its new equilibrium in about 18 quarters and slightly overshoots the equilibrium. Of the variables included in both models, only inventory exhibits a tendency to fluctuate in the Nadiri and Rosen model. However, the inventory fluctuations are of a very different character than those analyzed above. When sales rise, inventory likewise rises. Inventory fluctuates only in the sense that it expands beyond its new equilibrium, then settles back to its equilibrium value.

The difference in dynamic response of the two models appears to stem from the distinctive manners by which inventory investment is accomplished. In the SDNM consumer-goods sector model, output inventory increases when output exceeds shipments. If the sector wants to increase inventory, it must first acquire sufficient capacity to produce in excess
of shipments, or it must reduce shipments below the current capacity to produce. By contrast, in the Nadiri and Rosen model, inventory responds directly to desired inventory.\textsuperscript{14} When the production sector wants more inventory in the Nadiri and Rosen model, it adjusts its inventory upwards with a fixed adjustment time. There is no explicit flow of production in the model and no explicit coupling of current stocks of productive factors to the rate at which new inventory can be produced.\textsuperscript{15}

The different approaches to inventory investment in the SDNM and Nadiri and Rosen models reflect a more fundamental difference in modeling approach. The SDNM consumer-goods sector model is a consered flow model. That is, the model explicitly represents all flow variables and adjusts stocks only as a consequence of adjustments in flows. Such explicit treatment of stocks and flows seems essential in understanding the causes of overshoot and oscillation in economic systems. To see

\textsuperscript{14}That is, inventory INV changes according to an equation of the form:

$$\Delta INV = \lambda (INV^* - INV_{-1})$$

where INV* is desired inventory, which is a function of sales in the Nadiri and Rosen model, and $\lambda$ is an estimated adjustment parameter. Auerbach and Feldstein (1976) provide a survey of econometric equations for inventory investment.

\textsuperscript{15}In light of the above points, the conventional econometric aggregation of output inventory with inventories of raw materials appears inappropriate. Because materials are ordered and not produced within the sector, the typical econometric inventory investment equation applies for investment in inventories of materials. However, changes in finished inventories in an aggregate production sector should be related to productive capacity in the sector and to the rate at which finished inventory is being supplied to customers.
this, consider the behavior of inventory in both models in response to an 
exogenously imposed step-increase in sales. Assume each model starts in 
equilibrium with labor, capital, and inventory constant at their desired 
levels. As described above, the Nadiri and Rosen model responds to the 
increase in sales by increasing desired inventory and inventory towards 
the new inventory equilibrium. Inventory overexpands somewhat, then 
falls back to its new equilibrium value. By contrast, inventory falls 
initially in the SDNM consumer-goods sector because sales (shipments) 
exceeds output. Inventory continues to decline until the sector is able 
to raise output to the new higher rate of shipments. Once output has 
been expanded to equal shipments, it must continue to expand to rebuild 
the inventory lost during the time when shipments exceeded output. When 
inventory has been rebuilt, output exceeds shipments and excess inventory 
may begin to accumulate. Hence, the conserved flow viewpoint leads to 
overshoot and oscillation which does not occur when rates of flow are not 
portrayed explicitly.\textsuperscript{16}

Though the preceding discussion provides only a preliminary 
comparison of the two models, it points out an important feature of the 
SDNM production-sector model. By adopting a rigorous conserved-flow 
framework and relating all stock adjustments to adjustments in underlying 
flows, the present model captures aspects of production sector behavior 
omitted from many econometric models.

\textsuperscript{16}For other treatments of the above issues, see Low (1976) and Mass (1976).
III.C SUMMARY

This section has previewed behavior of the consumer-goods sector model with the full SDNM investment function. Figure 4-2 showed that the model generates short-term fluctuations in production, output inventory and backlog, and labor with a period of about 4 1/2 years in response to a step-increase in incoming orders for output. Capital stock and arrivals of capital exhibit a longer-term overshoot and fluctuation. The short-term fluctuations stem from adjustments in labor and factor utilization to correct imbalances in output inventory and backlog of unfilled orders for output. The longer-term overexpansion in capital stems from the longer delays in acquiring additional capital and from pressures to rebalance capital and labor after the more rapid initial expansion in labor.

A key feature of the model which gives rise to these modes of oscillatory behavior is the explicit representation of endogenous flows. The principle that stock variables can only change through explicit changes in associated rates of flow is essential in generating overshoot and oscillation.
IV. TESTS OF BEHAVIOR PLAUSIBILITY

This section analyzes whether hypotheses included in the SDNM investment function but omitted from the neoclassical investment function are necessary to produce plausible behavior in the consumer-goods sector model. Sections IV.A through IV.D examine behavior when each of the SDNM investment hypotheses is removed from the equations determining order starts for capital. The analysis in each section begins with a statement of the hypothesis in question, outlining why the hypothesis appears necessary for plausible behavior. Each section then examines the shifts in model behavior brought about by eliminating the hypothesis and presents an intuitive explanation of why the shifts occur. A detailed examination of model behavior without the hypothesis is then presented to verify the intuitive explanations. Lastly, the plausibility of behavior without the investment hypothesis is assessed.

IV.A INVENTORY AND BACKLOG CORRECTIONS

The Hypothesis. The SDNM investment function includes the hypothesis that output inventories and backlogs of unfilled orders for output provide important real-life measures of relative supply and demand and, hence, influence investment. For example, when backlogs of unfilled orders for output are high, delivery delays for output are long. Firms typically view long delivery delays as evidence of expansion opportunities. Moreover, if existing firms in an aggregate production sector are making customers wait long periods for delivery, one would expect new firms to
be motivated to enter the market in an attempt to attract dissatisfied customers from established firms.

Omitting output inventory and backlog conditions as influences on investment implies that both existing and prospective producers look only at sales as a guide in planning capital acquisition for future output needs. However, sales may be low because capacity and finished inventories are inadequate to meet demand. Conversely, sales may have been high in recent months due to the filling of back orders which, when filled, were not replaced. Clearly, managers have far more information available in planning for output needs than is embodied in past sales rates. Inventory and backlog conditions seem to embody some of this information.

Effects on Behavior of Eliminating the Hypothesis. Figure 4-5 presents two comparative plots which illustrate the key shift in the step-response of the production-sector model when output inventory and backlog corrections are omitted as influences on capital ordering. The figure compares the behavior of two variables—arrivals of capital AC and the production ratio for capital PRC—generated with and without inventory and backlog corrections in capital ordering. The curves drawn in solid line represent behavior of AC and PRC taken from the earlier step run with the full SDNM investment function (Figure 4-2b); The curves drawn in dotted lines represent AC and PRC for the model including the modified investment function. All conditions underlying the two simulations are
identical except for the differing equations for desired output in
capital planning. (See Appendix B.)

Figure 4-5 shows that, when capital ordering no longer responds
to output inventory and backlog conditions, capital expansion is delayed
because the perceived need for more capital to expand output is delayed.
With the full SDNM investment function, the production ratio for capital
rises immediately in response to rising backlog of unfilled orders for
output and falling output inventory.\textsuperscript{17} Without inventory and backlog
corrections in capital ordering, the production ratio for capital PRC
decays until year 2.5.\textsuperscript{18} PRC finally rises to a peak approximately 3
years later than the peak in PRC generated with the full SDNM investment
function. This shift in the pressure to expand capital in order to
expand output leads to a similar delay in the response of arrivals of
capital. With the full investment formulation, arrivals of capital rises
to a peak at year 3.1; without inventory and backlog corrections in
capital ordering, arrivals of capital does not reach a peak until year 5.

\textsuperscript{17}Note that elimination of inventory and backlog corrections in capital
ordering implies that there are now two "production ratios" in the
model—one which influences desired capital and a second which influences
desired labor and the multiplier from the production ratio MPR. The
former is termed the "production ratio for capital": the latter retains
the original term the "production ratio." In the ensuing analysis, the
production ratio influencing capital investment will always be referred
to as the production ratio for capital PRC, regardless of how PRC is
determined.

\textsuperscript{18}PRC, which now equals (ASHIP/PP), falls between year 1.25 and year
2.5, because potential production rises more rapidly than shipments (and
therefore average shipments) over the period.
Intuitive Explanation of Shifts in Behavior. Eliminating inventory and backlog conditions as influences on capital ordering eliminates early warning indicators of imbalances between supply and demand. Changes in backlog of unfilled orders for output provide the first indications of changes in demand. Movements of backlog and output inventory away from
desired levels signal excess demand or supply. By contrast, shipments, the indicator of desired output when inventory and backlog conditions no longer influence desired capital, are generally constrained by availability of inventory. If inventory is insufficient to fill orders at the desired rate, the sector must wait until more inventory is produced before shipments can expand. Hence, shipments indicates the sector's response to changes in demand, rather than reliably indicating changes in demand. Basing capital acquisition on shipments as the sole indicator of desired output can therefore lead to a much later expansion of investment than occurs when investment responds to inventory and backlog conditions.

An alternative way to describe the shift in behavior which occurs when investment no longer responds to output inventory and backlog conditions is that capital expansion now occurs as a consequence of expansion in labor. Labor expansion leads to capital expansion through two mechanisms. The first, involves the rebalancing of factor proportions. The initial expansion of labor leads to a perceived need to add capital to increase the capital-output ratio. The second involves the behavior of shipments as the indicator of desired output for capital planning. Since shipments cannot expand significantly until production and inventory have already expanded, increases in the production ratio for capital with the modified investment function stem from increases in labor and factor utilization. Therefore, capital expansion with the modified investment function can be viewed as consequences of prior expansions in labor.
Model Behavior with Modified Investment Function. Figure 4-6 shows the response of the modified consumer-goods sector model to a 10% step increase in orders for output. In the simulation desired capital is determined as the product of current capital CAP, the production ratio for capital PRC, and the perceived ratio of capital return to cost PRCRC:

$$DCAP_t = CAP_t \cdot PRC_t \cdot PRCRC_t$$

With inventory and backlog corrections eliminated, the production for capital PRC equals the ratio of average shipments ASHIP to potential production PP

$$PRC_t = ASHIP_t / PP_t$$

When compared to the earlier step-response of the production sector with the full SDNM investment function (Figure 4-2), the behavior in Figure 4-6 shows that the simplified investment function gives rise to a different sequence of pressures for capital expansion. Figure 4-2b shows that, when inventory and backlog corrections influence capital ordering, desired capital increases first in response to perceived need.

Note that some variables are plotted on different scales on Figure 4-2 and Figure 4-6. For example, capital and desired capital are plotted on a scale that ranges from 800 to 1000 in Figure 4-2; and in Figure 4-6 the two variables are plotted on a scale that ranges from 700 to 1100.
for more output, then in response to perceived need to rebalance factor proportions. The first pressure is represented by rising values of the production ratio, the second by rising values of the perceived ratio of capital return to cost PRCRC (see Figure 4-2b).

Figure 4-6b shows a different sequence of capital expansion pressures. Desired capital first begins a protracted expansion in response to rising values of PRCRC. PRCRC begins to rise at year 1.5 in Figure 4-6b and continues to rise until year 3. Desired capital continues to rise beyond the peak in PRCRC at year 3 because PRC is still increasing. With inventory and backlog corrections, capital expansion occurs, first, from the perception of inadequate capacity to meet demand,
then, from the perceived need to rebalance capital and labor. Without inventory and backlog corrections, the sequence of pressures for capital expansion is reversed.

Although eliminating inventory and backlog corrections in capital ordering affects the pattern of capital expansion, it has little impact on short-term fluctuations in production, labor, output inventory and backlog of unfilled orders for output. For example, production still fluctuates with a 4 1/2 year period and the timing of production fluctuations relative to fluctuations in backlog and inventory in unchanged from the earlier simulation with the full SDNM investment function.

Implications for Plausibility of Model Behavior. The changes in production-sector behavior brought about by eliminating the effect of inventory and backlog discrepancies on capital ordering have several implications for the plausibility of model behavior. First, the simplified investment function produces behavioral anomalies that seem implausible. In particular, consider the behavior of the production ratio for capital PRC in Figure 4-6b. PRC indicates the perceived need to expand capital in order to expand production. PRC declines from year 1.25 until year 2.5, staying below unity until year 3.5, because potential production responds more rapidly than shipments to the increase in demand. Consequently, from year 1.25 until year 3.5, the sector perceives that it needs less capital to meet demand for output. Such
perception directly contradicts the fact that output inventory is below its desired level from year 1.25 until year 2.6 and backlog of unfilled orders for output is above its desired level from year 1.25 and year 3.1. It is difficult to imagine pressures to decrease production capacity would coexist with such inventory and backlog discrepancies in a real production sector.

Throughout the simulation in Figure 4–6, the production ratio for capital PRC continues to generate pressures for capital investment which are in conflict with the sector's actual need for output. For example, PRC exceeds unity from year 3.5 to year 5.9, indicating pressures to expand capital for increased output. Yet, Figure 4–6c shows that inventory is above its desired level from year 3.1 to year 5, and backlog is below its desired level from year 3.1 to year 5.6. Therefore, eliminating inventory- and backlog corrections causes pressures to adjust capital to adjust output to be continuously out of phase with the sector's actual need for output.

Elimination of inventory and backlog corrections in capital ordering also restricts the variety of external changes to which the sector can plausibly respond. Consider, for example, sector response to growing demand in the context of a tight labor market. Given the simplified investment function, the sector attempts to arrest rising backlog and falling inventory solely by increasing utilization and adding labor. If the necessary additional workers are unavailable, or available only with a lengthy delay, and if increases in factor utilization cannot
fully absorb rising demand, backlogs would continue to rise and inventory would continue to decline. In such a circumstance, one would expect entrepreneurs to recognize the opportunity for investment reflected in growing inventory and backlog imbalances; yet the simplified model would not generate the expected investment demand.20

Summary. This section has shown that inventory and backlog corrections in capital ordering are necessary to generate plausible production-sector behavior. Elimination of inventory and backlog corrections in capital ordering eliminates leading information on shifts in the balance of supply and demand. As a result, capital expansion or contraction occurs only as a consequence of prior expansion or contraction in labor and production—that is, of prior shifts in supply. This shift in sector behavior gives rise to internal pressures to adjust capital to adjust output which are contrary to the sector's actual needs for more or less output. Making capital expansion dependent on prior expansion in labor and production also means that no capital expansion is possible if the sector is unable to expand labor.

20In a more complete model including endogenous pricing (of the sector's output) and endogenous changes in factor prices, increases in output price and decline in the relative price of capital (relative to labor) would tend to stimulate investment demand. But, changes in relative prices would be insufficient to guarantee rebalancing of output inventory and backlog if investment does not respond explicitly to inventory- and backlog discrepancies.
IV.B SUPPLY-LINE CORRECTION

The Hypothesis. The SDNM investment function includes the hypothesis that order starts for capital responds to the discrepancy between desired and actual levels of the supply line of unfilled orders for capital. As discussed in Chapter 2, the supply-line correction assumes that, when firms generate new order starts for capital, they take account of current capital projects in planning and on order. The supply-line correction also implies that capital ordering responds to changes in the time required to realize new capital acquisitions. The supply-line correction, in effect, asserts that, when a new capital project is initiated, producers do not continue to generate new order starts for the same project. Likewise, new orders are not generated for projects already in the process of being realized. Omitting the supply-line correction implies that producers continue to generate new orders for a capital project up until the time when the project is complete and is part of current production capacity.

Omitting the supply-line correction also implies that producers ignore changes in the time required to realize new capital acquisitions in planning. Yet changes in delivery delays for equipment or construction times affect the rate at which production can be expanded. If, for example, a firm desires to expand at a certain rate per year, capital must be ordered "further ahead" if the perceived delay in obtaining new capital rises.
Effects on Behavior of Eliminating the Hypothesis. Figure 4-7 illustrates the effects of eliminating the supply-line correction on model response to a 10% step increase in sales. The figure displays the behavior of two variables—desired capital and order starts for capital—in two different simulations. The curves drawn in solid lines are taken from Figure 4-2, the step-response with the full SDNM investment function. The curves drawn in dotted lines come from a simulation identical to that in Figure 4-2, with the exception that there is no longer a supply-line correction in capital ordering. Order starts for capital now responds only to the replacement orders, the discrepancy between desired and actual capital stock, and to expected growth in shipments (see Equation 2-1.)

Figure 4-7 shows that eliminating the supply-line correction increases the amplitude of fluctuations in order starts for capital. In particular, consider the behavior of desired capital and order starts for capital from year 1 to year 2.5. Over this period, the behavior of desired capital is almost identical in the two simulations. The two simulations of desired capital don't begin to diverge until year 2.25 and desired capital generated with the modified investment function exceeds desired capital in the original simulation by only about 0.5% at year 2.25. Over the same time interval, order starts for capital diverge noticeably in the two simulations. When the model is simulated without the supply-line correction in capital ordering, order starts rises to a value of 123 at year 2. By contrast, order starts rises to a value of
110 at year 2. with the full SDNM investment function. Therefore, the modified investment function generates a 12\% higher order rate, even though the behavior of desired capital is virtually identical in the two simulations.

Figure 4-7 shows that the amplitude of subsequent fluctuations in order starts is similarly increased by eliminating the supply-line correction. For example, the value of order starts at year 5.1 is about 50\% lower with the modified investment function (25 versus 50) even though the values of desired capital generated with the two investment functions deviate by only 1.1\% at the same time. Clearly, eliminating
the supply-line correction leads the sector to make much larger adjustments in capital ordering to accomplish a desired adjustment in capital stock.

**Intuitive Explanation of Shifts in Behavior.** Figure 4-7 shows that eliminating the supply-line correction considerably increases the amplitude of fluctuations in order starts for capital. This shift in behavior can be explained directly in terms of the managerial processes embodied in the supply-line hypothesis. Eliminating the supply-line correction implies that producers no longer "remember" capital projects in planning and on order. Hence, they continue to generate additional order starts for a project until the project is realized. This "double-ordering" of new capital causes a higher rate of order starts to be generated in order to attain a given level of desired capital. Analogously, when producers want to contract capital stock, they generate orders for new capital at a rate less than required to replace the existing stock. A reduction in order starts leads to a reduction in the number of projects in planning. The same reduction in order starts need not be repeated in the future unless further contractions in capital stock are desired. When the supply-line correction is eliminated from the investment function, the model generates an excessive cutback in order starts because, in effect, producers are assumed to not remember past reductions in order starts reflected in current levels of projects in planning and backlog of projects on order.
Model Behavior with the Modified Investment Function

Figure 4-8 shows the response of the consumer-goods sector model without the supply-line correction in capital ordering to a step increase in incoming orders. The basic pattern of response is quite similar to that observed with the full SDNM investment function (Figure 4-2). Production, output inventory, backlog of unfilled orders for output, and labor predominantly exhibit an approximate 4 1/2 year fluctuation about new equilibrium values. Capital predominantly exhibits a longer-term overshoot and adjustment to the new equilibrium. As noted earlier, the degree of overshoot in capital adjustment is greater than occurs with the full SDNM investment function. However, the pressures underlying capital expansion and contraction are essentially unchanged from response with the full SDNM investment function. Desired capital increases initially in response to perceived need to expand output, then continues to increase as the sector perceives a need to rebalance factor proportions. The first pressure is represented by rising values of the production ratio for capital from year 1 and year 1.75. The latter pressure is represented by rising values of the perceived ratio of capital return to cost from year 1.5 to year 3.25. Because the pressures underlying capital expansion are relatively unchanged by eliminating the supply-line correction in capital ordering, the relative timing of investment activity is likewise unchanged.
Implications for the Plausibility of Model Behavior. The preceding discussion has shown that eliminating the supply-line correction leads to at least one implausible feature of model behavior. Without the supply-line correction, the sector "double-orders" new capital because producers ignore current projects in planning and backlogs of unfilled orders for capital.
A second type of behavioral implausibility can arise from eliminating supply-line correction if the delivery delay for capital changes. In effect, eliminating the supply-line correction implies that producers are indifferent to the rate at which they acquire capital. For example, if delivery delay for capital rises, the rate of arrivals of capital will decline. If order starts do not increase to compensate for the longer delay in obtaining capital, the higher delivery delay will permanently depress the rate of capital acquisition. Conversely, if the delivery delay for capital falls, the sector will find itself acquiring capital stock more rapidly than desired. Clearly, if one considers extreme conditions, such as a ten-fold rise in delivery delay, the assumption that capital ordering does not respond to changes in the delivery delay for capital becomes highly implausible.

Summary. This section has shown that a supply-line correction in capital ordering is necessary to prevent redundant ordering of new capital. Elimination of the supply-line correction implies that producers continue to place orders for capital projects already in planning and on order. In addition to being an implausible description of investment decision making, such double ordering amplifies over and under expansions in capital ordering stemming from a desired adjustment in capital stock. Elimination of the supply-line correction also makes capital ordering
unresponsive to changes in delivery delay for capital, thereby making it impossible to re-establish desired rates of capital acquisition when delivery delay for capital changes.

IV.C EXPECTED GROWTH IN SHIPMENTS

The Hypothesis. The SDNM investment function includes the hypothesis that orders for capital respond to perceived trends in shipments or sales. As was argued in Chapter 2, when shipments have grown over an extended period, producers begin to incorporate expected future growth into their factor acquisition plans. If a firm's sales grow for an extended period of time, growth may become so much a part of the normal state of affairs that managers view planned additions to capacity from the standpoint of how much they will increase or decrease the rate of growth in output. Conversely, if an individual firm is too cautious in preparing for growth in sales opportunities, it may lose market share to competitors who are more able to satisfy a growing market. In an aggregate production sector, additional pressures to incorporate growth into capacity expansion plans may exist. Expected growth opportunities are often a primary motive for new firms entering an industry. Omitting the influence of growth expectations on capital ordering implies that producers consider only current needs for output and pressures to adjust the capital-output ratio in planning capital expansion. This implies that, for example, if current productive capacity is adequate and there are no indications that profitability would rise if production were more
capital intensive, producers will order only enough capital to maintain current stocks. Yet, if such an investment policy is pursued in the presence of a growing demand, capital stock will be inadequate in the future. Therefore, it seems more realistic to assume that producers take account of growth expectations in ordering additional capital.

Effects on Behavior of Eliminating the Hypothesis. As suggested above, the hypothesized influence of growth expectations on capital ordering is likely to have its greatest impact when demand is growing. For this reason, the ensuing analysis focuses on shifts in model response to steadily-rising "ramp" in orders for output. In the following simulations, orders for output starts at 1000 units/year, then increases by 100 units/year.

Figure 4-9 shows the behavior of desired and actual levels of capital, and the production ratio for capital given a ramp increase in orders for output. Figure 4-9a shows the ramp response of the three variables with the full SDNM investment function. Figure 4-9b displays the ramp response with the hypothesized influence of growth expectations on capital ordering eliminated. Conditions for the two simulations are otherwise identical save for the exclusion of growth expectations in

21 The effects of eliminating growth expectations in capital ordering for model response to a step-increase in orders for output are discussed in Section IV.D of Chapter 5.
Figure 4-9b. The simulations in Figure 4-9 cover 40 years; the plotting interval for each simulation is 0.5 years.

Figure 4-9 shows that the sector operates with perpetually inadequate production capacity when capital ordering no longer responds to growth expectations. For example, Figure 4-9a shows that, with the full SDNM investment function, the growth rate of capital gradually adjusts to the growth trend over the first fifteen years of the simulation. By year 15, capital equals desired capital and the two variables grow together for the remainder of the simulation. Figure 4-9b shows that capital never reaches desired capital with the modified investment function. Similarly, Figure 4-9a shows that the production ratio for capital stays above unity from year 1 until year 12.5 with the full SDNM investment function, signifying inadequate production capacity during the initial 7 years after orders for output begin to rise. After year 12.5, the production ratio fluctuates about unity. By contrast, the production ratio generated with the modified investment function stays above unity throughout the simulation, signifying perpetually inadequate production capacity.

**Intuitive Explanation for Shifts in Model Behavior.** The inability of the modified production-sector model to maintain desired levels of capital stock in Figure 4-9b suggests that, when growth expectations no longer influence investment, the sector is unable to generate sufficient orders for capital to meet rising demand. When growth trends are ignored,
Figure 4-9
Ramp Response with and Without Hypothesized Effect of Expected Growth in Shipments
capital is ordered on the basis of present needs for additional output. By the time the additional capital has arrived, orders for output have risen, thereby meaning that a higher rate of production is required to offset the higher rate of incoming orders. Hence, capital is always inadequate to meet the growing demand.

The inability of the modified production sector to maintain adequate production capacity can also be explained in terms of the conditions required for capital expansion when growth expectations no longer influence capital ordering. Capital stock can only grow if order starts for capital exceeds replacement orders for capital. With growth expectations eliminated, order starts for capital can only exceed replacement orders if either capital stock or the supply-line for capital is below its desired level. (In fact, both occur, though the supply-line and the desired supply-line are not plotted in Figure 4-9.) The sector, therefore, must operate with inadequate production capacity (production ratio above unity) have desired capital exceed capital and generate the pressure on capital ordering necessary for growth.

Model Behavior with the Modified Investment Function. Figure 4-10 shows the response of the consumer-goods sector model without the hypothesized influence of growth expectations on capital ordering to a ramp in incoming orders for output. Labor and related variables are plotted in Figure 4-10a. Capital and related variables are plotted in Figure 4-10b. Figure 4-10c displays the behavior of desired and actual levels
of backlog, production, and orders for output. The figure shows that production, backlog, and labor fluctuate with an approximate 4 1/2-year period about a growth trend. Arrivals of capital exhibits a longer term overshoot and adjustment to trend. The basic patterns of short-term fluctuations about trend for labor, production, and backlog and longer-term adjustment to trend for capital and arrivals of capital is unaffected by eliminating growth expectations.
What is affected by elimination of the hypothesized influence of growth expectations on capital ordering are the internal system conditions during growth. As noted above, capital stock remains below desired capital throughout the simulation (Figure 4-10b). Figure 4-10c shows that backlog also remains above desired backlog throughout the simulation. The perpetual backlog discrepancy reflects the continuing inadequacy of production capacity when growth expectations are omitted. As explained above, the modified production sector must maintain inadequate production capacity to generate pressures for growth. Perpetual surplus of backlog of unfilled orders for output signifies the inadequate production capacity.

Implications for Plausibility of Model Behavior. The above analysis has delineated several implausible features of behavior arising from elimination of the hypothesized influence of growth expectations on capital ordering in the SDNM investment function. In particular, elimination of growth expectations leads to persistent discrepancies between desired and actual levels of backlog of unfilled orders for output, and capital stock in the face of growing demand for output. In effect, elimination of growth expectations in capital ordering implies that producers are willing to operate in conditions of perpetually inadequate production capacity, even though the price of capital and the delivery delay in obtaining additional capital (which are constant in the above simulations) offer no constraint to expanding capacity.
Summary. This section has shown that the hypothesized influence of growth expectations on capital ordering is necessary to generate plausible behavior of the consumer-goods sector in the presence of growing demand for output. Eliminating the hypothesized influence of growth expectations shifts the burden for generating growth in investment to pressures to expand capital to meet current demand. However, shifting the burden for generating growth to pressures to meet current demand means that the sector can only generate growth by continually failing to meet present demand. Hence, eliminating the hypothesized effect of growth expectations on capital ordering implies that producers are willing to operate with perpetually inadequate production capacity (and depressed sales) when demand is growing.

IV.D PERCEIVED RATIO CAPITAL RETURN TO COST

The Hypothesis. The SDNM investment function differentiates the response of capital ordering to changing incentives to expand or contract output from the response to changing incentives to modify the capital-output ratio. The formulation embodies the assumption that producers modify productive capacity at current factor proportions more readily than they modify factor proportions. As discussed in Chapter 2, two considerations underlie the assumed difference in response. First is the observation that given types of capital require more or less fixed capital-labor ratios. Substantial variations in desired factor proportions usually
entail new types of capital and are therefore considered carefully before a commitment is made. Second, desired capital-output ratio changes slowly because of the time required to perceive incentives to modify factor proportions. Optimal factor proportions are never known with certainty, and considerable time may pass before producers recognize that adjustments in their current factor proportions are warranted.

Elimination of the delay in forming perceived ratio of capital return to cost implies that producers instantaneously perceive departures from the optimal capital-output ratio and immediately modify their desired stock of capital accordingly. Such an investment function is sometimes referred to as a "putty-putty" investment function because it assumes freely variable factor proportions (see Chapter 2). Past research has shown that putty-putty investment functions can lead to unrealistic behavior even when there is no feedback from current investment to future investment incentives (see Bischoff 1971b). The tests below extend previous analyses to show that elimination of the delay in perceiving the ratio of capital return to cost PR CRC leads to additional forms of implausible behavior when capital investment is analyzed within the consumer-goods sector model. By explaining basic shifts in behavior precipitated by eliminating PR CRC, the following analysis also provides background for behavior-mode tests of the PR CRC hypothesis in Chapter 5.
Effects on Behavior of Eliminating the Hypothesis. Figure 4-11 shows the behavior of two variables—desired capital and desired labor—generated with and without the hypothesized delay in forming perceived ratio of capital return to cost PRCRC. In both simulations, the consumer-goods sector model responds to a step-increase in orders for output. The simulations cover 10 years. Behavior without the hypothesized delay in forming PRCRC comes from a simulation which is identical in all respects except that there is no delay in perceiving and responding to nonoptimal factor proportions.22

Figure 4-11 shows that eliminating the delay in forming PRCRC alters the pattern of longer-term relatively gradual overshoot and oscillation in desired capital generated with the full SDNM investment function. Without the delay in forming PRCRC, fluctuations in desired capital have a greater amplitude, and desired capital exhibits none of the longer term fluctuation exhibited with the full SDNM investment function.

22To reflect the assumption of no delay in perceiving and responding to nonoptimal factor proportions, the new simulations presented in Figures 4-11 and 4-12 set perceived ratio of capital return to cost PRCRC equal to the current ratio of capital return to cost CRCRC and perceived ratio of labor return to cost PRCRC equal to the current ratio of labor return to cost RLRC. Both delays are eliminated because perfect knowledge of the optimal capital-output ratio implies perfect knowledge of the optimal labor-output ratio.
Figure 4-11
Comparative Plot of Behavior with and without Delay in Forming PRCRC. Ratio of Capital Return to Cost

For example, desired capital rises to an initial peak value of 975 units at year 2.25 with the full SDNM investment function. With the modified investment function, desired capital rises to a value of 1057 units at year 2.25. Desired capital falls to a value of 913 units at year 4.75 with the full SDNM investment function; desired capital falls to 825 units at year 4.75 with the modified investment function. The longer-term downswing evident in the original simulation between the peak in desired capital at year 2.25 and the trough at year 8.75 is not evident with the modified investment function.
Assuming that desired factor proportions respond immediately to departures from the optimal factor mix has an opposite effect on fluctuations in desired labor. Figure 4-11 shows that the modified model reduces the amplitude of the short-term fluctuations in desired labor. Whereas the assumed instantaneous response to nonoptimal factor proportions increases the aggressiveness with which the sector attempts to adjust capital, it decreases the aggressiveness with which the sector attempts to adjust labor.

Intuitive Explanation of Shifts in Behavior. An explanation of why desired capital rise and falls more rapidly with the modified investment function follows directly from the assumption that producers immediately recognize and respond to nonoptimal factor mixes. As discussed earlier, when pressures to expand production capacity develop, labor rises more rapidly than capital due to the shorter delays in acquiring additional labor. The more rapid acquisition of labor moves the mix of labor and capital away from the optimal factor mix which existed initially. With the modified investment function, capital orders respond immediately as the nonoptimal factor mix develops. Desired capital begins to rise more rapidly to counter the imbalance in productive factors.

Conversely, as soon as the sector begins to acquire labor more rapidly than capital, it also slows the rate of increase in desired labor. Less rapid increase in desired labor is a natural concomitant to the more rapid increase in desired capital, as the sector attempts to
maintain an optimum balance of the two factors. Both responses arise more quickly in the modified model due to the immediate response to nonoptimal factor proportions.

Model Behavior with the Modified-Investment Function. Figure 4-12 shows the response of the modified consumer-goods sector model to a 10% step increase in incoming orders for output. Because the delay in forming PRCRC is eliminated, desired capital DCAP is determined as the product of capital CAP, the production ratio for capital PRC, and the ratio of capital return to cost RCRC in the simulation:

\[ DCAP_t = CAP_t \cdot PRC_t \cdot RCRC_t \]  

\((4-4)\)
Figure 4-12

Step Response without Delay in Forming Perceived Ratio of Capital Return to Cost
When compared to the step response with the full SDNM investment function, the major shift in the behavior in Figure 4-12 appears to be the emergence of dominant short-term fluctuations in capital and related variables with the modified investment function. As compared to the long-term overshoot and decline in capital with the full SDNM investment function (Figure 4-2b), capital in Figure (4-12b) rises towards its new equilibrium, overshoots, then fluctuates with an approximate 4 1/2 year period. Similarly, the longer-term overshoot and decline in arrivals of capital with the full SDNM investment function (Figure 4-2b) gives way to dominant short-term fluctuations in the behavior of arrivals of capital generated without the delay in forming PRCRC.

The increased short-term fluctuations in arrivals of capital and capital stem from the increased short-term fluctuations in desired capital noted above. When the sector is assumed to respond immediately to departures from the nonoptimal factor mix, desired labor and desired capital fluctuate with the same period and amplitude. (The synchronous fluctuations in desired labor and desired capital can be seen most clearly in Figure 4-11.) To see why desired capital and desired labor move together, observe that eliminating the delays in perceiving and responding to nonoptimal factor mixes implies that the desired capital-labor ratio always equals the optimum capital-labor ratio. The optimum ratio of the two factors depends only on their relative cost. Since the factor costs are held constant in the present tests, the optimum capital-labor ratio likewise is constant. Therefore,
fluctuations in desired capital and desired labor generated with the modified model have the same period and amplitude because the desired capital-labor ratio is assumed to always equal the (constant) optimum ratio.

Behavior of labor, production, and output inventory and backlog is relatively unchanged by assuming immediate response to nonoptimal factor mixes. All variables fluctuate with about a 4 1/2-year period. The amplitude of fluctuations in production, inventory and backlog is reduced somewhat due to the reduced amplitude of labor fluctuations. As explained above, fluctuations in desired labor are smaller in the modified model due to increased pressures to maintain an optimum capital-labor ratio.

Implications for the Plausibility of Model Behavior. The preceding analysis has shown that, when the delay in forming the perceived ratio of capital return to cost is eliminated, desired capital and capital expand and contract more rapidly than occurs with the full SDNM investment function. This shift in behavior has important implications for the fluctuations in investment behavior explored in Chapter 5. The present discussion considers the implications for the relative volatility of desired stocks of capital and labor.

When the delay in forming perceived ratio of capital return to cost is eliminated, desired capital and desired labor fluctuate with the same period and the same relative amplitude. For example, desired labor
rises to a peak value of 1270 workers at year 2.25 in Figure 4-12a, 15% above the eventual equilibrium value of 1100 workers. Desired capital rises to a peak value of 1055 units at year 2.25 in Figure 4-12b, 15% above its eventual equilibrium of 917 units. The desired factor stocks are also equally volatile in downswings. Such behavior seems contrary to the conventional managerial view of capital as a longer-term commitment than labor. The costs of overexpanding fixed capital are generally greater than the costs of overexpanding labor. Likewise, an insufficient stock of production workers can usually be remedied more quickly, and is therefore less costly, than insufficient capital. On the basis of such considerations, one would expect the desired stock of capital in real production sectors to be considerably less volatile than the desired stock of labor, not equally volatile, as occurs when producers are assumed to respond immediately to nonoptimal factor mixes.23

Summary. This section has argued that the delay in forming perceived ratio of capital return to cost PRCRC is necessary for plausible investment behavior. Eliminating the hypothesized delay is tantamount to assuming that producers have perfect information concerning optimal factor mixes and they respond immediately to this information.

23Note also that the equal volatility of desired capital and desired labor without the delay in forming PRCRC contradicts the conventional idea that adjustments in labor are the preferred means for correcting inventory and backlog imbalances.
Eliminating the hypothesized delay causes investment to respond equally rapidly to needs for more output and to incentives to modify capital intensity, a behavioral characteristic of Jorgenson's model which many economists have criticized.

The preceding analysis has shown that eliminating the hypothesized delay in forming PRCRC also leads capital stock and investment to no longer exhibit the relatively gradual long-term upswings and downswings generated with the full SDNM investment function. In fact, due to pressures to maintain the constant optimum capital-labor ratio, desired capital fluctuates with the same period and relative amplitude as desired labor. Such behavior contradicts the common view of capital as a long-term commitment which producers do not desire to adjust as rapidly as labor.
V. SUMMARY OF BEHAVIOR PLAUIBILITY TESTS

The preceding tests have shown that each SDNM investment hypothesis plays a role in generating plausible behavior of the consumer-goods sector model. The hypothesized influence of expected growth in shipments and the delay in forming perceived ratio of capital return to cost PRCRC are necessary for plausible behavior of desired capital. Eliminating growth expectations leads desired capital to perpetually exceed capital. Eliminating the delay in forming PRCRC leads desired capital to fluctuate with the same period and relative amplitude as desired labor, thereby contradicting the common view of capital as a longer-term commitment than labor. The supply-line correction is necessary for plausible behavior of order starts for capital. Elimination of this hypothesis causes double ordering of new capital and eliminates adjustments in capital ordering to compensate for changes in the delivery delay for capital. Lastly, the hypothesized inventory and backlog corrections are necessary for internally consistent pressures for expansion and contraction within the sector and for plausible response to rising demand in the presence of a tight labor market. Because each SDNM investment hypothesis is omitted from the neoclassical investment function, the above findings imply that the neoclassical investment function is unable to generate plausible production-sector behavior.
Table 4-1 provides a more detailed summary of results of the behavior-plausibility tests. The table summarizes the changes in the determinants of investment, basic shifts in model behavior, explanation of behavioral shifts, and implausible features of behavior when each SDNM investment hypothesis is eliminated from the investment function in the consumer-goods sector model. For example, elimination of inventory and backlog corrections in capital ordering leaves shipments as the measure of desired output in capital planning and leads capital adjustments (expansion or contraction) to occur later relative to adjustments in labor and production than occurs with the full SDNM investment function. With the modified investment function, investment becomes dependent on prior adjustments in production and shipments—which in the present model means prior adjustments in labor. The shifts in behavior brought about by eliminating inventory and backlog corrections implies that capital cannot expand if labor does not first expand. A second implausible feature of behavior with the modified investment function is that desired output for capital planning (average shipments) tends to move out of phase with the sector's need for output to correct inventory and backlog imbalances. Consequently, the modified investment function frequently indicates need for less output when current capacity is inadequate and more output when capacity is in excess.
<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Changes in Determinants of Investment</th>
<th>Shifts in Behavior</th>
<th>Explanation of Behavioral Shifts</th>
<th>Features of Implausible Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inventory and Backlog Corrections</strong></td>
<td>Desired output equals average shipments in capital planning.</td>
<td>Capital expansion/contraction occurs later relative to adjustments in labor and production.</td>
<td>Capital adjustments become dependent on prior adjustments in labor rather than on imbalances in supply and demand.</td>
<td>Capital cannot expand unless labor and production first expand (e.g., no capital expansion in tight labor market.)</td>
</tr>
<tr>
<td><strong>Supply-Line Correction</strong></td>
<td>Capital ordering no longer responds to changes in supply-line of unfilled orders for capital or to delivery delay for capital.</td>
<td>Increases amplitude of fluctuations in order starts for capital, arrivals of capital, and capital stock.</td>
<td>Order starts for capital no longer &quot;remember&quot; capital projects already in process.</td>
<td>&quot;Double ordering&quot; of new capital</td>
</tr>
<tr>
<td><strong>Expected Growth in Shipments</strong></td>
<td>Capital ordering no longer responds to trends in shipments.</td>
<td>Given steadily increasing orders for output,</td>
<td>Burden for generating capital growth shifts to discrepancy between desired and current stocks of capital.</td>
<td>Given steadily increasing orders for output,</td>
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<td></td>
<td></td>
<td>Creates discrepancies between actual and desired levels of capital and backlog of unfilled orders for output.</td>
<td></td>
<td>Current production capacity must be inadequate to meet demand.</td>
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<tr>
<td><strong>Perceived Ratio of Capital Return to Cost</strong></td>
<td>No delay in perceiving and responding to nonoptimal factor mixes.</td>
<td>Desired capital, capital and arrivals of capital expand and contract more rapidly.</td>
<td>Capital expands and contracts more rapidly due to increased pressure to maintain optimal factor mix. Labor expands and contracts more slowly for same reason.</td>
<td>Investment responds equally rapidly to needs for more or less output and to nonoptimal factor mixes.</td>
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<td>Desired labor and capital fluctuate with same period and relative amplitude.</td>
<td>Desired capital-labor ratio always equals optimal capital-labor ratio.</td>
<td>Desired capital and desired labor become equally volatile.</td>
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</tbody>
</table>
CHAPTER 5 MODEL-BEHAVIOR TESTS--PART II: BEHAVIOR-MODE TESTS

I. INTRODUCTION AND PREVIEW OF RESULTS

The preceding chapter has shown that each of the SDNM investment hypotheses is necessary for plausible behavior of the consumer-goods sector model. The tests showed that the consumer-goods sector model without the SDNM investment hypotheses could not respond in a plausible fashion to simple test inputs such as a step increase in orders for output or a continually rising rate of incoming orders. These findings deepened confidence that the SDNM investment hypotheses reflect features of real investment decision making.

This chapter presents a second series of model-behavior tests of the SDNM investment function. The purpose of the following tests is to determine if the SDNM investment hypotheses are important for two modes of oscillatory behavior generated by the consumer-goods sector model--an approximate 5-year cycle in production and labor and longer-term fluctuations in investment and capital stock. (The average period of the capital fluctuations equals about 18 years.) The two behavior modes emerge distinctly when the consumer-goods sector model including the full SDNM investment function responds to a small random component in demand for output. The modes also appear to be present in aggregate and industry data. The shorter periodicity resembles the 3- to 7-year business cycles common to a wide range of economic time series. The longer-term fluctuations match the period of the so-called "Kuznets
cycles" observed in data for investment, capital stock, growth in output, and productivity collected for many countries.

The tests presented below show that the SDNM investment hypotheses are important in generating the two distinct behavior modes. If one eliminates all five SDNM investment hypotheses, the resulting neoclassical-type investment function blurs the previously sharp distinction between short-term labor-induced fluctuations and long-term capital-induced fluctuations. The longer-term fluctuations in capital investment are replaced by dominant short-term fluctuations. The dominant longer-term fluctuations in capital stock are replaced by a more even mix of long- and short-term fluctuations. Moreover, the period of short-term fluctuations in labor and production increases, furthering diminishing the distinction between the two periodicities. Of the five SDNM investment hypotheses, the delay in forming perceived ratio of capital return to cost PRCRC appears to play the most important role in generating the two distinct behavior modes. Elimination of this hypothesis alone is sufficient to make short-term fluctuations the dominant mode of behavior of capital investment, to significantly increase the degree of short-term fluctuation in capital stock, and increase the period of short-term fluctuations in production and labor.

The significance of finding that the SDNM investment hypotheses are important in generating the two distinct modes of consumer-goods sector behavior is illustrated by the Nathaniel Mass's study of alternative business cycle theories (Mass 1975). Mass argues that many
business cycle theories and economic stabilization policies are predicated on the assumption that capital investment is an intrinsic cause of short-term business cycles. On the other hand, if capital investment, in fact, gives rise to longer-term fluctuations,

...policies that attempt to control fixed capital investment may have relatively little leverage (on business cycles) or may be less effective than policies directly aimed at employment and inventories. (Mass 1975, p. 128)

Therefore, the finding that SDNM investment hypotheses are necessary in creating dominant longer-term fluctuations in investment and capital stock has potentially significant implications for understanding the causes of economic fluctuations and the effects of alternative stabilization policies.

Section II shows the two modes of oscillatory behavior generated when a small amount of random noise impinges on the consumer-goods sector model including the full SDNM investment function. Data for several historical time series are also examined in an attempt to corroborate the existence of the behavior modes in real life. Section II also introduces a tool, spectral analysis, useful in delineating the presence of oscillatory behavior modes in stochastic time series. Section III shows that eliminating all five SDNM investment hypotheses sharply alters model-generated spectra, producing several behavioral features not seen in the data. Section IV analyzes the effects on the two behavior modes of eliminating each SDNM investment hypothesis. Lastly, Section V considers the effects variations in parameter values on behavior-mode test outcomes. Section VI summarizes the behavior-mode test results.
II. OSCILLATORY MODES OF CONSUMER-GOODS SECTOR BEHAVIOR

II.A BEHAVIOR MODES GENERATED BY THE CONSUMER-GOODS SECTOR MODEL

This section shows that the consumer-goods sector model including the full SDNM investment function generates two distinct oscillatory modes of behavior: a cycle with an approximate 5-year period and a cycle with an approximate 18-year period. The short-term cycle is most apparent in order starts and arrivals of labor (new hires), labor, production, output inventory and backlog of unfilled orders for output. The longer-term fluctuation is most apparent in investment and capital stock.

Conditions for the Simulations. In the simulations for this and the following section, the simple deterministic test inputs employed previously are replaced by more realistic random fluctuations in incoming orders for the sector's output. Random fluctuations in incoming orders represent relatively unsystematic variations in demand for consumer goods such as sudden changes in employment, weather, stock market prices, or political climate. To simulate such randomness, a small "noise" signal is superimposed on a constant rate of incoming orders. The noise has a standard deviation equal to 5% of the constant order rate. The noise is also autocorrelated to reflect the autocorrelated character of random
factors which impinge upon real production sectors. The random
component in incoming orders serves to excite the production-sector model
to exhibit its inherent "natural" periodicities. Noise in any other of
the sector's inputs (such as delivery delay or factor prices) could serve
the same purpose. The role of randomness to draw out the natural
frequencies in a dynamic model has been discussed by several authors
(see, for example, Frisch 1933 and Forrester 1961, Appendix F).

All other conditions in the simulations presented in Chapter 5
match conditions in Chapter 4. The SDNM production-sector model is taken
to represent a consumer-goods sector. Capital and labor are available at
constant prices and fixed delivery delays. Parameter values in the model
correspond to estimates based on data for total nondurable manufacturing.

Model Behavior in the Time Domain. Figure 5-1 shows behavior of the
consumer-goods sector model when driven by the "noisy" flow of orders for
output. As before, the sector starts in equilibrium. The noise signal
begins at year 5. The simulation covers 100 years, and each plot
interval equals 1.25 years.

The noise is formed by passing white (uncorrelated) noise through a
first-order delay (or exponential smooth) with a 1 year delay time. The
resulting signal has an approximate exponentially decaying
autocorrelation function with a 1 year decay time. (See Bryson and Ho
1969, pp. 334-5).
FIGURE 5-1

BEHAVIOR OF CONSUMER-GOODS SECTOR MODEL WITH FULL SOND INVESTMENT FUNCTION AND RANDOM NOISE IN ORDERS FOR OUTPUT

The behavior in Figure 5-1 exhibits two characteristic periods of fluctuation. Labor and arrivals of labor (Figure 5-1a) primarily fluctuate with an approximate 5-year period. Production and inventory likewise fluctuate most noticeably with about a 5-year period. By contrast, capital and arrivals of capital (Figure 5-1b) exhibit a tendency toward a longer-term fluctuation. For example, the most noticeable fluctuation of capital has an average period of about 20 years. In fact, most variables exhibit combinations of the two

2 Periodicities of fluctuation in Figure 5-1 are estimated by counting peaks between two points in time. For example, the estimated average periodicity of capital fluctuations is obtained by counting the number of major peaks, 3, from year 8.9 to year 67.5, and dividing that figure into the duration, 60 years, between the beginning of the first cycle and the end of the last cycle.
periodicities, though the precise nature of the combination is difficult
to ascertain by mere inspection of the behavior plotted against time.

**Model Behavior in the Frequency Domain.** In order to examine the
periodicities present in the stochastic time series with greater
precision, the following behavior-mode testing makes extensive use of
spectral analysis. Spectral analysis is a technique for projecting
behavior plotted against time onto the frequency domain. That is,
behavior of a variable over time is decomposed into its component
frequencies. The resulting spectrum shows the relative power of each
frequency present in the behavior.

For stochastic time series, spectral analysis can be viewed as a
decomposition of the total variance of a time series attributable to
cycles of different periods. The relative variance of different
periodicities is represented in the spectra by the estimated squared
amplitude at each frequency. The integral of the squared amplitude over
all frequencies equals the total variance of the time series. A larger
amplitude at one frequency than another means a larger degree of the
total variance of the time series, often termed a larger "degree of
power," is present at that periodicity. For a more detailed discussion
of the technique and interpretation of spectral analysis of economic time
series see Granger (1964) or Engle (1974).
To illustrate the application of spectral analysis, Figure 5-2 shows power spectra for four variables plotted against time in Figure 5-1. The spectra are computed from yearly samples of the 100-year simulation. Figure 5-2a shows the power spectrum for capital; Figure 5-2b shows the spectrum for arrivals of capital. Figure 5-2c and 5-2d respectively show spectra for labor and production. Each figure displays frequency, measured in cycles per year, along the horizontal axis and amplitude, measured as the logarithm (to the base 10) of the squared amplitude at that frequency, along the vertical axis. For example, the power spectrum for capital (Figure 5-2a) shows the greatest concentration of power between the frequencies 0.094 cycles per year and 0.031 cycles per year. This frequency band corresponds to a range of periods from 10.7 to 32.0 years. The power over this frequency band equals about $10^{5.0}$ at the extremes (frequencies of 0.094 and 0.31 cycles per year) and $10^{5.33}$ over the plateau ranging from 0.069 to 0.038 cycles per year. On either side of the 11- to 32-year periodicity range, the capital spectrum falls off sharply, signifying much less power in fluctuations with periods longer than 32 years and shorter than 11 years.

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3The spectra in Figure 5-2, and those presented below, are computed by rectangular smoothing of the respective periodgram with a smoothing window of 0.096 cycles/year. There is no prewhitening. All model-generated data are analyzed as variations about a constant mean; the first five years of each simulation are ignored because the noise is not actuated until year 5. The empirical time series are detrended as described in the text.
Figure 5-2: Power Spectra for Model Behavior with Full SDNN Investment Function
The two distinct periodicities of fluctuation identified in behavior plotted against time emerge again as two "coherent" periodicities in the spectra. The longer term periodicity manifests as power concentrated in cycles having periods between 11 and 32 years. The longer term periodicity is most apparent in the behavior of capital stock (Figure 5-2a). The shorter-term periodicity manifests as power concentrated in cycles having periods between 4 and 7 years (frequencies from 0.25 to 0.14 cycles per year). The short-term periodicity most strongly dominates the behavior of labor (Figure 5-2c). The production spectrum shows a more nearly equal concentration of the two periodicities. Both periodicities are present in all production-sector variables. However, the relative power of each periodicity varies considerably from variable to variable.

The following analysis of model behavior modes focuses on two features of each spectrum in Figure 5-2—the average period of the long- and short-term fluctuations and the ratio of power concentrated in long-term fluctuations to power concentrated in short-term fluctuations. Table 5-1 presents this information for the spectra in Figure 5-2. For example, the table shows that the two periodicities of production behavior (Figure 5-2d) have average periods of 17.8 and

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4The term "coherent periodicity" refers to a concentration of power in the frequency spectra—that is, a narrow band of frequencies with amplitudes much higher than in neighboring frequencies.
4.6 years. The table also indicates that the ratio of average power concentrated in the long-term periodicity to the average power concentrated in the short-term periodicity, expressed in logarithms, equals \(-0.20\)--i.e., \(10^{-0.20} = 0.63\). That is, the production spectrum has approximately 1.6 times more power in short-term fluctuations than in longer-term fluctuations. The log power ratio for labor equals \(-0.84\) (0.145 in natural numbers)--which implies approximately 7 times more power in short-term labor fluctuations than in long-term labor fluctuations.

By contrast, capital and arrivals of capital have positive power ratios, signifying more power in longer term fluctuations for these variables. The two average periods for capital respectively equal 17.8

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5 Average periods are determined as a weighted average of frequencies in the specified frequency band. For example, short-term fluctuations in production are concentrated in frequencies ranging from 0.238 to 0.175 cycles/year (4.2- to 5.7-year periodicities). The midpoint of this frequency band equals 0.206 cycles per year. Because slightly higher levels of power appear toward the high frequency side of the midpoint, the average frequency equals approximately 0.213 cycles/year, corresponding to a 4.6-year average period.

6 Table 5-1 shows that the average power (in logs) in short-term fluctuations equals 5.40. The average long-term power equals 5.20. Subtracting the former from the latter gives a log power ratio for long-term to short-term periodicities of \(-0.20\).
and 4.6 years. The power ratio for capital equals $10^{4.3}$ signifying approximately 20,000 times more power in long-term than in short-term capital fluctuations. Arrivals of capital exhibits more of a mixture of the two periodicities, in the sense that the average long term period and the power ratio are smaller than the respective figures for capital. The average long term period for arrivals of capital equals 14.5 years. The power ratio for arrivals of capital equals $10^{2.04}$. Even though arrivals of capital behavior is more a composite of the two oscillatory behavior modes, the arrivals of capital spectrum shows approximately 100 times more power in long (11- to 27-years) term periodicities than in
short-term periodicities.  

II.B COMPARISON TO EMPIRICAL BEHAVIOR MODES

This section attempts to verify that the two modes of consumer-goods sector behavior identified above are present in economic time series. In particular, the preceding examination of model behavior suggests three questions to be answered by inspection of available data:

1. Are capital-stock- and arrivals of capital (investment) time series dominated by longer term fluctuations with periodicities ranging from 10 to 32 years?

2. Are production time series dominated by periodicities in the 4-6-year range?

3. Do production time series also contain distinct concentrations of power in longer term (approximately 18-year) fluctuations?

Behavior Modes in Investment and Capital Stock Data Many economists have gathered evidence suggesting the existence of economic cycles with an approximate 20-year period (see, for example, Kuznets 1930, Burns 1934, Hickman 1963 and Abramowitz 1961). These fluctuations, generally referred to as "Kuznets cycles", have been identified in aggregate and disaggregate data on investment, capital stock, output, productivity,

7Note that the arrivals of capital spectrum has a local peak at 0.125 cycles per year, suggesting the possibility of a third periodicity intermediate between the short- and longer-term periodicities. Possible causes for this 8-year cycle are discussed in Section IV.C below.
migration, and several other variables. However, despite the numerous empirical studies, data appropriate for comparison to behavior generated by the consumer-goods sector model are quite limited.

Industry data for investment and capital stock are only available for the past 30 years. Such a brief time span is virtually meaningless in searching for an 18-year cycle. Hence, the following analysis must rely on aggregate data for investment and capital stock.

Figure 5-3 plots data for capital stock in all manufacturing industries compiled by the Bureau of Economic Analysis (Wasson et. al. 1970). The data are plotted against time for years 1925 to 1968 (the last year covered in the survey). The data appear in absolute terms (in 1958 dollars) and as deviations from a linear trend. Figure 5-4 plots aggregate data on capital formation from 1871 to 1974. The data from 1871 to 1953 are compiled by Simon Kuznets (1961). Kuznets' data represent five-year moving averages of annual data, deflated to 1929 prices. The data from 1954 to 1974 are constructed similarly to Kuznets' data using Bureau of Economic Analysis data for the component series (construction, output of producers durables, and changes in manufacturers inventories). The BEA data are deflated to 1929 prices and averaged by a 5-year moving average. The data are plotted in Figure 5-4 in absolute

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FIGURE 5-3

Data for Capital Stock in Total Manufacturing, 1925-1968
(in 1958 dollars)

FIGURE 5-4

Data for Capital Formation in National Economy, 1871-1974
(in 1929 dollars)
terms (in constant 1929 dollars) and as deviations from a logarithmic trend.  

Both time series exhibit longer-term fluctuations with periods in the range of interest. For example, the two peaks in the detrended BEA capital stock data (Figure 5-3) are 27 years apart; the two troughs are separated by 20 years. Evidence of the periodicity of interest is somewhat less clear in Kuznets' data, due mainly to the effects on the trend line of the extreme decline in investment from 1927 to 1933. (Note that the detrended data remains above zero from 1888 to 1929). To overcome the effects of the 1927-1933 period, Figure 5-5 presents an alternative plot of the capital formation data. In Figure 5-5, the data are divided into two subseries—one from 1871 to 1929 and one from 1930 to 1974—and presented as deviations from a logarithmic trend in each subseries. The revised data clearly show fluctuations which are 10 to 15 years apart. For example, peaks in the revised capital formation data occur in 1880, 1891, 1905, 1918, 1927, 1942, and 1967.

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10 That is, the original data (Figure 5-4) are transformed by a (natural) logarithmic transformation, then plotted as deviations from a linear trend.
Figures 5-6 and 5-7 present power spectra for the capital and capital formation data. The spectra are formed from the detrended data in Figures 5-3 and 5-4. Both spectra show sharp concentrations of power in long-term periodicities. In the BEA capital-stock data (Figure 5-6) power is concentrated in cycles with periods between 12- and 32-years, approximately the same periodicity range over which power was concentrated in model-generated capital-stock behavior (Figure 5-2a). Power is concentrated in slightly longer periodicities in the capital formation data.

Although the spectra in Figures 5-6 and 5-7 are interesting, they must be viewed with caution. The concentrations of power in long-term periodicities observed in each spectrum may reflect the existence of fluctuations in the 10- to 32-year range of interest.
However, the spectra may also reflect still longer cycles (such as the Kondratieff wave\textsuperscript{11}) or residual time trends—that is, growth-trend components of the series not completely removed by detrending. Hence, the spectra in Figure 5-7 probably overestimate the relative power levels in 10- to 32-year cycles.

\textbf{Behavior Modes in Production Data.} Appropriate production and labor data for comparison to the consumer-goods sector are also limited. Most annual data for production and employment in consumer-goods producing industries span only the past 30 years (Semi-annual data exists over a longer period). Such data are inadequate for examining the hypothesis

\textsuperscript{11} See Kondratieff (1935), or, more recently, Forrester (1976).
of two distinct oscillatory modes in the behavior of production and employment.

One possible source of data for comparison to production behavior in the consumer-goods sector model is the set of disaggregate production series collected by Arthur Burns (1934). The series, most of which range from 1870 or 1880 to 1929, include measures of output for several industries within the aggregate consumer-goods producing sector. Figure 5-8 plots behavior for canned corn, canned tomatoes and flour measured by Burns. In each case, the data are plotted in raw form (measured in real terms) and as deviations from a logarithmic trend. When detrended, each production time series shows a strong short-term fluctuation. For example, the detrended data for canned tomatoes show a regular fluctuation with peaks about 5 to 6 years apart. In some cases, the series also suggest the presence of longer-term fluctuations. For example, the detrended data for production of flour suggests a longer term cycle in the peaks at years 1903 and 1920 and the troughs at years 1905 and 1921.
Figure 5-8a
Production of Canned Corn
(1885 to 1929)

Figure 5-8b
Production of Canned Tomatoes
(1885 to 1929)
To examine more closely whether the production time series reflect two distinct modes of oscillatory behavior, Figure 5-9 presents the power spectra for the three detrended data series. On the whole, the empirical power spectra support the dynamic hypothesis of two distinct modes of consumer-goods sector behavior. All three spectra show some concentration of power in the two frequency bands of interest. In two of three cases, production of canned corn and canned tomatoes, the greatest power concentration is in fluctuations in the 4- to 6-year range. In addition to 4- to 6-year fluctuations, the canned-corn output and canned-tomato output spectra each show a distinct longer term periodicity, though the longer term period in canned tomatoes production is less distinct than that in canned corn production. In one case, the
flour spectrum, the greatest power concentration is in periodicities ranging from 12.3 to 32 years, and a slightly smaller power concentration is in periodicities from 3.8 to 4.9 years.¹²

¹²A few additional production series collected by Burns were examined but rejected. Although all contained the two distinct periodicities predicted by the model, the rejected series had strong time trends which proved difficult to remove.
II.C SUMMARY

This section has identified the two modes of oscillatory behavior generated when the consumer-goods sector model includes the full SDNM investment function. Production and labor are dominated by short-term fluctuations with an average period of about 5 years. Arrivals of capital and capital are dominated by longer term fluctuations, with the average period of capital fluctuations being about 18 years. The relative amounts of power concentrated in short- and long-term periodicities differ for each variable: ranging from labor, which shows the largest relative amount of short-term fluctuations, to capital, which shows the largest relative amount of long-term fluctuations.
The examination of empirical behavior modes revealed evidence for the two modes of consumer-goods sector behavior. Capital stock and capital formation data showed the existence of fluctuations in the 11- to 32-year range generated by the model, although the aggregate nature of the data precluded examining capital behavior modes for consumer-goods producing sectors. More disaggregate data are available for production. The production series provided evidence of the two distinct periodicities of consumer-goods sector behavior generated by the consumer-goods sector model.
III. BEHAVIOR MODES GENERATED WITH A NEOCLASSICAL-TYPE EQUATION FOR CAPITAL ORDERING

III.A MODEL-GENERATED BEHAVIOR MODES

The preceding section has shown that the consumer-goods sector model generates two distinct oscillatory behavior modes with the full SDNM investment function. These two modes appear also to be present in economic time series. This section shows that a neoclassical-type investment function that excludes the five SDNM investment hypotheses draws together the two behavior modes to the extent that capital stock behavior is dominated to a much lesser degree by longer-term fluctuations, and capital investment is no longer dominated by a periodicity which can be sharply distinguished from the periodicity which dominates labor and production.

Conditions for the Simulation. In the following simulation, all five SDNM investment hypotheses are eliminated. As shown in Chapter 2, when the SDNM investment function is simplified in this manner, desired capital is determined along neoclassical lines as a function of desired output, marginal revenue (price of output), elasticity of production with respect to capital (the exponent for capital in the Cobb-Douglas production function), and the cost of capital services. Desired output

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13 Simulations with the neoclassical-type investment function also entail eliminating the delay in perceiving factor return to cost for labor, as was done in Section IV.D of Chapter 4.
becomes equal to average shipments. The delay structure of the simplified investment function still differs from the delay structure of the Jorgenson neoclassical investment function. In the simplified SDNM formulation, order starts for capital respond to the discrepancy between desired capital and current capital. As shown in Chapter 2, the simplified formulation for order starts for capital leads to a similar response of investment expenditures to changes in desired capital to that obtained with Jorgenson's estimated lag distribution for total nondurable manufacturing.\textsuperscript{14}

All other conditions for the following simulation are identical to conditions in the preceding section. Orders for output of the consumer goods sector include an autocorrelated 5% random component superimposed on a constant rate of incoming orders. Parameter values in the model are again based on estimates for total nondurable manufacturing.

Model Behavior in the Frequency Domain. Figure 5-10 shows the power spectrum for capital, arrivals of capital, labor, and production from the simulation with the neoclassical-type investment function. When compared to the spectra in Figure 5-2, the spectra in Figure 5-10 show significant

\textsuperscript{14}To verify the above statements, the simulations discussed below have been repeated with Jorgenson's estimated lag distribution for total nondurables (Jorgenson and Stephenson 1967b). The simulation with the Jorgenson investment function differs from that presented below only to the extent that there is less long-term fluctuation in capital and investment than is present with the "neoclassical-type" investment function.
shifts in power concentrated in each behavior mode. For example, the capital spectrum still shows the greatest concentration of power in longer term periodicities. However, capital behavior now exhibits a significant short-term periodicity not present with the full SDNM investment function. This short-term periodicity appears as a plateau in the capital spectrum from 0.175 to 0.125 cycles per year (5.7 to 8 year cycles). The power in this range of short-term periodicities is quite close to the power concentrated in longer term capital fluctuations.

An even more noticeable shift in behavior mode can be seen in the spectrum for arrivals of capital (Figure 5-10b). The spectrum for arrivals of capital shows relatively little of the power concentrated in the 11- to 27-year periodicity range seen with the full SDNM investment function (Figure 5-2b). Rather, the arrivals of capital spectrum in Figure 5-10b shows a maximum power in frequencies ranging from 0.175 to 0.125 cycles per year, corresponding to periodicities ranging from 5.7 to 8 years. With the neoclassical investment function, short-term rather than longer-term periodicities dominate capital investment.

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The continued presence of longer-term fluctuations in capital behavior with the neoclassical-type investment function is consistent with previous simulation results reported by Adelman (1964) and Low (1976). Both have shown that models equipped with simple accelerator-type investment functions can generate longer-term cycles in capital stock with 15-to-25 year periods when driven by random noise. (The models used in the simulations are similar to the consumer-goods sector model in that capital is supplied exogenously at a fixed price and delivery delay.) Such longer-term capital fluctuations generated with simplified investment functions stem solely from the longer delays in acquiring and depreciating capital.
Figure 5-10
Power Spectra for Simulation with Neoclassical-Type Investment Function
The neoclassical-type equation for capital ordering also leads to a lengthening of the period of the short-term fluctuations. For example, with the full SDNM investment formulation, the average period of short-term production fluctuations equaled 4.6 years (see Table 5-1). With the neoclassical-type ordering equation, power in short-term production fluctuations is concentrated in frequencies ranging from 0.188 to 0.125 cycles per year in Figure 5-10d. This corresponds to an average short-term period of 6.4 years. The periods of short-term fluctuations in labor, capital, and arrivals of capital similarly lengthen with the neoclassical-type investment function.

Table 5-2 summarizes the average periods and log power ratios for each power spectrum generated with the neoclassical-type investment function. The information in Table 5-2 should be compared to the information in Table 5-1. For example, Table 5-2 shows that the power ratio for capital with the neoclassical-type investment function equals $10^{0.81} = 6.5$. By contrast, the power ratio for capital with the SDNM investment function equaled $10^{4.30}$. That is, the relative concentration of power in long- versus short-term capital fluctuations has dropped from a factor of about 20,000 to a factor of 6.5. Table 5-2 shows that the log power ratio for arrivals of capital now equals -0.80, as compared to 2.04 with the SDNM investment function. The shift from positive to negative log power ratio corresponds to the shift from dominant longer term fluctuations to dominant short-term fluctuations in the behavior of arrivals of capital. The log power ratios for production
Table 5-2
Average Periods of Fluctuation and Power Ratios
For Simulation with Neoclassical-Type Investment Function

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>PERIOD OF LONG-TERM FLUCTUATION</th>
<th>PERIOD OF SHORT-TERM FLUCTUATION</th>
<th>LOG POWER RATIO #1</th>
<th>LOG POWER RATIO #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPITAL</td>
<td>14.8 yrs. (10.7 - 26.7)</td>
<td>6.7 yrs. (5.3 - 8.0)</td>
<td>0.81</td>
<td>4.64 - 3.83</td>
</tr>
<tr>
<td>ARRIVALS OF CAPITAL</td>
<td>14.5 yrs. (10.7 - 26.7)</td>
<td>6.7 yrs. (5.3 - 8.0)</td>
<td>-0.80</td>
<td>2.43 - 3.23</td>
</tr>
<tr>
<td>LABOR</td>
<td>16 yrs. (10.7 - 26.7)</td>
<td>6.4 yrs. (5.3 - 8.0)</td>
<td>-0.68</td>
<td>5.45 - 6.03</td>
</tr>
<tr>
<td>PRODUCTION</td>
<td>17.8 yrs. (10.7 - 26.7)</td>
<td>6.4 yrs. (5.3 - 8.0)</td>
<td>-0.13</td>
<td>5.20 - 5.33</td>
</tr>
</tbody>
</table>

# Range of periods in which power is concentrated in parentheses
# Log of average long-term and average short-term power in parentheses.

and labor decline in absolute value, relative to the respective log power ratios in Table 5-1, signifying a reduction in the degree to which short-term fluctuations dominate production and labor behavior.

III.B COMPARISON TO EMPIRICAL BEHAVIOR MODES

The shifts in power concentrated in the two behavior modes in Figure 5-10 suggests two questions for available data:

1. Does there exist a distinct short-term periodicity in capital stock with a power level only slightly below the power concentrated in longer term fluctuations?

2. Is investment behavior dominated by short-term periodicities?
As was discussed above, uncertainties in detrending longer term time series make it difficult to obtain conclusive answers to questions concerning the existence of long-term fluctuations or the relative power in short- and longer term periodicities. However, questions concerning short-term fluctuations in capital and investment are more nearly commensurate with existing industry data. For example, the question of dominant short-term fluctuations in capital investment can be answered by inspection of available investment expenditures data for total nondurable manufacturing. Figure 5-11 displays the data plotted against time and decomposed into frequency components. The data begin in the first quarter of 1953 and continue until the second quarter of 1977. As can be seen by visual inspection of the time behavior or by examination of the power spectrum, capital investment behavior is not dominated by short-term fluctuations as implied by the neoclassical-type investment function. When expenditure data is plotted against time, the most noticeable peaks in the detrended data occur around the first quarter of 1957 and the first quarter of 1967; the most distinct troughs occur in fourth quarter of 1958 and the third quarter of 1972. The spectrum for investment expenditures shows some power concentrated in the 4 to 8.4 year range of periodicities (0.25 to 0.12 cycles per year), but the power level is much lower for the short-term periodicities than in longer term periodicities.

Capital stock data for total nondurable manufacturing show even
Figure 5-11
Investment Expenditures for Total Nondurable Manufacturing (First Quarter, 1953 to Second Quarter, 1975)
less short-term fluctuations. Figure 5-12 displays the behavior in the
time and frequency domains. The data show no indication of the distinct
short-term periodicity seen in behavior with the neoclassical-type
investment function. Rather, the capital stock data shows a distinct
longer-term fluctuation with peaks around the first quarters of 1947 and
1971 and troughs around the first quarters of 1964 and 1974.¹⁶

¹⁶If one looks at the time plots of the detrended capital stock data in
Figures 5-3 and 5-12, two distinct cycles of the approximately 18-year
capital cycle can be seen. Peaks in capital stock occur in 1930 (Figure
5-3), 1957 (Figures 5-3 and 5-12), and 1971. Troughs in capital stock
occur in 1944 (Figure 5-3), 1964 (Figures 5-3 and 5-12) and 1974 (Figure
5-12).
Figure 5-12

Capital Stock for Total Non-Durable Manufacturing
(First Quarter, 1953 to Second Quarter, 1975)
III.C SUMMARY

The preceding simulation has shown that elimination of all five SDNM hypotheses sharply alters the modes of behavior generated by the consumer-goods sector model. The neoclassical-type investment function draws together the previously distinct modes of capital- and labor-related fluctuations. Capital investment (arrivals of capital) becomes dominated by short-term fluctuations, and capital stock exhibits a significant short-term periodicity. The two oscillatory modes in production and labor draw together in terms of a lengthening period for short-term fluctuations and an almost flat power distribution between short- and longer term fluctuations.

At least two features of behavior with the neoclassical-type investment function contradict behavior modes observed in nondurable manufacturing data: the dominant short-term periodicity in investment and the coherent short-term periodicity in capital stock.
IV. THE IMPORTANCE OF SDNM INVESTMENT HYPOTHESES IN GENERATING CONSUMER-GOODS BEHAVIOR MODES

The preceding section has shown that eliminating the five SDNM investment hypotheses draws together the two oscillatory modes of consumer-goods-sector behavior generated with the full SDNM investment function. The following analysis deepens understanding of the two behavior modes by examining the effects of eliminating each SDNM investment hypothesis individually. Understanding the effects of each investment hypothesis on the behavior modes reveals why a neoclassical-type investment function is unable to generate the two distinct modes of consumer-goods sector behavior.

IV.A PERCEIVED RATIO OF CAPITAL RETURN TO COST

The delay in forming the perceived ratio of capital return to cost PRCRC appears to be the most important investment hypothesis in generating the two modes of consumer-goods sector behavior. The analysis in Chapter 4 showed how eliminating the delay in forming PRCRC leads desired labor and desired capital to fluctuate with the same period. The two desired stocks fluctuate in tandem because the desired factor mix always equals the optimum factor mix in the modified model. That is, when producers are assumed to have perfect knowledge of optimal factor proportions, they continually adjust factor ordering to keep desired labor and desired capital in the optimal proportions. Chapter 4 showed
that one consequence of this shift in model behavior was elimination of longer term overshoot and decline in desired capital. The following analysis shows that eliminating the delay in forming PRCRC similarly reduces longer term overshoot and decline in arrivals of capital and capital stock, and therefore has an important impact on longer term fluctuations in the consumer-goods sector model.

Figure 5-13 displays the behavior of arrivals of capital, capital, and labor when the consumer-goods sector model with and without PRCRC responds to a 10% step increase in orders for output. The two simulations cover 20 years; the behavior is plotted every .25 year. The variables plotted in Figure 5-13 clearly show the elimination of the longer term overshoot and decline behavior in arrivals of capital and capital stock. For example, capital stock gradually rises to a peak value of 955 units at year 6 with the full SDNM investment function. Capital rises to a peak at year 4.25 when the delay in forming PRCRC is eliminated. The longer term overshoot and oscillation in capital generated with the full SDNM investment function gives way to fluctuations with approximately a 4½-year period when the delay in forming PRCRC is eliminated. A similar shift occurs in the behavior of arrivals of capital, which also exhibits a strong 4½-year periodicity with the modified investment function.

Figure 5-13 also displays the behavior of labor in the two simulations. The plot of labor behavior shows that capital, arrivals of capital, and labor all fluctuate with the same 4½-year period in the
revised model. By contrast, only labor exhibited dominant short-term fluctuations with the full SDNM investment function. Comparison of labor behavior in the two simulations also shows that the amplitude of the short-term labor fluctuations is reduced, damping is increased, and the period of labor fluctuations increases with the modified investment function. The reduced amplitude and increased damping and period for labor reflect a desire to adjust labor less aggressively to prevent imbalances in the capital-labor ratio, and a reduced need for aggressive labor adjustments due to the greater burden assumed by capital adjustments for correcting output-inventory and backlog imbalances.
On the basis of the preceding analysis, we would expect the spectra for noise-driven behavior without the delay in forming perceived ratio of capital return to cost, when compared to spectra generated with the full SDNM investment formulation, to exhibit (1) a greater degree of short-term power in capital and arrivals of capital, (2) a reduced degree of short-term power in labor, and (3) a longer period of labor fluctuations. The spectra in Figure 5-14, computed from a 100-year simulation involving a 5% random noise component in incoming orders, bear out these expectations. The spectrum for capital (Figure 5-14a) shows a considerable increase in the relative concentration of power in short-term fluctuations, when compared to the corresponding spectra in Figure 5-2a. For example, the relatively flat power "plateau" over the frequency band 0.175 to 0.125 cycles per year in Figure 5-14a represents a concentration of short-term power not present with the full SDNM investment function. The arrivals-of-capital spectrum in Figure 5-14 shows a greater concentration of power in short-term fluctuations than in long-term fluctuations. The dominant long-term power in the arrivals of capital spectrum generated with the full SDNM investment function (Figure 5-2b) is not present in Figure 5-14b.

The labor spectrum shows the expected reduction in short-term power and lengthening of the short-term period. The average power in short- and long-term labor fluctuations are somewhat closer together than with the full SDNM investment function (Figure 5-2c), but the most noteworthy shift in the labor spectrum concerns the average period. The
average period of short-term labor fluctuations rises to 6.2 years without the delay in forming PRCRC (average frequency of 0.163 cycles/year). The average period equals 5.3 years in Table 5-1. The period of short-term fluctuations in the other variables likewise range from 6.2 to 6.7 years. Clearly, the assumption of imperfect knowledge of current factor proportions plays an important role in generating dominant longer-term fluctuations in investment and capital stock and in generating short-term fluctuations with a period comparable to the period of observed business cycles.

Table 5-3 summarizes the average periods and power ratios for the simulation without the delay in forming perceived ratio of capital return to cost PRCRC. The information in Table 5-3 should be compared to the information in Table 5-1. The comparison shows that the ratio of power in long-term fluctuations to power in short-term fluctuations for capital falls from $10^{4.04}$ to $10^{1.45} = 28$ with the modified investment function. The power ratio for arrivals of capital falls from $10^{2.04}$ with the full SDNM investment function to $10^{-2.25} = 0.56$ with the modified investment function, signifying the shift to predominant short-term fluctuations in arrivals of capital. The power ratios for labor and production both increase toward zero, reflecting the reduced power levels in short-term fluctuations in these variables.
Figure 5-14
Power Spectra for Simulation Without Delay in Forming Perceived Ratio of Capital Return to Cost
### Table 5-3

**Average Periods of Fluctuation and Power Ratios**

For simulation without delay in forming perceived ratio of capital return to cost

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital</strong></td>
<td>17.8 yrs. (12.3 to 26.7)</td>
<td>6.7 yrs. (5.7 to 8.0)</td>
<td>1.45 (4.97 to 3.52)</td>
</tr>
<tr>
<td><strong>Arrivals of Capital</strong></td>
<td>16 yrs. (11.4 to 26.4)</td>
<td>6.4 yrs. (5.3 to 7.6)</td>
<td>-0.25 (2.64 - 2.89)</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>16 yrs. (10.7 to 26.7)</td>
<td>6.2 yrs. (5.3 to 8.0)</td>
<td>-0.67 (5.33 - 5.9)</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>16 yrs. (10.7 to 26.7)</td>
<td>6.2 yrs. (5.3 to 8.0)</td>
<td>-0.15 (5.12 - 5.27)</td>
</tr>
</tbody>
</table>

* Range of periods in which power is concentrated, in parentheses.
** Logs of average long-term and average short-term power in parentheses.

The preceding analysis has shown that, by assuming producers to perceive and respond immediately to nonoptimal factor mixes, elimination of the delay in forming the perceived ratio of capital return to cost greatly speeds adjustments in capital stock and reduces amplitude of adjustments in labor. When the model responds to randomness in incoming orders, arrivals of capital is not longer dominated by longer-term periodicities, capital behavior exhibits a significant degree of short-term fluctuation and the period of short-term fluctuations in labor and production increases to 6.2 years.

**IV.B INVENTORY- AND BACKLOG CORRECTIONS**

Output-inventory and backlog corrections in capital ordering
also play an important role in generating two distinct oscillatory modes of consumer-goods behavior. Eliminating the two components of the SDNM investment function leaves average shipments the sole indicator of desired output for capital planning. As shown in Chapter 4, capital expansion and contraction then become dependent on prior expansions and contractions in production and shipments. The following analysis shows how this shift in the determinants of investment eliminates the long, relatively smooth, periods of capital expansion and contraction generated with the full SDNM investment function and increases short-term fluctuation in investment and in capital stock.

Figure 5-15 shows the behavior of desired capital and arrivals of capital from the step-response with the full SDNM function (Figure 4-2) and from the step-response with the investment function modified to exclude output-inventory and backlog corrections in capital ordering (Figure 4-5). Behavior with the two investment functions is plotted for 10 years; each plot interval equals 0.125 year.

The increased degree of short-term fluctuation in arrivals of capital is readily apparent. With the full SDNM investment function, arrivals of capital rises to a peak at year 3.38, then exhibits a relatively smooth decline up until about year 9.25. With the modified investment function, arrivals of capital peaks at year 5, falls, then peaks again at year 9.25.

The greater degree of short-term fluctuation in arrivals of capital stems from the increased short-term fluctuation in desired
capital when order starts for capital no longer responds to output-inventory and backlog corrections. Causes for the shift in desired capital behavior can be understood in terms of the basic shifts in behavior discussed in Chapter 4. Recall that, with the full SDNM investment function, desired capital and desired labor first move together in response to perceived need for more or less output. Pressure for capital expansion or contraction then continues due to needs to rebalance factor mix, which is disturbed from optimum due to the quicker adjustments that can be made in labor than in capital. Consequently, periods of expansion and contraction in desired capital tend to be much longer than periods of expansion and contraction in desired labor. The
tendency for protracted expansion and contraction of desired capital with the full SDNM investment function can be seen in Figure 5-15 as the variable rises to a value of 975 at year 2.25, remains high for about a year (due to pressure to rebalance factor mix), then declines to a trough value of 875 units at year 9 (The protracted decline in desired capital is interrupted by a short-term upswing from year 5 to year 6).

When desired capital no longer responds to the "early warning signals" of imbalance between demand and supply implicit in output-inventory and backlog conditions, the succession of pressures to, first, expand capacity, then, rebalance factor proportions no longer occurs. With the modified investment function, the two pressures for capital expansion and contraction both arise only after labor and production have expanded to meet the higher demand for output. The most important consequence for model-generated behavior modes of this shift in behavior is the increased degree of short-term fluctuation in desired capital, as seen in Figure 5-15. The increased degree of short-term fluctuation in desired capital results from a shift in the relative timing of pressures to adjust production capacity and pressures to adjust factor proportions.17 With the full SDNM investment function, pressures to adjust capital to adjust output and pressures to adjust capital to rebalance factor proportions tend to be almost 180° out of

17Note that the third variable affecting desired capital is capital stock (see Equation 2-6), which exhibits relatively little short-term fluctuation. Hence, PRC and PRCRC determine the degree of short-term fluctuations in DCAP, since both variables are dominated by short-term fluctuations.
phase—that is, pressures to rebalance factor proportions lag pressures to adjust output by almost one-half cycle (see production ratio for capital PRC and perceived ratio of capital return to cost PRCRC in Figure 4-2b). With the modified investment function, the two pressures more nearly coincide, since both arise from prior adjustments in labor and production. (Production ratio for capital lags perceived ratio of capital return to cost by about 90°—1/4 cycle—in Figure 4-6b.) The closer coincidence of the two pressures affecting desired capital leads to more short-term fluctuation in desired capital.\(^{18}\)

The preceding analysis has shown that eliminating output-inventory and backlog corrections increases the degree of short-term fluctuations in desired capital and arrivals of capital. The power spectra in Figure 5-16 show the effects of the shift in behavior on consumer-goods sector behavior modes when the model responds to a 5% random component in orders for output. Table 5-4 summarizes the periodicities and power ratios for the spectra. The spectra in Figure 5-16 are computed from a simulation identical to that in Section II except that inventory and backlog corrections are omitted from the equations for capital ordering. The spectra show a larger amount of

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\(^{18}\) An additional source of increased short-term fluctuation in order starts for capital stems from the shift in relative timing of desired capital. Because desired capital with the modified investment function tends to follow shipments, expansions and contractions in desired capital often reinforce fluctuations in expected growth in shipments, thereby further increasing short-term fluctuations in order starts for capital. The reinforcement of desired capital and growth expectations occurs for the same basic reasons as the increased short-term fluctuations in desired capital—because investment incentives become dependent upon preceding adjustments in labor and production.
power present in short-term periodicities in capital stock and arrivals of capital than was observed with the full SDNM investment function (Figure 5-2). In particular, the power in short-term fluctuations of arrivals of capital increases sharply relative to short-term power in Figure 5-2b. The arrivals-of-capital spectrum in Figure 5-16b shows an almost equal concentration of power in frequencies ranging from 0.175 to 0.131 cycles per year (5.7- to 7.6-year periodicities) and in frequencies ranging from 0.094 to 0.038 cycles per year (10.7- to 26.7-year periodicities). The log power ratio for arrivals of capital drops from 2.04 in Table 5-1 to 0.08 in Table 5-2. A comparable increase in the degree of short-term fluctuation can be seen by comparing log power ratios for capital in Table 5-4 and Table 5-1.

On the other hand, the spectra for production and labor in Figure 5-16 show a shift toward relatively more power in longer term fluctuations. For example, the log power ratio for production becomes positive in Table 5-4, signifying that the average power concentrated in longer term production fluctuations exceeds the average power concentrated in short-term production fluctuations. Labor shows a comparable drop in short-term power (rise in log power ratio towards zero). The decline in short-term power in production and labor apparently stems from the large capital surpluses accumulated with the modified investment function; the capital surpluses cushion the sector in times when capacity is inadequate and reduce the need for large adjustments in labor. The reduced pressure for labor adjustments also manifests in
longer average periods for short-term fluctuations in labor and production.

The preceding analysis has shown that inventory- and backlog corrections play an important role in generating dominant longer-term fluctuations in investment and capital stock. Eliminating output-inventory and backlog corrections increases power in short-term fluctuations in investment and capital stock and decreases power in short-term production and labor fluctuations. Both shifts tend to reduce previously sharp distinctions between longer-term fluctuations in investment and capital stock and short-term fluctuations in labor and production.
Figure 5-16
Power Spectra for Simulation without Inventory and Backlog Corrections in Capital Ordering
### Table 5-4
**Average Periods of Fluctuation and Power Ratios**

For Simulation Without Inventory and Backlog Corrections in Capital Ordering

<table>
<thead>
<tr>
<th>Variable</th>
<th>Period of Long-term Fluctuation</th>
<th>Period of Short-term Fluctuation</th>
<th>Log Power Ratio XX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>14.7 yrs. (12.3 to 32.0)</td>
<td>6.7 yrs. (4.1 to 8.9)</td>
<td>2.25 (5.42 - 3.17)</td>
</tr>
<tr>
<td>Arrivals of Capital†</td>
<td>14.5 yrs. (10.7 to 26.7)</td>
<td>6.4 yrs. (5.7 to 7.6)</td>
<td>0.08 (3.25 - 3.17)</td>
</tr>
<tr>
<td>Labor</td>
<td>16 yrs. (10.7 to 26.7)</td>
<td>5.9 yrs. (4.2 to 8.0)</td>
<td>-0.45 (5.60 - 4.65)</td>
</tr>
<tr>
<td>Production</td>
<td>16 yrs. (10.7 to 32.0)</td>
<td>5.0 yrs. (4.1 to 7.5)</td>
<td>0.12 (5.35 - 5.23)</td>
</tr>
</tbody>
</table>

*Range of periods in which power is concentrated, in parentheses.
Log of average long-term and average short-term power in parentheses.

**IV.C Supply-line Correction**

The supply-line correction in capital ordering affects the period of longer-term fluctuations in capital investment but is not essential in generating two distinct modes of consumer-goods sector behavior. The analysis in Chapter 4 showed how elimination of the supply-line correction increases overshoot in order starts for capital and arrivals of capital due to "double-ordering" of new capital. The following analysis shows that the increased amplitude of fluctuation in order starts for capital brings out a shorter dominant periodicity for arrivals of capital. Nonetheless, the consumer-goods sector model without the supply line correction in capital ordering still generates two distinct modes of oscillatory behavior.
Figure 5-17 plots the behavior of order starts for capital and arrivals of capital from the step response of the consumer-goods sector model with the full SDNM investment function (Figure 4-2) and from the step response without the supply-line correction in capital ordering (Figure 4-8). The simulation covers 20 years and each plot interval equals 0.25 year. The figure shows the increased amplitude of fluctuation for order starts for capital due to the double-ordering produced by the modified investment function. The figure also shows that eliminating the supply-line correction brings out an approximate 8-year cycle in order starts and arrivals of capital. The 8-year periodicity can be seen in the peaks of order starts at year 2.25 and year 10.5 and in the peaks of arrivals of capital at years 3.5 and 11.5. A highly damped version of this periodicity is evident in behavior with the full SDNM investment function. (Note the peaks at years 2 and 10.25 in OSC generated with the full SDNM investment function.) Eliminating the supply-line correction reduces damping of the 8-year fluctuation in order starts and thereby makes the periodicity evident in arrivals of capital.19

19Eliminating the supply-line correction increases the amplitude of the 8-year fluctuation in order starts for capital because double ordering leads capital stock to expand and contract more rapidly. (To see this more rapid movement, note that capital takes almost four years to decline from its peak value to its new equilibrium, 916 units, in Figure 4-2b, and only 3 years to cover the same distance in Figure 4-8b.) More rapid expansion and contraction of capital increases amplitude of 8-year fluctuations in order starts for capital because capital excesses unaccumulate more rapidly, thereby increasing potential for an upswing in order starts for capital every second cycle of rising demand for output.
Figure 5-17

Comparative plot of behavior with and without supply line correction in capital ordering.

The power spectra in Figure 5-18 show the effects of eliminating the supply-line correction on behavior of the consumer-goods model in the presence of a random component in orders for output. The most significant effect can be seen in the spectrum for arrivals of capital. With the full SDNM investment function, arrivals-of-capital behavior is dominated by longer-term fluctuations with an average period of 14.5 years. Without the supply-line correction in capital ordering, arrivals-of-capital behavior is dominated by periodicities ranging from 5.7 to 8.9 years (0.175 to 0.113 cycles per year) with an average period of about 7.6 years. As noted above, the shorter periodicity emerges from the increased over- and undershoots of capital ordering when information on the supply-line of unfilled orders for capital no longer influences capital ordering.
Figure 5-18
Power Spectra for Simulation Without Supply Line Correction in Capital Ordering
Table 5-5 summarizes the average periodicities and power ratios for the spectra in Figure 5-18. The table shows that capital and arrivals of capital behavior are still dominated by longer term fluctuations (positive log power ratios), and labor and production still exhibit more power in short-term periodicities (negative log power ratios). In this sense, the spectra generated without the supply-line correction match the spectra generated with the full SDNM investment function. The spectra differ from the spectra generated with the full SDNM investment function in the extent to which longer-term fluctuations dominate capital behavior (the log power ratio for capital declines from 4.30 in Table 5-1 to 3.24 in Table 5-5) and in the average period of longer-term fluctuations in arrivals of capital.

**Table 5-5**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>PERIOD OF LONG-TERM FLUCTUATION</th>
<th>PERIOD OF SHORT-TERM FLUCTUATION</th>
<th>LOG POWER RATIO £X</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPITAL</td>
<td>16 yrs. (10.7 to 26.7)</td>
<td>4.6 yrs. (4.1 to 4.8)</td>
<td>3.24 (5.20 - 1.96)</td>
</tr>
<tr>
<td>ARRIVALS OF CAPITAL</td>
<td>7.6 yrs. (5.7 to 8.9 )</td>
<td>4.4 yrs. (3.7 to 4.8)</td>
<td>1.65 (3.38 - 1.73)</td>
</tr>
<tr>
<td>LABOR</td>
<td>14.5 yrs. (10.7 to 26.7)</td>
<td>5.5 yrs. (4.2 to 7.6)</td>
<td>-1.07 (5.15 - 4.02)</td>
</tr>
<tr>
<td>PRODUCTION</td>
<td>16 yrs. (10.7 to 26.7)</td>
<td>5.0 yrs. (4.2 to 7.0)</td>
<td>-0.36 (5.40 - 5.46)</td>
</tr>
</tbody>
</table>

* Range of periods in which power is concentrated, in parentheses.

** Log of average long-term and average short-term power in parentheses.
To summarize, the supply-line correction in capital ordering contributes to coherent fluctuations in investment and capital stock with a distinctly longer periodicity than short-term labor and production fluctuations. Eliminating the supply-line correction in capital ordering increases power in intermediate (approximately 8-year) fluctuations in investment and capital stock. Hence, the supply-line correction in capital ordering is not necessary for generating distinct modes of capital-related and labor-related behavior, but it does contribute to the degree of distinction between the modes.

IV.D EXPECTED GROWTH IN SHIPMENTS

The hypothesized influence of growth expectations on capital ordering increases the amplitude of longer-term fluctuations in investment and capital stock but is not essential in generating two distinct oscillatory modes of consumer-goods sector behavior. The hypothesis affects amplitude because upswings and downswings of shipments are perceived as trends and capital ordering is adjusted accordingly. For example, when shipments rise, a perceived growth trend develops and additional orders start for capital are placed. Because growth expectations typically develop in later phases of capital expansion, they serve to prolong and accentuate the expansion.

To illustrate the effects of growth expectations on capital ordering, Figure 5-19 shows the behavior of order starts for capital, capital, and expected growth in shipments from two simulations in which
the consumer-goods sector model responds to a 10% step increase in orders for output. In one simulation, the full SDNM investment function is employed (see Figure 4-2); in the second simulation the hypothesized influence of growth expectations on capital ordering is eliminated. The two simulations cover 10 years; the plot intervals for the simulations equal .125 years.

Figure 5-19 shows the amplification in capital expansion caused by growth expectations. In particular, note that order starts generated with the full SDNM investment function exceed order starts generated with the modified investment function from year 2 to year 5.25. As a consequence of the additional order starts generated during this time period, capital stock generated with the full SDNM investment function rises to a value of 956 units by year 6; capital stock with the modified investment function rises only to a value of 931 units by year 8. Note also that capital rises continuously until year 6, then declines smoothly with the full SDNM investment function; without growth expectations in capital ordering, capital shows more short-term fluctuation in its ascent.

Figure 5-19 shows how the additional order starts for capital stimulated by rising growth expectations can buoy a period of capital expansion and thereby amplify expansion. To see why growth expectations often coincide with periods of capital expansion, reconsider the basic production sector response to an increase in orders for output. Following the increase in incoming orders, hiring and investment rise to meet the perceived need for additional output. Once production expands,
and output inventory and backlog imbalances begin to be corrected, the need for more capital to expand output diminishes and capital expansion becomes driven by pressures to rebalance factor mix. At the same time, as inventory is replenished, shipments rise. With the expansion in shipments, growth expectations develop. Hence, growth expectations typically rise somewhat after expansion of labor and production has ended and serve to buoy the latter phases of expansion of capital.

The sequence of pressures described above can be seen in Figure 5-19. The initial upswing in order starts for capital lasts until about year 1.9 (with both investment functions). By year 2, pressure to expand production capacity is beginning to fall because labor and production
have expanded (see production ratio for capital—Figure 4-2b). Expected
growth in shipments begins to rise at year 1.6 and continues to rise
until year 4. The rise in expected growth stems from increases in
shipments and serves to increase order starts for capital above order
starts generated with the full SDNM investment function from year 2 to
year 5.

The preceding analysis has shown that rising growth expectations
can amplify capital expansion because producers perceive rising shipments
as a possible growth trend and order additional capital to prepare for
expected growth. The analysis suggests that spectra for a noise-driven
simulation without growth expectations in capital ordering would show a
reduction in the degree of power concentrated in long-term capital
fluctuations with the full SDNM investment function. The spectra
presented in Figure 5-20 and summarized in Table 5-6 show the anticipated
shifts in behavior modes. For example, the spectrum for capital, when
compared to the corresponding spectrum generated with the full SDNM
investment function shows a reduction in power ratio from 10^{4.30} to
10^{3.25}. The arrivals of capital spectrum shows a reduction in
long-term power ratio from 10^{2.04} to 10^{0.70}.

Although the hypothesized effect of growth expectations
contributes to the amplitude of fluctuations, it does not seem to be
essential for generating the two distinct modes of behavior. Table 5-6
shows that the mix of short- and longer term periodicities is not altered
by eliminating growth expectations in capital ordering. The power ratios
Figure 5-20

Power Spectra for Simulation without the Hypothesized Effect of Expected Growth in Shipments on Capital Ordering
### Table 5-6

**Average Periods of Fluctuation and Power Ratios**

*For Simulation without Expected Growth in Shipments*

| VARIABLE   | **Period of Long-Term Fluctuation** | **Period of Short-Term Fluctuation** | **Log Power Ratio**
|------------|-------------------------------------|--------------------------------------|-------------------
| Capital    | 17.8 yrs. (12.3 to 32.0)            | 4.7 yrs. (4.1 to 52)                 | 3.25 (4.63 - 1.38) |
| Arrivals   | 14.5 yrs. (10.7 to 26.7)            | 4.6 yrs. (4.1 to 4.8)                | 0.70 (2.38 - 1.58) |
| Capital    |                                      |                                      |                   |
| Labor      | 16 yrs. (10.7 to 26.7)               | 5.0 yrs. (4.1 to 4.0)                | -0.75 (5.38 - 6.13) |
| Production | 17.8 yrs. (10.7 to 26.7)             | 4.7 yrs. (4.1 to 5.7)                | -0.27 (5.17 - 5.44) |

*Range of periods in which power is concentrated, in parentheses.*

**Log** of average long-term and average short-term power in parentheses.

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for capital and arrivals of capital remain strongly positive, indicating dominant longer term fluctuations; the power ratios for labor and production remain negative, indicating dominant short-term fluctuations.

To summarize, the hypothesized effect of growth expectations on capital ordering appears to increase the amplitude and relative power concentrated in longer-term fluctuations in investment and capital stock. The hypothesis does not appear to be essential for the existence of two distinct oscillatory modes of consumer-goods-sector behavior or for the periods of fluctuation.
V. PARAMETER SENSITIVITY OF BEHAVIOR-MODE-TEST RESULTS

This section briefly considers the effects of variations in parameter values on the behavior-mode-test results presented above. By illustrating the extent to which plausible variations in model parameters can alter behavior-mode test results, the analysis clarifies the generality of the preceding findings.

Section V.A presents a general discussion of the possible effects of parameter variation on behavior-mode test results. Section V.B illustrates the possible effects of variations in parameter values for the importance of the delay in forming PRCRC in generating two distinct modes of consumer-goods-sector behavior.

V.A POSSIBLE EFFECTS OF PARAMETER VARIATION ON BEHAVIOR-MODE-TEST RESULTS

Variations in model parameters can alter the specific consequences of the behavior-mode tests presented above but not the underlying shifts in behavior which give rise to the consequences. For example, the basic shift in model behavior brought about by eliminating the delay in forming PRCRC is the entrainment of fluctuations in desired labor and desired capital. The behavior shift does not depend on parameter values. If one assumes that producers immediately recognize nonoptimal factor mixes and adjust desired factor proportions to equal optimal factor proportions, desired capital and desired labor must move together to keep the desired capital-labor ratio equal to the optimal capital-labor ratio. The basic shift in model behavior underlying the
behavior-mode-test result is **qualitative** in the sense that the shift is absolute, not a matter of degree.

On the other hand, the consequences of the basic behavioral shift brought about by eliminating the delay in forming PRCRC are a matter of degree and do depend on parameter values. The consequence of eliminating the delay in forming PRCRC in Section IV was the emergence of dominant short-term fluctuations in investment and coherent short-term fluctuations in capital. As will be illustrated below, these consequences can be altered to a certain extent by plausible variations in model parameters. With certain parameter values, eliminating the delay in forming PRCRC may not only lead to dominant short-term fluctuations in investment but create equal degrees of short- and long-term fluctuations in capital stock. With other parameter settings, eliminating the delay may only increase the **degree** of short-term fluctuation in investment, leaving longer-term fluctuations the dominant mode of investment-and capital-stock behavior.

Similarly, the specific consequences of eliminating other SDNM investment hypotheses depends on parameter values. Moreover, the relative importance of the different hypotheses can shift with changes in parameter values. For example, if parameters are changed to increase the periods of the short- and longer-term fluctuations, growth expectations can play a greater role in generating longer-term fluctuations in capital because the increased duration of longer-term upswings and downswings in shipments give rise to more persuasive indications of growth trends.
In general, the direction of change in behavior modes caused by eliminating each SDNM hypothesis in Section IV is highly insensitive to reasonable variations in model parameters. The degree of change in behavior modes is more dependent on parameter values. The sensitivity tests below illustrate the extent to which variations in parameter values can affect the degree of change in behavior modes when the delay in forming PRCRC is eliminated from the SDNM investment function.

V.B TWO EXAMPLES OF THE EFFECTS OF PARAMETER VARIATION ON BEHAVIOR-MODE-TEST RESULTS

To supplement the preceding general discussion of parameter sensitivity, this section presents two examples of the effects of varying model parameters on behavior-mode tests. The tests focus on the influence of model parameters in assessing the importance of the delay in forming PRCRC. This hypothesis is chosen for the sensitivity analysis because of its apparent importance in generating two distinct modes of consumer-goods-sector behavior.

Choice of Parameter Setting for the Sensitivity Tests. In selecting variations in model parameters, I pursue the following sensitivity analysis strategy.\(^\text{20}\) Since the central issue is the importance of the delay in forming PRCRC for generating two distinct modes of oscillatory behavior, sensitivity analysis should focus on plausible combinations of parameter values most likely to undermine the importance of the delay in

\(^{20}\) The strategy is similar to that proposed by Wong (1978).
forming PRCRC. Two possible cases warrant consideration: parameter changes which make the average periods of the two oscillatory modes (generated with the full SDNM investment function) more nearly equal and parameter changes which make the average periods of the two oscillatory modes less equal. Intuitively, the two extreme cases pose the following questions. If the two oscillatory modes are "closer together" initially, is the delay in forming PRCRC still significant in distinguishing the modes? If the oscillatory modes are "further apart" initially, will eliminating the delay in forming PRCRC still draw the two modes together to a significant extent?

Table 5-7 lists the parameter values used in the sensitivity tests. The table shows that five parameters are varied in the tests--time to correct the stock of capital TCSC, delivery delay for capital DDC, time to correct labor TCL (analogous to TCSC for labor), delivery delay for labor DDL (the delay in filling vacancies), and time to correct inventory and backlog TCIB. These five parameters are chosen for the sensitivity tests because each has a clear influence on either the short or the longer-term period of model behavior. The second column of Table 5-7 indicates the effect of increasing each parameter on the difference between the periods of the two oscillatory behavior modes--that is, the average period of capital fluctuations minus the average period of labor fluctuations. For example, increasing TCSC slows
TABLE 5-7
PARAMETERS FOR SENSITIVITY TESTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect of Increase in Parameter Value on Difference in Two Periods *</th>
<th>Estimated Parameter Values (used in preceding simulations)</th>
<th>Sensitivity Test #1 (Periods more Equal)</th>
<th>Sensitivity Test #2 (Periods less Equal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCSC  Time to Correct Stock of Capital</td>
<td>+</td>
<td>1.0 yrs.</td>
<td>0.75 yrs.</td>
<td>1.5 yrs.</td>
</tr>
<tr>
<td>DDC  Delivery Delay for Capital</td>
<td>+</td>
<td>1 yr.</td>
<td>0.75 yrs.</td>
<td>1.5 yrs.</td>
</tr>
<tr>
<td>TCL  Time to Correct Labor</td>
<td>-</td>
<td>0.3 yrs.</td>
<td>0.45 yrs.</td>
<td>0.2 yrs.</td>
</tr>
<tr>
<td>DDL  Delivery Delay for Labor</td>
<td>-</td>
<td>0.1 yr.</td>
<td>0.15 yrs.</td>
<td>0.075 yrs.</td>
</tr>
<tr>
<td>TCIB Time to Correct Inventory/Backlog</td>
<td>-</td>
<td>0.433 yrs.</td>
<td>0.6 yrs.</td>
<td>0.3 yrs.</td>
</tr>
</tbody>
</table>

*Average Period of Capital fluctuations minus Average Period of Labor fluctuations

capital adjustments and tends to increase the period of the longer-term cycle. Increasing TCSC increases the difference between the two periods; hence, the positive sign ("+") in Table 5-7. Increasing DDC has a similar effect. On the other hand, increasing TCL slows labor adjustments and tends to lengthen the period of short-term fluctuations in labor and production. Increasing the period of the short-term cycle reduces the difference between the two periods; hence, the negative sign ("-"") in Table 5-7. Increasing DDL has a similar effect. Increasing TCIB reduces pressures to correct output-inventory and backlog imbalances and therefore also lengthens the period of short-term fluctuations in labor.
The last three columns in Table 5-7 display the parameter values used for the preceding simulations and for the following sensitivity tests. The parameter values used in the preceding simulations are discussed in the Appendix to Chapter 3 and in Appendix A at the end of the text. In the first sensitivity test, all five parameters are varied in the direction which will tend to draw together the periods of the two oscillatory behavior modes. TCSC and DDC are reduced to shorten the period of capital fluctuations. TCL, DDL, and TCIB are increased to lengthen the period of labor fluctuations. All parameters are varied 25% to 50%. In the second test, all five parameters are varied in the direction which will tend to pull apart the two periods of oscillation. Once again, parameters are varied 25% to 50% from their original values.

**Sensitivity Test #1.** Figure 5-21 presents a comparative plot showing the step response of the consumer-goods sector model with and without the delay in forming PRCRC. The two simulations compared in Figure 5-21 employ the parameters for Sensitivity Test #1, as shown in Table 5-7. The figure compares the behavior of labor, capital, and arrivals of capital from the two simulations. The simulations cover 20 years; the plot interval for the simulations equals .25 year.

Figure 5-21 shows that the parameter variations greatly increase the degree of short-term fluctuation in arrivals of capital AC and capital CAP generated with the full SDNM investment function. With the original parameters, both variables showed little short-term fluctuation
**Figure 5-21**

**Comparative Plot for Sensitivity Test #1:**

Behavior with and without delay in forming perceived ratio of capital return to cost when the model including the full SDNM investment function responded to a step increase in orders for output (see Figure 5-13). The increased short-term fluctuation in AC and CAP generated with the full SDNM investment function in Figure 5-21 stems primarily from the reduced values for TCSC and DDC which speed adjustments in investment and capital. The increased short-term fluctuation in AC and CAP also stems indirectly from the parameter changes which slow labor adjustments.

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21 Note that the parameters chosen for the first sensitivity test represent an extreme case. TCSC is less than two times longer than TCL and only slightly longer than TCIB. Such a relatively short adjustment time is quite unrealistic for fixed capital stock.
and thereby cause greater pressures on capital adjustment to manage output inventory and backlog. Clearly, the parameter variations for the first sensitivity test draw the two oscillatory behavior modes generated with the full SDNM investment function much closer together.

Despite the drawing together of the two behavior modes generated with the full SDNM investment function in Figure 5-21, eliminating the delay in forming PRCRC still has a significant impact on behavior. The amplitude of short-term fluctuations in arrivals of capital increases appreciably with the modified investment function. Likewise, the modest short-term fluctuations in capital give way to pronounced short-term fluctuations when the delay in forming PRCRC is eliminated.

To examine the shift in behavior modes more precisely, Figure 5-22 shows the power spectra for capital and arrivals of capital from noise-driven simulations with the two investment functions. Figure 5-22a shows the two spectra for the simulation with the full SDNM investment function. Figure 5-22b shows the spectra for the simulation without the delay in forming PRCRC. Both simulations employ the parameters for Sensitivity Test #1.

The spectra in Figure 5-22 show that eliminating the delay in forming PRCRC leads to an approximately equal concentration of short- and longer-term fluctuations in capital and causes short-term fluctuations to strongly dominate the behavior of arrivals of capital. The capital spectrum generated with the full SDNM investment function shows approximately 10 times more power in long-term periodicites than in
short-term periodicities. The capital spectrum generated without the
delay in forming PRCRC exhibits almost equal levels of power in short-
and longer-term periodicities. The arrivals of capital spectrum
generated without the delay in forming PRCRC shows $101.625 = 42.2$ times
more power in short-term fluctuations than in longer-term fluctuations,
as compared with about 3 times more power in short-term fluctuations with
the full SDNM investment function.

The above simulations show that varying parameters to draw
together the two oscillatory behavior modes does not diminish the
importance of the delay in forming PRCRC. On the contrary, with the
parameters for Sensitivity Test #1, the delay in forming PRCRC becomes
essential in generating dominant longer-term fluctuations in capital
stock.

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22 The spectrum for capital in Figure 5-22a has an average power in
longer-term fluctuations of about 5.28 (in logarithms) and an average
power in short-term fluctuations of about 4.2. Hence the log power ratio
for capital equals 1.08, signifying about 10 times more power in
long-term fluctuations.

23 The spectrum for arrivals of capital in Figure 5-22b has an average
power in short-term fluctuations of 4.25 (in logs) and an average power
in longer-term fluctuations of about 2.625; hence, arrivals of capital
without the delay in forming PRCRC has about $101.625 = 42.2$ times more
power in short-term fluctuations. With the full SDNM investment
function, arrivals of capital has about $10.5 = 3.16$ times more power in
short-term fluctuations.
a) SPECTRA with FULL SONIM INVESTMENT FUNCTION

b) SPECTRA without DELAY in FORMING PRCR C

Figure 5-22
Power SPECTRA FOR SENSITIVITY TEST #1
Sensitivity Test #2. Figure 5-23 presents a comparative plot again showing the step response of the model with and without the delay in forming PRCRC. The two simulations in Figure 5-23 employ the parameter values for Sensitivity Test #2 (see Table 5-7). As discussed above, these parameter values are chosen to increase the degree of separation between the two modes of behavior generated with the full SDNM investment function.

**Figure 5-23**
Comparative Plot for Sensitivity Test #2
The figure shows that the more rapid adjustment in labor created by reducing the parameters TCL, DDL, and TCIB, shortens the period of labor fluctuations generated with the full SDNM investment function to about 3 1/4 years (as compared with 4 1/2 years with the original parameters—see Figure 5-13). Conversely, the slower adjustment in capital created by lengthening TCSC and DDC leads to a slow smooth overshoot in capital and arrivals of capital with the full SDNM investment function. Clearly, the parameter values for the second sensitivity test "separate" the two behavior modes much further than occurs with the original parameter values.

Figure 5-23 shows that eliminating the delay in forming PRCRC in Sensitivity Test #2 noticeably increases the degree of short-term fluctuation in arrivals of capital, but has little impact on the behavior of capital. The increased short-term fluctuation in arrivals of capital can be seen in the peaks at year 2.75 and year 6 with the modified investment function, as compared to the smooth longer-term rise and fall of arrivals of capital with the full SDNM investment function.

Figure 5-24 shows the two power spectra for arrivals of capital for the second sensitivity test. The spectra show that eliminating the delay in forming PRCRC increases the degree of power in short-term periodicities in arrivals of capital, but does not alter the fact that longer term periodicities still dominate the behavior of arrivals of capital. With the full SDNM investment function, arrivals of capital has
about $10^{4.0}$ times more power in longer-term fluctuations; without the delay in forming PRCRC, arrivals of capital has about $10^{1.5} = 31.6$ times more power in longer-term fluctuations.  

Figure 5-23 and 5-24 show a case in which the delay in forming PRCRC is not necessary for generating coherent longer-term fluctuations in arrivals of capital and capital. The average periods of labor and capital fluctuations are sufficiently far apart in this sensitivity test that two distinct oscillatory modes emerge even without the delay. Nonetheless, the delay in forming PRCRC still enhances the coherence of longer-term fluctuations in arrivals of capital; eliminating the delay greatly reduces the ratio of power in longer-term fluctuations of arrivals of capital to power in short-term fluctuations of arrivals of capital.

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24 The arrivals of capital spectrum with the full SDNM investment function in Figures 5-24 has an average long-term power of 2.96 (in logs) and an average short-term power of -1.04. (Note that the average period of the short-term cycle with the full SDNM investment function is about 3.08 years—a frequency of 0.325.) Without the delay in forming PRCRC, arrivals of capital has an average long-term power of 2.50 and an average short-term power of 0.83. (Note that the average period of the short-term cycle with the modified investment function is about 4.2 years—a frequency of 0.238.)
Figure 5-24
Power Spectra for Sensitivity Test #2
Summary. The preceding sensitivity tests have shown that varying parameters in the direction of drawing the average periods of labor and capital fluctuations closer together does not reduce the importance of the delay in forming PRCRC. Sensitivity Test #1 showed that, with such parameter values, the delay in forming PRCRC may be essential for generating dominant longer-term fluctuations in capital. If parameters are varied in the direction of pulling the average periods of labor and capital fluctuations further apart, the delay in forming PRCRC may become less important for generating two distinct oscillatory modes of behavior. In Sensitivity Test #2, eliminating the delay in forming PRCRC increased the degree of short-term fluctuation in arrivals of capital but left longer-term fluctuations the dominant mode of arrivals-of-capital and capital behavior.

The sensitivity analysis has illustrated how varying parameter values can alter the extent to which eliminating the delay in forming PRCRC increases short-term fluctuations in investment and capital stock. The sensitivity analysis has also shown that varying parameters does not alter the general direction of change in behavior precipitated by eliminating the hypothesis. The delay in forming PRCRC significantly increases the tendency of the consumer-goods sector model to generate longer-term fluctuations for widely differing parameter values. The only case in which the delay is not necessary for dominant longer-term fluctuations in either investment or capital stock occurs when delays
involved in adjusting capital stock are so much longer than delays in adjusting labor that the delay times alone are sufficient to guarantee two distinct modes of consumer-goods sector behavior.  

Note that the above sensitivity tests focus only on the effects of eliminating the delay in forming PRCRC. If all five SDNM investment hypotheses are eliminated, the model equipped with the parameter values in Sensitivity Test #2 fails to generate dominant longer-term fluctuations in investment despite the extreme parameter values favoring distinct longer-term fluctuations. Hence, the overall finding that a "neoclassical-type" investment function is unable to generate distinct longer-term fluctuations in investment would still emerge with the parameters used in Sensitivity Test #2.
VI. SUMMARY OF BEHAVIOR-MODE TESTS

This chapter has shown that the SDNM investment hypotheses are important in generating two distinct modes of consumer-goods sector behavior. With the full SDNM investment function, the behavior of capital stock and arrivals of capital is dominated by longer term fluctuations with respective average periods of 17.8 and 14.5 years. Labor and production behavior is dominated by short-term fluctuations with an approximate 5-year period, though these variables also exhibit longer term periodicities.

A neoclassical-type investment function significantly reduces the capability of the consumer-goods sector model to generate dominant longer-term fluctuations in investment and capital stock, and realistic business cycles. Section III showed that elimination of all five SDNM investment hypotheses leads to dominant short-term fluctuations in arrivals of capital (investment) and a large relative degree of short-term fluctuation in capital stock. The neoclassical-type investment function also increases the average period of short-term fluctuations in production and labor to 6.4 years. Behavior with the neoclassical investment function also undermines the view suggested by the SDNM investment function that capital investment and labor adjustments lead to sharply differing modes of consumer-goods sector behavior and that stabilization policies need to be designed with a clear focus on which mode a policy is intended to influence.
Sections II and III also compared behavior generated with each investment function to empirical modes of oscillatory behavior. Although appropriate data for investment and capital stock in the consumer-goods sector appear to be unavailable, historical data for aggregate capital stock and capital formation clearly reveal dominant longer-term fluctuations in the range of periodicities predicted by simulations with the SDNM investment function. Section III also presented three production time series for consumer-goods producing industries which appear to exhibit the two distinct behavior modes generated with the full SDNM investment function. On the other hand, model behavior with the neoclassical-type investment function clearly contradicts empirical evidence. In particular, data for nondurable manufacturing do not exhibit the dominant short-term fluctuations in investment and coherent short-term periodicity in capital stock generated when all five SDNM investment hypotheses were eliminated.

The behavior-mode analysis in Section IV showed that three of the five SDNM investment hypotheses play a major role in generating the two distinct modes of consumer-goods-sector behavior. The hypothesized delay in forming perceived ratio of factor return to cost PRCRC appears to be the most important hypothesis for generating the two distinct coherent cycles in model behavior. Elimination of the hypothesized delay in perceiving and responding to nonoptimal factor proportions causes capital investment behavior to be dominated by short-term fluctuations,
capital stock to exhibit a coherent short-term periodicity, and lengthens the period of short-term fluctuations in production and labor. Such drawing together of the two behavior modes occurs because the assumed perfect knowledge of optimal factor proportions causes the desired capital-labor ratio to always equal the (constant) optimal capital-labor ratio, thereby entraining fluctuations in desired capital and desired labor.

The analysis also showed that output-inventory and backlog corrections are important in creating the two distinct consumer-goods sector behavior modes. Eliminating the hypotheses leads desired capital to strongly reflect short-term labor fluctuations rather than the sequence of pressures to expand capacity and rebalance factor mix generated with the full SDNM investment function. Consequently, the dominant longer term fluctuations in investment generated with the full SDNM investment function give way to equal degrees of short- and longer term fluctuation when inventory- and backlog corrections are eliminated.

Section IV also showed that the supply-line correction and expected growth in shipments respectively contribute to the period and amplitude of the two oscillatory behavior modes but are not essential for generating the modes. Eliminating the supply-line correction shortens the average period of investment fluctuations but still leaves two distinct periodicities of behavior. Eliminating growth expectations reduces the amplitude of longer-term fluctuations in investment and
capital stock but likewise does not affect the existence of two distinct oscillatory modes.

The behavior-mode analysis in Section IV provided general explanations for why an investment function, such as the neoclassical investment function, which omits the SDNM investment hypotheses, has limited ability to generate two distinct oscillatory modes of consumer-goods sector behavior. The parameter sensitivity discussion in Section V illustrated the generality of the behavior analysis by showing that the delay in forming PRCRC continued to contribute significantly to the coherence of longer-term fluctuations in investment and capital stock despite multiple changes in parameter values specifically chosen to reduce the importance of the delay.
CHAPTER 6 SUMMARY AND SUGGESTIONS FOR FUTURE WORK

This study has compared the investment function developed as part of the System Dynamic National Model (SDNM) to the neoclassical investment function developed by Dale Jorgenson. The comparison has attempted to determine which formulation provides a fuller description of the determinants of capital investment and a better basis for understanding how investment affects the behavior of economic systems. The two investment functions have been compared as alternative theories of the determinants of investment and as alternative explanations of observed investment activity for aggregate industry groups. The effects of the two formulations on the behavior of a generic production-sector model have also been examined. This chapter summarizes the findings of the study and indicates directions for future work.

I. SUBSTANTIVE FINDINGS OF THE RESEARCH

The following summary highlights the primary substantive findings of the research. For a more complete summary of results, the reader is referred to the chapter summaries concluding Chapters 3, 4 and 5.

Chapter 2 presented the SDNM investment function and compared it to the neoclassical investment function as an alternative theory of the determinants of capital investment. The comparison revealed that the SDNM formulation offers a more general theory of the determinants of
capital investment. In particular, the SDNM formulation embodies five key hypotheses not present in the neoclassical investment function:

1. **Inventory Correction**: Desired output, and hence desired capital, responds to the discrepancy between desired and actual levels of inventory of output.

2. **Backlog Correction**: Desired output, and hence desired capital, responds to the discrepancy between desired and actual levels of the backlog of unfilled orders for capital.

3. **Supply-Line Correction**: Capital ordering responds to the difference between the desired and actual levels of the "supply-line" of unfilled orders for capital (capital orders in planning and backlog of unfilled orders for capital).

4. **Expected Growth in Shipments**: Capital ordering responds to expectations of future growth in shipments, which in turn are based on perceived growth trends in shipments.

5. **Perceived Ratio of Capital Return to Cost**: Desired capital responds only after a delay to departures of the current capital-output ratio from the optimal capital-output ratio. (Perceived ratio of capital return to cost is formed by exponential smoothing of the ratio of capital return to cost, the marginal revenue product of capital divided by the marginal cost of capital.)

Chapter 2 showed how each SDNM investment hypothesis could be identified as an element of investment decision-making and could be related to theories advanced in the investment- and production-planning literatures. Chapter 2 also showed that the neoclassical formulation for the desired stock of capital can be derived from the SDNM formulation for desired capital by assuming that output inventory and backlog have no effect on capital ordering, that desired capital responds immediately to departures from the optimal factor mix, and that capacity utilization is
constant. The neoclassical formulation for the response of investment activity to changes in desired capital similarly omits the influence of desired and actual supply line of unfilled orders for capital and the effect of growth expectations included in the SDNM investment function.

Chapter 3 presented a series of statistical tests of the two investment functions. The tests showed that inclusion of the SDNM investment hypothesis improved equation performance for four independent sets of industry data. For example, when the two investment functions were compared using polynomial-distributed (Almon) lags, the SDNM function substantially improved upon the fit, residual autocorrelation, and statistical significance of the neoclassical investment function for each set of industry data. Chapter 3 also showed that plausible statistically significant estimates could be obtained for the SDNM investment function. Not only were all parameter estimates acceptable, but the shape and duration of all four lag distributions included in the SDNM formulation conformed closely to lag distributions used in earlier simulations involving the SDNM investment function.

The significance of the statistical test results is two-fold. First, they demonstrated the consistency of the SDNM investment function with available data. Consistency was demonstrated by improved measures of equation performance and by plausible parameter estimates. Second, the statistical test results showed that the SDNM investment function is more able to account for observed movements in investment activity than investment functions derived within the neoclassical framework.
This latter finding is especially interesting in light of the superior statistical performance exhibited by the neoclassical investment function when compared to many alternative investment functions (Jorgenson and Siebert 1968, Jorgenson, Hunter and Nadiri, 1970a, b).

The limitation of the statistical test results lies in the incomplete picture they provide of why the SDNM investment function is superior to the neoclassical formulation. To understand why the SDNM investment function is superior, Chapters 4 and 5 presented a variety of model-behavior tests to examine the effects of each SDNM investment hypothesis on the behavior of an economic production sector.

The behavior-plausibility tests in Chapter 4 showed that each SDNM investment hypothesis plays a role in producing plausible production-sector behavior. For example, the hypothesized supply-line correction in capital ordering reflects producers' knowledge of capital projects already in planning or on order. Elimination of the supply-line correction leads to "double ordering" for new capital. Eliminating the supply line correction, in effect, implies that producers continue to initiate capital planning for projects already in planning or on order. Elimination of the supply-line correction also makes capital ordering unresponsive to changes in the delivery delay for capital, thereby implying that producers do not adjust capital ordering when changing delivery delays threaten the desired rate of capital acquisition. Chapter 4 similarly isolated implausible features of model behavior precipitated by eliminating the four other SDNM investment hypotheses.
The behavior-mode tests in Chapter 5 showed that the SDNM investment hypotheses are important in generating two distinct modes of observed consumer-goods sector behavior—a short-term fluctuation in production and labor with an average period of about 5 years and longer term fluctuations in capital and investment (The average period of the longer term fluctuation in capital equals about 18 years; the average period of the longer term fluctuation in investment equals about 14 1/2 years.). Elimination of the five SDNM investment hypotheses draws the two behavior modes together: investment becomes dominated by short-term fluctuations, capital exhibits a significant degree of short-term fluctuation, and the average period of short-term fluctuations in production and labor increases to about 6½ years. Of the five SDNM investment hypotheses, the hypothesized delay in forming perceived ratio of capital return to cost PRCRC and the hypothesized effect of inventory- and backlog corrections in capital ordering play the most important roles in generating the two distinct behavior modes.

The behavior mode analysis suggests that the additional hypotheses included in the SDNM investment function may be important in understanding an observed mode of economic behavior, the so-called "Kuznets cycle," and in analyzing the effects of alternative stabilization policies. A neoclassical-type investment function generates significant short-term fluctuations in investment and capital stock and thereby implies that capital investment may provide an effective channel for influencing short-term business cycles. By
contrast, the SDNM investment function suggests that capital investment belongs to a behavior mode distinct from the business cycle and that policies which influence investment have little leverage on business cycles.

In conclusion, the model-behavior tests complement the statistical tests by providing a deeper understanding of why the additional hypotheses included in the SDNM investment function capture important elements of investment decision-making. The behavior-plausibility tests show why each SDNM investment hypotheses is necessary for plausible production-sector behavior. The behavior-mode tests show why the SDNM hypotheses are important in understanding the source of observed longer-term fluctuations in investment and capital stock. By implication, investment functions derived within the neoclassical framework omit feedback mechanisms necessary for plausible production-sector behavior, for explaining observed fluctuations in investment and capital stock, and for analyzing the effects of alternative policies intended to influence economic stability.
II. METHODOLOGICAL CONCLUSIONS--THE USEFULNESS OF MODEL-BEHAVIOR TESTING

One of the objectives of this thesis has been to examine the benefits of model-behavior testing as an extension to conventional statistical tests of equation specification. When viewed in this light, the test results in Chapters 3, 4, and 5 reveal several benefits of model-behavior testing which warrant recognition.

Perhaps the single most important distinction of model-behavior testing is the context it provides for understanding why an hypothesis should or should not be included in a model. By analyzing the causes of a behavior-test outcome, one can understand the feedback mechanisms which give rise to the outcome. Such understanding is always possible, although it may require considerable time and effort.

Similar understanding of statistical test outcomes is not always available. Poor statistical test results may reflect limitations of the model, the data, the statistical technique, or a combination of the three. Even if the model-builder is confident that a poor statistical estimate or statistical outcome does not stem from an inappropriate estimation technique, the implications of the statistical result remain ambiguous. For example, a statistically insignificant parameter estimate may reflect an incorrect causal hypothesis or a correct hypothesis which is difficult to measure.¹ The statistical testing procedure itself provides no means for ascertaining which is the case.

¹The hypothesis may be difficult to measure because the relevant explanatory variables are measured with error, are impossible to measure directly (and are replaced by proxies), or are highly correlated with other explanatory variables over the sample period.
The capability of understanding model-behavior test outcomes leads to three unique advantages of model-behavior tests of equations specification. First, model-behavior testing can lead to generalizable insights into the behavioral implications of an hypothesis. Second, model-behavior testing can reveal why an hypothesis is incorrect. Third, it can provide guidance for respecifying incorrect hypotheses.

The results of testing the hypothesized delay in forming perceived ratio of capital return to cost PRCRC illustrate the general insights available through model-behavior testing. First, consider the results of statistical tests of the hypothesized delay. The statistical tests presented in Chapter 3 agreed with earlier tests conducted by Bischoff (1971a) by rejecting the hypothesis that capital ordering responds equally rapidly to changes in desired output and changing incentives to adjust capital-output ratio. That is, the statistical results suggested that the hypothesized delay in forming PRCRC is valid in the sense of being a measurable influence on industry investment behavior. However, the statistical tests provided no compelling rationale for why it might be important to include the hypothesized delay in a production sector model.

By contrast, the model-behavior tests demonstrated the importance of the hypothesized delay in forming PRCRC for understanding economic fluctuations. In particular, the behavior-mode tests in Chapter 5 showed that the delay in forming PRCRC plays a key role in generating two distinct oscillatory modes of consumer-goods sector behavior. With
the delay, desired capital expands and contracts more slowly than desired labor, thereby giving rise to fluctuations in investment and capital which have a distinctly longer period than fluctuations in labor. Given such behavior, policies designed to influence capital investment and fixed capital stock have little impact on short-term (business-cycle) fluctuations in labor and production. When the delay in forming PRCRC is eliminated, desired capital and desired labor fluctuate in tandem, and the sharp distinction between capital- and labor-related modes of behavior breaks down. Such behavior has quite different policy implications because it suggests that capital investment may be an effective channel for influencing short-term fluctuations in production and employment.

Moreover, analysis of the causes of model behavior with and without the hypothesized delay in forming PRCRC clarified why the hypothesis is important in generating the two distinct behavior modes. The analysis in Chapter 5 showed that the potential for two modes of consumer-goods sector behavior stems from the inherently different speeds with which labor and fixed capital can be adjusted. The hypothesized delay in perceiving and responding to nonoptimal factor proportions exaggerates the distinct periodicities inherent in labor and capital adjustments by encouraging the production sector to adjust production capacity with the factor, labor, which can be obtained and released most quickly. By encouraging short-term adjustments in labor to correct supply-demand imbalances, the delay implicitly encourages longer term
over- and underexpansion of capital to correct imbalances in factor mix.

The above example shows how model-behavior tests can lead to general insights into the relation between investment-function specification and production sector behavior. Understanding how the delayed response to nonoptimal factor proportions can generate distinct periodicities of labor and capital behavior represents an insight which can be transferred to other economic systems or to alternative consumer-goods sector models. The insight would be especially important for any model intended to illuminate causes of economic fluctuations. Similarly, general insights were obtained in the model-behavior tests of the other SDNM investment hypotheses. In each case, the tests revealed relationships between structure (i.e., investment-function specification) and behavior of broad applicability.

Model-behavior tests can provide equally compelling evidence for rejecting hypotheses and discovering defects in model structure. To illustrate, consider behavior tests of an investment function which excluded any effect of growth expectations on investment. In particular, consider a behavior test involving a growing demand for output. As was shown in Chapter 4, omitting the effect of growth expectations in capital ordering leads to perpetually inadequate production capacity in the face of steadily rising demand. Such behavior occurs because, in the absence of growth expectations, continuous undercapacity is necessary to provide pressure for capital expansion. In a real production sector, undercapacity might occur in the initial period following the onset of a
new growth trend, but it is difficult to believe that such undercapacity would last indefinitely in the face of a constant rate of demand growth.

The above example also illustrates the third major benefit of model-behavior testing—namely, that behavior tests can provide useful guidance in improving specification. A clear understanding of why the investment function described above results in perpetually inadequate production capacity suggests an appropriate improvement in model structure. One comes to realize that, if producers repeatedly experienced inadequate production capacity because investments to meet current demand repeatedly fell short of future demand, they would begin to prepare for future increases in demand. That is, understanding the causes of implausible behavior leads the model builder to recognize elements of structure previously omitted from the model.

This section has shown that model behavior testing provides a useful context for discovering general insights into the behavioral implications of alternative hypotheses, leads to clear reasons for rejecting incorrect hypotheses and revising model defects, and provides guidance in improving model structure. All three benefits derive from the ability to analyze and understand the feedback mechanisms created by alternative hypotheses. For these reasons, model-behavior testing appears to offer a significant extension to conventional statistical testing. The following section outlines specific areas in which the promise of this approach to testing should be explored further.
III. SUGGESTIONS FOR FUTURE RESEARCH

The present research might be profitably extended in several directions. First, there are several limitations of the investment function tested above which should be corrected. One limitation concerns the response of desired capital to changes in relative prices of productive factors. In the present formulation of ratio of capital return to cost RCRC, desired capital responds to changes in the cost of capital services relative to marginal revenue. Such a formulation precludes a response of desired capital to changes in prices of other factors which are not reflected in changes in marginal revenue. For example, Jorgenson (1977) has recently suggested that rising energy costs may have a significant depressive impact on capital investment in the later 1970's and early 1980's. The way in which relative prices enter the present SDNM investment function appears inadequate for dealing with such an issue. A modified version of the SDNM investment function has been recently developed which appear to describe the effects of relative prices on desired capital in a more general manner (see Mass 1977b). Behavior testing of the modified SDNM investment function would probably require an extended model involving endogenous changes in relative prices. Such a model could be assembled from the consumer-goods, capital-goods, and labor sectors of the SDNM.

The investment function tested above also omits at least two factors—liquidity and return on investment—which appear to have a role in a general theory of investment. Financial considerations such as the
availability of investible funds and expected returns often appear to dominate investment decision-making within individual firms. Yet, most investment functions, including the SDNM investment function tested above, fail to explicitly represent financial pressures. An expanded SDNM investment function including the effects of liquidity and return on investment on capital ordering has been formulated and undergone preliminary behavior testing. An extension of the present research might focus on systematic behavior testing of the expanded SDNM investment function to determine whether explicit representation of liquidity and return on investment as influences on investment leads to new modes of production-sector behavior or illuminates implausible features of behavior generated without explicit financial pressures. The production-sector model for such testing should include endogenous price setting and the financial stocks and flows included in the full SDNM production sector (see Mass 1977a). To focus the testing, the expanded SDNM investment function might be contrasted to other investment functions emphasizing financial factors (such as the formulations developed by Anderson 1964, Meyer and Glauber 1964, Eisner 1965, Coen 1971) and to Brimmer and Sinai's (1976) simulation study of the effects of explicitly representing corporate flows of funds on alternative investment tax policies.

The present research should also be extended in the direction of deepening understanding of behavior modes related to capital investment. In particular, the behavior mode tests in Chapter 5 should be repeated to
analyze the importance of investment-function specification for generating the so-called "Kondratieff wave," an approximately 50-year cycle generated when the SDNM investment function is included in a capital producing sector (see Forrester 1976 and Mass 1976a). Due to its far greater amplitude and resistance to change, the 50-year cycle has a greater potential significance for macroeconomic behavior and policy than the 18-year cycle in consumer-goods sector behavior explored above.

Initial analyses of the 50-year cycle suggests that it also stems from different mechanisms than the 18-year cycle in consumer-goods sector behavior. Investment within the capital-producing sector differs from investment within a consumer-goods sector because the capital sector orders capital from itself. Consequently, an increase in demand for capital from other economic sectors, such as the consumer-goods sector, stimulates several positive feedback processes which give rise to the long wave behavior. For example, if an capital sector is producing at full capacity, the increase in demand for capital causes the sector to attempt to expand its own capital stock. The resulting increase in orders for capital increases the backlog of unfilled orders for capital and causes the delivery delay for capital to rise. The rising delivery delay causes producers to place still more orders, which increases backlog and delivery delay still further.

The roles of SDNM investment hypotheses in generating the 50-year cycle may be quite different than the roles of the hypotheses in generating the 18-year consumer-goods-sector cycle. As the above example
suggests, the supply-line correction may play a more significant role in
the 50-year cycle than in the 18-year cycle. Eliminating the supply-line
correction eliminates the positive feedback loop by which increases in
capital ordering raise delivery delay for capital and lead to further
increases in capital ordering.

A second important follow-up to the present analysis of the
18-year cycle would be to relate the analysis to existing theories of the
Kuznets cycle. Foremost among contemporary theorists who have addressed
this mode of behavior is Moses Abramowitz. Abramowitz' view of the
Kuznets cycle emphasizes the role of immigration and subsequent
residential construction in producing protracted upswings in the rate of
economic growth from 1840 to 1914 (Abramowitz 1961, 1968). By contrast,
the mechanisms underlying the 18-year cycle generated by the
consumer-goods sector model concern expansion and contraction of capital
stock and rebalancing of capital and labor in consumer-goods sectors of
the economy.

Reconciliation of these two views of the 18-year cycle would
require behavior testing with an expanded model encompassing population
growth and the determinants of immigration and demand for residential
construction. Such a model might be assembled from the consumer-goods,
household- and demographic sectors of the SDNM. Given such a model, it
would be possible to determine which set of mechanisms, those outlined by
Abramowitz or the consumer-goods sector mechanisms analyzed above, is
more important in generating the 18-year cycle. It would also be
possible to analyze the comparative effectiveness of policies designed to influence investment versus policies designed to influence immigration or housing demand in controlling the cycle. Such an analysis would be especially useful for countries still experiencing significant waves of immigration in response to economic opportunities.

Analysis of the expanded model would also be useful for countries such as the United States in which immigration is now only a minor flow in augmenting the labor force. If the Kuznets cycle fundamentally originates from fluctuations in immigration and consequent housing demand, countries beyond the period of significant immigration flows would not be subject to significant Kuznets cycles. Such reasoning lies behind Abramowitz's statement that:

\[
\text{(the Kuznets cycle)...is a particular form of growth which belonged to a particular period of history and that the economic structure and institutions which imposed that form on the growth process have evolved, or been changed, into something different...The Kuznets cycle in America lived, it had its day, but its day is past}^2.\]

On the other hand, if the cycle originates from more enduring processes of capital accumulation and responses to nonoptimal factor mixes in individual firms, the cycle is likely to continue beyond the cessation of significant waves of immigration.

\[\text{In addition to altered immigration flows, Abramowitz also cites the emergence of significant levels of government expenditures, the shift in capital export patterns, the disappearance of the gold standard, and the reduced "vulnerability of the American economy to serious depression" (due to reduced reliance on volatile residential construction and, presumably, tighter economic controls) as institutional changes which have caused the disappearance of the Kuznets cycle.}\]
Lastly, future studies might contrast the SDNM investment function to more recent neoclassical investment functions such as the formulation developed by Ando, et al (1974) and employed in the MPS macroeconometric model. The MPS investment function has as a particular focus the response of investment to expectations of price and technological change. The two investment functions could be compared within a consumer-goods sector or a capital-goods sector including endogenous price setting and financing. However, a model with endogenous technological progress might provide a more interesting framework for the comparison. It should be possible to assemble such a model in the future, once adaptation of the generic SDNM investment production sector to describe the generation of technological know-how has been completed.
APPENDIX A: EQUATIONS FOR THE CONSUMER-GOODS SECTOR MODEL

This appendix presents the equations for the consumer-goods sector model employed in the present study. Section A.1 discusses simplifications made to the generic SDNM production-sector model for the present study. Section A.2 presents model equations, paying special attention to the rate equations not discussed in the model overview in Chapter 4. Section A.2 also identifies all changes in symbols and terminology of the SDNM production sector made for the present study. Section A.3 lists all changes in parameter values (relative to values used in former consumer-goods adaptations of the SDNM production sector) made for the present study and explains why the changes are made. Lastly, Section A.4 identifies all simplifications of the capital ordering equations in the SDNM production sector needed to derive the SDNM investment function tested in the present study.

A.1. RELATION OF MODEL TO FULL SDNM PRODUCTION SECTOR

The generic production sector model developed in the System Dynamics National Project describes how a firm or aggregate producing sector of an economy orders factors of production (such as labor, capital, materials, energy, land, transportation, and services), combines the factors of production to generate an output stream, determines delivery delay and price, and finances its operation. The production-sector model includes endogenous factor stocks, in-process and
finished inventories, and backlogs of unfilled orders for output. The model also keeps a full balance sheet including accounts receivable, short- and long-term borrowing, savings, and money, as well as the value of physical assets. By incorporating a broad array of factors and processes, the production-sector model is intended to serve as a common framework for representing diverse economic sectors (see Forrester, Mass, and Ryan 1976). Forrester and Mass (1976) give a detailed equation-by-equation description of the SDNM production sector model.

The model-behavior tests presented in Chapters 4 and 5 employed a simplified version of the SDNM production sector. The model employed in Chapters 4 and 5 is simplified by including only two factors of production, labor and capital, and by omitting endogenous price-setting and financial variables. The model includes two factors of production to simplify analysis of model behavior yet permit identification of unique modes of behavior related to capital investment (such as the 18-year cycle analyzed in Chapter 5). Endogenous price-setting, borrowing, savings, and financial accounting are similarly omitted to simplify the model and focus attention on feedback mechanisms essential for comparing the SDNM and neoclassical investment functions. The major distinctions between the two investment functions concern the inclusion of several real variables — output inventories and backlogs, backlog and delivery delay for capital, and expected changes in sales — and the respective specifications of delays in the investment process. By in large, analysis of the influence of these variables and delay specifications on
production-sector behavior can be carried out by including only the real (that is, nonfinancial) feedbacks linking capital ordering and accumulation to output, shipments, and changes in inventory and backlog. Findings of the present study can be reevaluated in the future by repeating the simulations with endogenous pricing, borrowing, and accounting (i.e., billing, money flows, and profits).  

Adaptation of the generic production-sector model to describe a consumer-goods producing sector involves appropriate choice of parameter values in the model. Specific parameter values are discussed in Section A.3 below.

A.2 MODEL EQUATIONS

Before presenting the equations of the consumer-goods sector model, several notes concerning the origin, format, and substance of the equations are necessary to prepare the reader.

The model is assembled from component sets of equations developed for the System Dynamics National Project. The equation sets fall into six categories: macros (standardized programs called on to compute variables such as trends and noise sequences), production-sector model equations, parameter settings, equations for variables used in but

---

1Simulations to date with the financial equations indicate only relatively minor changes in consumer-goods sector behavior. This suggests that the behavior of a single production-model sector stems primarily from the real feedback interactions included in the present study.
not determined in the presented model (of which there are four types: sector coupling equations, equations for sector variables not defined, equations for factor variables not defined, and equations for national variables not defined), equations for the "backlog test generator" (a simplified production-sector model used to generate demand -- i.e., orders -- for consumer-goods), and plot statements. The equation sets which comprise the model are part of the permanent files of the System Dynamics National Project.\(^2\)

The model equations are written for simulation using the DYNAMO III compiler. The array facility of this compiler permits one set of equations to be extended to multiple production sectors and factors of production. Factor and sector postscripts provide the means for implementing the array facility. For example, the first of the production-sector model equations determines an array of values for arrivals of factor AF:

\[
AF.K(F,S) = BF.K(F,S)/DDF.K(F,S),
\]

where "F" is a "for variable" (index) which ranges from 1 to 2 (the number of factors in the present model) and "S" is a for variable which ranges from 1 to 1 (the number of sectors in the present model). In the present model, labor is the first factor of production and capital is the

\(^2\)Note that each set of equations bears an identification number.
second; hence, \( AF.K(1,1) \) denotes the rate of arrivals of labor and \\
\( AF.K(2,1) \) denotes the rate of arrivals of capital.\(^3\) All factor specific \\
variables are determined in two-dimensional arrays.\(^4\) All \\
sector-specific variables are determined in one-dimensional arrays (i.e., \\
as scalars).

Though useful for simulation, the factor-sector postscripts are \\
awkward for describing a model. To make the meaning of model terms more \\
clear, all postscripts are replaced by appropriate verbal descriptors \\
when the model is discussed in the body of this study. For example, \\
\( AF(1,1) \) becomes arrivals of labor \( AL \), and \( AF(2,1) \) becomes arrivals of \\
capital \( AC \). Other terms renamed to enhance clarity include expected \\
growth in shipments \( EGS \) (originally termed long-term growth \( LfG \)) and \\
orders for output \( O \) (originally termed orders in test generator \( OTG \)). \\
Table A-1 lists all parameters and variables designated in the text by \\
terms which differ from terms used in the following equation listing. \\
(Terms are listed in order of the equations by which they are defined in \\
the subsequent equation listing.)

\(^3\)In the computation sequence of the DYNAMO compiler, ".K" denotes the \\
present point in time, ",J" denotes the immediately preceding point in \\
time, and ",L" denotes the immediate next point in time. The time \\
postscript ",JK" denotes a rate of flow over the interval \( .JK \) (see \\
Forrester 1961 or Mass 1975, Appendix C).

\(^4\)In most cases, the arrays are dimensioned \( (F,S) \) but in a few instances \\
arrays for factor-specific variables are dimensioned \( (PF,S) \), \( (EF,S) \), or \\
\( (NWF,S) \). The for variable \( PF \) (for productive factors) ranges from 1 to \\
2; the for variables \( EF \) (for employment factor) and \( NWF \) (for \\
non-workforce factor) respectively range from 1 to 1 and from 2 to 2.
TABLE A-1
GLOSSARY OF CHANGES IN TERMINOLOGY

<table>
<thead>
<tr>
<th>Term Used in Equation Listing</th>
<th>Term Used in Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF Arrivals of Factor</td>
<td>AL Arrivals of Labor</td>
</tr>
<tr>
<td></td>
<td>AC Arrivals of Capital</td>
</tr>
<tr>
<td>CO Cancellation of Orders</td>
<td>COL Cancellation of Orders for Labor</td>
</tr>
<tr>
<td></td>
<td>COC Cancellation of Orders for Capital</td>
</tr>
<tr>
<td>BF Backlog of Factor</td>
<td>BL Backlog of Orders for Labor</td>
</tr>
<tr>
<td></td>
<td>BC Backlog of Orders for Capital</td>
</tr>
<tr>
<td>OF Orders for Factor</td>
<td>OL Orders for Labor</td>
</tr>
<tr>
<td></td>
<td>OC Orders for Capital</td>
</tr>
<tr>
<td>OP Orders in Planning</td>
<td>OPL Orders in Planning for Labor</td>
</tr>
<tr>
<td></td>
<td>OPC Orders in Planning for Capital</td>
</tr>
<tr>
<td>CP Cancellation of Plans</td>
<td>CPL Cancellation of Plans for Labor</td>
</tr>
<tr>
<td></td>
<td>CPC Cancellation of Plans for Capital</td>
</tr>
<tr>
<td>SL Supply Line</td>
<td>SLL Supply Line for Labor</td>
</tr>
<tr>
<td></td>
<td>SLC Supply Line for Capital</td>
</tr>
<tr>
<td>OS Order Starts</td>
<td>OSL Order Starts for Labor</td>
</tr>
<tr>
<td></td>
<td>OSC Order Starts for Capital</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Term Used in Equation Listing</th>
<th>Term Used in Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDB  Perceived Delay in Backlog</td>
<td>PDDL Perceived Delivery Delay for Capital</td>
</tr>
<tr>
<td></td>
<td>PDDC Perceived Delivery Delay for Labor</td>
</tr>
<tr>
<td>ROF  Replacement Orders for Factor</td>
<td>RO Replacement Orders (for capital -- no comparable term given for replacement orders for labor)</td>
</tr>
<tr>
<td>IF   Inventory of Factor</td>
<td>L Labor</td>
</tr>
<tr>
<td></td>
<td>CAP Capital</td>
</tr>
<tr>
<td>RF   Reduction of Factor</td>
<td>RL Reduction of Labor</td>
</tr>
<tr>
<td></td>
<td>RC Reduction of Capital</td>
</tr>
<tr>
<td>MLF  Multiplier for Loss of Factor</td>
<td>MLL Multiplier for Loss of Labor</td>
</tr>
<tr>
<td></td>
<td>MLC Multiplier for Loss of Capital</td>
</tr>
<tr>
<td>CIF  Correction in Inventory of Factor</td>
<td>CL Correction in Labor</td>
</tr>
<tr>
<td></td>
<td>CCAP Correction in Capital</td>
</tr>
<tr>
<td>DSL  Desired Supply Line</td>
<td>DSLL Desired Supply Line for Labor</td>
</tr>
<tr>
<td>Term Used in Equation Listing</td>
<td>Term Used in Text</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>ORSL  Order Reference for</td>
<td>DS LC Desired Supply Line for Capital</td>
</tr>
<tr>
<td>Supply Line</td>
<td></td>
</tr>
<tr>
<td>DIF   Desired Inventory of</td>
<td>DL Desired Labor</td>
</tr>
<tr>
<td>Factor</td>
<td></td>
</tr>
<tr>
<td>LTG   Long-Term Growth</td>
<td>DCAP Desired Capital</td>
</tr>
<tr>
<td>DI    Desired Inventory</td>
<td></td>
</tr>
<tr>
<td>I     Inventory</td>
<td>EGS Expected Growth in Shipments</td>
</tr>
<tr>
<td>PRFRC Perceived Ratio of</td>
<td>DIO Desired Inventory of Output</td>
</tr>
<tr>
<td>Factor Return to Cost</td>
<td>IO Inventory of Output</td>
</tr>
<tr>
<td>PRCRC Perceived Ratio of</td>
<td>PRLRC Perceived Ratio of Labor Return</td>
</tr>
<tr>
<td>Capital Return to Cost</td>
<td>to Cost</td>
</tr>
<tr>
<td>PRCRC Perceived Ratio of</td>
<td>PRCRC Perceived Ratio of Capital Return</td>
</tr>
</tbody>
</table>
TABLE A-1
GLOSSARY OF CHANGES IN TERMINOLOGY
(Cont'd)

<table>
<thead>
<tr>
<th>Term Used in Equation Listing</th>
<th>Term Used in Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFRC  Ratio of Factor Return</td>
<td>RLRC  Ratio of Labor Return</td>
</tr>
<tr>
<td>to Cost</td>
<td>to Cost</td>
</tr>
<tr>
<td>MC    Marginal Cost</td>
<td>MCL    Marginal Cost of Labor</td>
</tr>
<tr>
<td>for Backlog</td>
<td>CCSC   Cost of Capital Services</td>
</tr>
<tr>
<td>TPDB  Time to Perceive Delay</td>
<td>TPDSLL  Time to Perceive Delay in</td>
</tr>
<tr>
<td>for Backlog</td>
<td>Supply Line for Labor</td>
</tr>
<tr>
<td>TCIFF Time to Correct Inventory of Factor for Factor</td>
<td>TCL   Time to Correct Labor</td>
</tr>
<tr>
<td>TPFRC Time to Perceive Factor</td>
<td>TPRLRC  Time to Perceive Ratio of</td>
</tr>
<tr>
<td>Return to Cost</td>
<td>Labor Return to Cost</td>
</tr>
<tr>
<td>NLF   Normal Loss of Factor</td>
<td>NLL    Normal Loss of Labor</td>
</tr>
<tr>
<td>NIF   Normal Inventory of Factor</td>
<td>NLC   Normal Loss of Capital</td>
</tr>
<tr>
<td>E     Exponent</td>
<td>EL     Exponent for Labor</td>
</tr>
<tr>
<td></td>
<td>EC     Exponent for Capital</td>
</tr>
</tbody>
</table>
TABLE A-1

GLOSSARY OF CHANGES IN TERMINOLOGY
(Cont'd)

<table>
<thead>
<tr>
<th>Term Used in Equation Listing</th>
<th>Term Used in Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDF  Delivery Delay for Factor</td>
<td>DDL  Delivery Delay for Labor</td>
</tr>
<tr>
<td>ESN  Exponent for Shipments in Nation</td>
<td>DDC  Delivery Delay for Capital</td>
</tr>
<tr>
<td>IRB, IRCL Interest Rate at Bank, Interest Rate at Corporate Lender</td>
<td>ES  Exponent for Shipments</td>
</tr>
<tr>
<td>PRF  Price of Factor</td>
<td>r    Interest rate</td>
</tr>
<tr>
<td>OTG  Orders in Test Generator</td>
<td>PL   Price of Labor</td>
</tr>
<tr>
<td></td>
<td>PCAP  Price of Capital</td>
</tr>
<tr>
<td></td>
<td>O     Orders for Output</td>
</tr>
</tbody>
</table>
The key rate equations in the consumer-goods-sector model are described in Section II of Chapter 4. These include order starts for labor, production and shipments (as well as order starts for capital described in Chapter 2). Four remaining rate equations warrant brief explanation: the equations for arrivals of labor and capital, and reduction of labor and capital. Arrivals for each factor equals the backlog of unfilled orders for the factor divided by the respective delivery delay for the factor.\(^5\) Factor delivery delays are determined outside the sector. In the present consumer-goods sector, delivery delay for both labor and capital are constant (see Section A.3 for parameter values). In a fuller version of the SDNM, delivery delay for labor and capital are respectively determined within the labor and capital sectors.

Reduction of capital RC equals the product of capital CAP, normal loss of capital NLC, and multiplier for loss of capital MLC:

\[
RC_t = CAP_t \cdot NLC \cdot MLC_t
\]  

The product of CAP and NLC equals the standard loss of capital -- the rate of physical discard of capital which prevails when the sector has an adequate amount of capital. Multiplier for loss of capital MLC depends

\(^5\)When the outflow rate for a level variable equals a constant fraction \((1/k)\) of the level, the fraction \(k\) equals the average dwell time for units in the level (see Goodman 1974, p. 237). Therefore, formulating arrivals of labor and capital as the ratio of the respective backlogs divided by the respective delivery delays is consistent with the concept of a delivery delay as an average time to fill an order.
upon desired and actual levels of capital. MLC raises reduction of capital relative to the standard loss when desired capital is below current capital. MLC lowers reduction of capital below the standard loss of capital when DCAP exceeds CAP. The multiplier for loss of capital reflects the ability of firms to increase capital wear-out rate through neglect and disuse or, to a lesser extent, reduce capital wear-out through careful maintenance and repair.

Reduction of labor RL equals the sum of a product similar to that in Equation (A-1), quit rate QR, and reduction in sector employed RSE:

\[ RL_t = L_t \cdot NLL \cdot MLL_t + QR_t + RSE_t \]  \hspace{1cm} (A-2)

The first term in Equation (A-2) corresponds to layoffs. Normal loss of labor NLL corresponds to a normal fractional layoff rate. Multiplier for loss of labor MLL permits the sector to modify layoffs depending on whether the sector wants to expand or contract labor. If labor is at its desired level (MLL equals unity), layoffs still occur because (1) some firms continue to seek more suitable workers and (2) individual firms within the aggregate production sector will have excess labor even though the sector as a whole has the desired level of labor.

Quit rate QR represents voluntary quits. Reduction of sector employed RSE represents workers leaving the sector's labor pool due to death or retirement. In a fuller version of the SDNM, quit rate QR and
reduction in sector employed RSE are specified within the labor sector. For the present simulations, both will be represented as simple functions of the current level of labor and, respectively, normal fractional quit rate NFQR and normal fractional reduction in sector employed NFRSE:

\[ QR_t = NRQR \cdot L_t \]  
\[ RSE_t = NFRSE \cdot L_t \]  

(A-3)  
(A-4)

Table A-2 presents an equation listing for the consumer-goods sector model. Table A-3 presents an "Analyzer" listing for the model which provides definitions for all variables and parameters in the model and identifies the equations in which the variable or parameter appears. (Section A.3 of Appendix A begins on page 363)
TABLE A-2

EQUATION LISTING FOR
CONSUMER GOODS SECTOR MODEL

- N237 IS A 2F(LAB & CAP) / 1S(GOODS) MODEL: PROD39(NO ACCT)
  NOTE  N237 IS A TWO FACTOR (LABOR AND CAPITAL), ONE SECTOR
  NOTE  (CONSUMER GOODS) MODEL USING PROD39. N237 IS
  NOTE  SPECIFICALLY DESIGNED FOR USE IN TESTING
  NOTE  ALTERNATIVE INVESTMENT FUNCTION SPECIFICATIONS.
  NOTE  IN PARTICULAR, THE MODEL ALLOWS FOR SIMPLIFICATION
  NOTE  OF THE SUM EQUATIONS FOR ORDER STARTS FOR
  NOTE  CAPITAL (G5(2,5)) TO HAVE ORDER STARTS DETERMINED
  NOTE  BY A NEOCLASSICAL-TYPE INVESTMENT FORMULATION.
  NOTE  N237 IS USED FOR ALL SIMULATIONS IN PETER SCHOF’S
  NOTE  PH.D. THESIS, “THE SysteM DYNAmIcs NATIONAL MODEL
  NOTE  INVESTMENT FUNCTION: A COMPARISON TO THE
  NOTE  NEOCLASSICAL INVESTMENT FUNCTION”.
  NOTE  (N237 IS AN EDITED VERSION OF N232, CHANGING
  NOTE  PSI BACK TO THE "A PRIORI" VALUE OF .1. N232
  NOTE  WAS AN EDITED VERSION OF N225. PSI IS A VARIABLE
  NOTE  AND MSV IS INCLUDED ON THE OPT CARD SO THAT
  NOTE  COMPARATIVE PLOTS CAN BE DONE.)
  NOTE  MACRO, NOVEMBER 3, 1976
  NOTE  MACRO HAS BEEN EDITED IN N237 TO MAKE PSI A
  NOTE  VARIABLE SO THAT IT CAN BE CHANGED IN REPRINT
  NOTE  TREND MACRO
  NOTE  MACRO TPNC (INPUT, TOTRN, ITRN)
  NOTE  B  $STAI = TOTRN - TSI
  NOTE  D  $AIN1 = INPUT.I + ($STAI * TTRN)
  NOTE  E  $PSI = TOTRN ($PSI)
  NOTE  G  $AIN2 = INPUT.I + ($STAI * TTRN)
  NOTE  H  $AIN = 1
  NOTE  I  PINK NOISE MACRO
  NOTE  MACRO PKNM(MNS, SDN, TCM)
  NOTE  L  PKNM.K = PKNM.J + (DT/TCM) ($SPNM * NOISE.J) + MNS - PKNM.J
  NOTE  M  PKNM = MNS
  NOTE  N  $SPN = SDN * SQRT (24*TCM/DT)
  NOTE  M = NUMBER OF FACTORS AND SECTORS
  NOTE  C  TP=2
  NOTE  D  TP=1
  NOTE  E  TP=2
  NOTE  F  TP=1
  NOTE  G  THF=2
  NOTE  H  THF=2
  NOTE  FOR VARIABLES
  NOTE  FOR F=1, TP
TABLE A-2

EQUATION LISTING FOR CONSUMER GOODS SECTOR MODEL

(Cont'd)

FOR S=1,TS  
FOR PP=1,TDF  
FOR NSP=PINF,TPM  
FOR EF=1,TEF  
NOTE PROD39, AUGUST 31, 1977  
NOTE PROD39 IS EDITED IN M237 TO DELINE EQUATIONS FOR ACCOUNTING  
NOTE ORDERING EQUATIONS  
NOTE  
A  
AP.Κ(F,S) = DP.Κ(F,S)/DDP.Κ(F,S)  
B  
CO.Κ(F,S) = BP.Κ(F,S) * COCO.Κ(F,S) / DDP.Κ(F,S)  
L  
BP.Κ(F,S) = Σ(TJ(F,S) + (OT) (OF.Κ(F,S) - AP.Κ(F,S) - CO.Κ(F,S)))  
N  
BP.Κ(F,S) = 3NF.Κ(F,S)  
A  
DP.Κ(F,S) = OP.Κ(F,S) / TOP.Κ(F,S)  
L  
OP.Κ(F,S) = OP.Κ(F,S) + (OT) (OS.Κ(F,S) - OP.Κ(F,S) - CP.Κ(F,S))  
A  
DP.Κ(F,S) = TOP.Κ(F,S)  
R  
CP.Κ(F,S) = OP.Κ(F,S) * COCO.Κ(F,S) / TOP.Κ(F,S)  
A  
COCO.Κ(F,S) = TOP.Κ(F,S) / TOP.Κ(F,S)  
A  
DN.Κ(F,S) = N1 * CS.Κ(F,S) / DP.Κ(F,S) - 1 * COCO.Κ(F,S)  
A  
SL.Κ(F,S) = DP.Κ(F,S) + BN.Κ(F,S)  
A  
OS.Κ(F,S) = AP.Κ(F,S) * VΟ.Κ(F,S)  
M  
RF.Κ(F,S) = RKX(F,S) + DDD.Κ(F,S) / ICO.Κ(F,S)  
M  
SD(J,F,S) = SEC(F,S) * CSRDS(S) * CDROC  
M  
AOP.Κ(F,S) = OF.Κ(F,S) * RC.Κ(F,S)  
A  
(ρωΚ.Κ(F,S) = 1 - SFP(F,S) + SFP(F,S) * ρο.Κ(F,S))  
N  
Pο.Κ(F,S) = PO.Τ(F) * ζ05(S) * PN.Κ(F,S)  
A  
MD.Κ(F,S) = TABLE (TDN, PDO.Κ(F,S), -1, .5, 5)  
A  
RDO.Κ(F,S) = 1 * (PDO.Κ(F,S) / CRDC.Κ(F,S)) - 1 * (PDO.Κ(F,S))  
M  
CDD.Κ(F,S) = CDROC.Κ(F,S) * CDROC  
L  
PDO.Κ(F,S) = PDO.Κ(F,S) + (DT/TDFD(F,S)) (DDP.Κ(F,S) - PDO.Κ(F,S))  
N  
PDD.Κ(F,S) = DDF.Κ(F,S)  
A  
CDD.Κ(F,S) = DDF.Κ(F,S) + (TD.Κ(F,S) - NDDP.Κ(F,S)) * PDO.Κ(F,S)  
L  
TD.Κ(F,S) = TDN.Κ(F,S) / TDN.Κ(F,S) + (DT/TDFD(F,S)) (PDO.Κ(F,S) - TD.Κ(F,S))  
M  
TD.Κ(F,S) = PDO.Κ(F,S)  
A  
DB.Κ(F,S) = DDF.Κ(F,S) + (PDO.Κ(F,S) - NDDP.Κ(F,S)) * CBA.Κ(F,S)  
M  
CBA.Κ(F,S) + DAP(F,S) * CBA(S) * CRN  
M  
NDDP.Κ(F,S) = DDF.Κ(F,S)  
L  
PDD.Κ(F,S) = PDO.Κ(F,S) < (DT/TDFD(F,S)) (DDP.Κ(F,S) - PDO.Κ(F,S))  
M  
PDD.Κ(F,S) = DDF.Κ(F,S)  
A  
DDP.Κ(F,S) = DAP.Κ(F,S) * (1 + HCDF.Κ(F,S)) * LEP.Κ(F,S) * NDC.Κ(F,S)  
A  
NDC.Κ(F,S) = TANH(TANH, CIF.Κ(F,S) / POP.Κ(F,S), -1.5, .5, 0.25)  
A  
POP.Κ(F,S) = AP.Κ(F,S) + SLP.Κ(F,S) + SLT.Κ(F,S)  
A  
UP.Κ(F,F) = ζ09(FZP, S) * SE.Κ(EP,F)  
A  
HP.Κ(F,F) = ζ09(CDROC.Κ(F,S) - CRN.Κ(F,S))  
A  
SLF.Κ(F,S) = IF.Κ(F,S) * M237.Κ(F,F)  
N  
SLF.Κ(F,S) = M237.Κ(F,F)  
A  
IF.Κ(F,F) = IF.Κ(F,F) * IFN(F,F, S)  
A  
IF.Κ(F,F) = IFN(F,F, S) * IFN(F,F)  
A  
EL.Κ(F,F) = SLF.Κ(F,F) * EL.F.Κ(F,F)  
A  
MF.Κ(F,F) = TANH(TANH(F,F, S) * IFN(F,F, S))  
A  
M2.Κ(F,F) = TANH(TANH(F,F, S))  
E  
M2.Κ(F,F) = MTANH(TANH(F,F, S)) * IFN(F,F, S)  
A  
NDC.Κ(F,F) = TANH(TANH, CIF.Κ(F,F) / POP.Κ(F,F), -1.5, .5, 0.25)  
A  
M2.Κ(F,F) = TANH(TANH(F,F, S))  
A  
20
TABLE A-2

EQUATION LISTING FOR CONSUMER GOODS SECTOR MODEL (Cont’d)

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<td>LEP.K(F,S) = IF.K(F,S) / STDP(F)</td>
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<td>CIF.K(F,S) = CIFG.K(F,S) * (CTP.K(F,S) - IF.K(F,S) - CSS(K))</td>
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<td>DSI.K(F,S) = SLK.K(F,S) - SLK.K(F,S) / TICP(F,S)</td>
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<td>CIF.K(F,S) = CIFG(F,S)</td>
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<td>TICP(F,S) = CIFP(F) * TCTPS(F) * TCTIFN</td>
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<td>DSI.K(F,S) = DBP.K(F,S) + DOP.K(F,S)</td>
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<tr>
<td>CSSK.K(F,S) = DBS.K(F,S) + GSPS.K(F,S)</td>
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<tr>
<td>ORSL.K(F,S) = DOP.K(F,S) + GSSL.K(F,S)</td>
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<td>NGSK.K(F,S) = (TMSL.WH, CTEG.K(F,S)) / RCP.K(F,S) + 1.5, 3, 0.5</td>
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<td>CTEG.K(F,S) = IF.K(F,S) * I, K(F,S) * CEP(F,S)</td>
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<tr>
<td>CGE.K(F,S) = CGPP(F) * CEPK(F,S)</td>
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<td>GI.K(F,S) = STG.K(F,S) * (1 - TICPS(F)) * TICP(F,S)</td>
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<td>GI(F,S) = TGPN</td>
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<td>DIF.K(P,F,S) = IFK.P(F,S) + PRK.P(F,S) * (1 - PFRP.C.K(P,F,S))</td>
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<td>* PFRP.C(P,F,S) * PFRP.K(P,F,S)</td>
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<tr>
<td>CMPK(P,F,S) = CMPS(P,F,S) + SMPF(P,F) + CMPS(P,F) * CRMN</td>
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Note: PRODUCTION AND SHIPPING EQUATIONS
TABLE A-2

EQUATION LISTING FOR
CONSUMER GOODS SECTOR MODEL

(Cont'd)

NOTE
ICN3, SEPTEMBER 29, 1975

NOTE
INITIAL CONDITIONS FOR NATION

NOTE
IVH3 EDITED IN N237 TO DELETE ACCOUNTING EQUATIONS

NOTE
CONDITIONS FOR INVENTORY AND

NOTE
ORDERING EQUATIONS

NOTE
PFI12, JANUARY 12, 1977

NOTE
PARAMETERS FOR FACTORS--LABOR, CAPITAL, ENERGY,

NOTE
LONG-TERM LOANS AND SHORT-TERM LOANS

NOTE
ACCOUNTING

NOTE
PFI12 EDITED IN N237 TO DELETE EQUATIONS FOR
TABLE A-2

EQUATION LISTING FOR
CONSUMER GOODS SECTOR MODEL
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### Table A-2

**Equation Listing for Consumer Goods Sector Model**

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**Note:**

PFS17, August 31, 1977

**Parameters for Sectors—Goods and Capital**

**Note:**

PFS10, October 12, 1976

**Parameters for Sectors—Goods and Capital**

**Note:**

PFS10 Edited in W237 to Delete Equations for Accounting and the Capital Sector

**Note:**

**** For the Sector Goods ****

**Note:**

Parameters for Inventory and Ordering Equations

**Note:**

CSROS(1) = 1

**Note:**

CPMS(1) = 1

**Note:**

CBLS(1) = 1

**Note:**

BGS(1) = 1

**Note:**

CDOS(1) = 1

**Note:**

CILPS(1) = 1

**Note:**

COOS(1) = 1

**Note:**

CTCIFS(1) = 1

**Note:**

CTGOS(1) = 1

**Note:**

CTLTS(1) = 5

**Note:**

CMPS(1) = 5

**Note:**

CSTFC(1) = 3

**Note:**

CTCR(1) = 1.0

**Note:**

WBC(1) = 3

**Note:**

WBC(1) = 3

**Note:**

TTBC(1) = 2

**Note:**

UIC(1) = 0.5

**Note:**

MIC(1) = 3

**Note:**

ui(1) = 2

**Note:**

TASHP(1) = .5

**Note:**

MHL(1) = 1

**Note:**

TIP(1) = 3

**Note:**

WNP(1) = 1

**Note:**

TCPH(1) = 1

**Note:**

SMPS(1) = .03

**Note:**

MPROD(1) = 1030

**Note:**

SSP(1) = 1

**Note:**

PFS17, August 31, 1977

**Note:**

Parameters for Factors in Sector

**Note:**

Sectors—Goods and Capital

**Note:**

Factors—Labor, Capital,

**Note:**

Short-term and Long-term Loans

**Note:**

PFS17 Edited in W237 to Delete Accounting Equations and the Capital Sector
### TABLE A-2

**EQUATION LISTING FOR CONSUMER GOODS SECTOR MODEL**

<table>
<thead>
<tr>
<th>NOTE</th>
<th>EQUATION LISTING FOR LABOR IN THE GOODS SECTOR</th>
<th>1275</th>
<th>1255</th>
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<td>NOTE</td>
<td>PARAMETERS FOR INVENTORY AND ORDERING EQUATIONS</td>
<td>1276</td>
<td>1256</td>
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<tr>
<td>NOTE</td>
<td>MLF(1,1) = 0.25</td>
<td>1277</td>
<td>1257</td>
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<td>NOTE</td>
<td>MIF(1,1) = 1000</td>
<td>1278</td>
<td>1258</td>
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<tr>
<td>NOTE</td>
<td>CRMPS(1,1) = 1</td>
<td>1279</td>
<td>1259</td>
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<tr>
<td>NOTE</td>
<td>SWA(1,1) = 0</td>
<td>1280</td>
<td>1260</td>
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<tr>
<td>NOTE</td>
<td>E(1,1) = 0.65</td>
<td>1281</td>
<td>1261</td>
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<tr>
<td>NOTE</td>
<td>MPAP(1,1) = 1</td>
<td>1282</td>
<td>1262</td>
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<tr>
<td>NOTE</td>
<td>NFC(1,1) = 1</td>
<td>1283</td>
<td>1263</td>
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<tr>
<td>NOTE</td>
<td>SCI(1,1) = 1</td>
<td>1284</td>
<td>1264</td>
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<tr>
<td>NOTE</td>
<td>SGB(1,1) = 1</td>
<td>1285</td>
<td>1265</td>
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<tr>
<td>NOTE</td>
<td>SPRFC(1,1) = 1</td>
<td>1286</td>
<td>1266</td>
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<tr>
<td>NOTE</td>
<td>MLF(2,1) = 0.06</td>
<td>1287</td>
<td>1267</td>
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<td>NOTE</td>
<td>MIF(2,1) = 333.333</td>
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<td>NOTE</td>
<td>CRMPS(2,1) = 1</td>
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<td>1269</td>
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<td>NOTE</td>
<td>SWA(2,1) = 1</td>
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<td>NOTE</td>
<td>E(2,1) = 0.35</td>
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<td>1271</td>
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<td>MPAP(2,1) = 1</td>
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<td>NOTE</td>
<td>NFC(2,1) = 1</td>
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<td>1273</td>
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<td>NOTE</td>
<td>SCI(2,1) = 1</td>
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<td>NOTE</td>
<td>SGB(2,1) = 1</td>
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<td>1275</td>
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<tr>
<td>NOTE</td>
<td>SPRFC(2,1) = 1</td>
<td>1296</td>
<td>1276</td>
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<td>NOTE</td>
<td>SC224, JULY 26, 1976</td>
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<td>NOTE</td>
<td>SECTOR COUPLING EQUATIONS FOR A</td>
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<td>NOTE</td>
<td>1P (LABOR AND CAPITAL) 13 (GOODS) MODEL</td>
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<td>NOTE</td>
<td>SC224 EDITED IN W237 TO DELETE ACCOUNTING EQUATIONS</td>
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<td>NOTE</td>
<td>EQUATIONS FOR INVENTORY AND ORDERING EQUATIONS</td>
<td>1300</td>
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<td>NOTE</td>
<td>A DDF.K(1,5) = DFW.K(1,5)</td>
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<td>1301</td>
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<tr>
<td>NOTE</td>
<td>A DDF.K(2,5) = NDTC*(1+STEP(FIDDC,TSDDC))</td>
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<tr>
<td>NOTE</td>
<td>C FIDDC=1.5</td>
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<td>NOTE</td>
<td>C TSDDC=1</td>
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<td>NOTE</td>
<td>A AK(1)=BTG.K</td>
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<td>NOTE</td>
<td>A DDG.K=DD.K(1)</td>
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<td>NOTE</td>
<td>A PTG.K=PO.K(1)</td>
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<td>NOTE</td>
<td>PH17, JANUARY 5, 1977</td>
<td>1308</td>
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<td>NOTE</td>
<td>PARAMETERS FOR NATION</td>
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<td>NOTE</td>
<td>PH17 EDITED IN W237 TO DELETE ACCOUNTING EQUATIONS</td>
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<tr>
<td>NOTE</td>
<td>TABLE FUNCTION TROOP CHANGED TO TPPN</td>
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### TABLE A-2

**EQUATION LISTING FOR CONSUMER GOODS SECTOR MODEL**  
(Cont'd)

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<tr>
<th>NOTE</th>
<th>PARAMETERS FOR INVENTORY AND ORDERING EQUATIONS</th>
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<tr>
<td><strong>T</strong></td>
<td>TNCMW = 3/2/1/0/5/2/0</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>NQCK = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CSDW = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TVSGMLN = 1/3.5/1.5/1.1/1.05/2.1/2.2/4.2/2.5</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CBAM = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>BSN = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TDNW = 1/3/1.3/1.2/1/75/1.5/1.12/15/1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CDW = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TRCC = -85/-82/-72/-6.5/-85/-6.25/0/0/0</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TPCR = 0/0/0/0.25/0.45/0.45/0.72/0.9/0.95/0.97</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CFFN = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CGPN = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CSDPN = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CTCISP = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TIECN = 3/2.75/1.5/1.0/1.75/1.5/0.35</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CTSN = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CTSTWN = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TNPNM = 1</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>CMPPN = 1</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>TPRN = 1/1/2/3/4/5/6/7</td>
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<td><strong>C</strong></td>
<td>ESN = 0.25</td>
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<td><strong>T</strong></td>
<td>TMLN = 0.8/1/1.9/2/2.8/3.8</td>
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<td><strong>C</strong></td>
<td>CMHPN = 0</td>
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</table>

**NOTE**  
YMSG, JULY 1, 1976  
VARIABLES NOT DEFINED---SECTORS

**NOTE**  
YMSG EDITS IN #237 TO DELETE ACCOUNTING

**NOTE**  
EQUATIONS AND ADD NDDW, PR, PSE TO ALLOW

**NOTE**  
CHANGES TO BE MADE IN SURVEY

**NOTE**  
VARIABLES FOR INVENTORY AND ORDERING EQUATIONS

**NOTE**  
THE FOLLOWING TWO EQUATIONS (FOR DDW AND UP)

**NOTE**  
SHOULDBE DELETED WHEN ASSEMBLING WORKER-MOBILITY SECTOR

**NOTE**  
A DDW.K(1,S)=NDDW+STEP(SHDW,STNW)

**NOTE**  
N HNW = 15

**NOTE**  
A OR.K(PP,S)=.25*EP.K(EP,S)

**NOTE**  
WHEN ASSEMBLING MODEL WITH PRICING,
<table>
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<tr>
<th>NOTE</th>
<th>PROFIT, AND MONEY FLOW EQUATIONS</th>
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<td>A</td>
<td>MMO.K(S)=1.0</td>
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<tr>
<td>A</td>
<td>P0(S)=IPO(S)</td>
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<td>A</td>
<td>PIPP.K(S)=0</td>
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<td>NOTE</td>
<td>VDN3, APRIL 26, 1976</td>
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<td>NOTE</td>
<td>VARIABLES NOT DEFINED - NATION</td>
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<td>NOTE</td>
<td>VDN3 EDITED IN W237 TO DELETE EQUATIONS</td>
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<td>NOTE</td>
<td>FOR ACCOUNTING AND TO SUBSTITUTE IRII FOR IRS</td>
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<td>NOTE</td>
<td>VARIABLES FOR INVENTORY AND</td>
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<tr>
<td>NOTE</td>
<td>ORDERING EQUATIONS</td>
</tr>
<tr>
<td>NOTE</td>
<td>INTEREST EQUATION</td>
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<tr>
<td>A</td>
<td>IVTRN.K=0</td>
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<tr>
<td>A</td>
<td>CRETRN.K=0</td>
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<tr>
<td>A</td>
<td>SSTN.K=0</td>
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<tr>
<td>A</td>
<td>RPCR.F=0</td>
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<tr>
<td>A</td>
<td>IRB.K=0.06</td>
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<tr>
<td>A</td>
<td>INCL.K=0.06</td>
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<tr>
<td>A</td>
<td>STN.F=0</td>
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<td>NOTE</td>
<td>VNDP8, JULY 1, 1976</td>
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<td>NOTE</td>
<td>VARIABLES NOT DEFINED - FACTORS</td>
</tr>
<tr>
<td>NOTE</td>
<td>VNDP3 EDITED IN W237 TO DELETE EQUATIONS</td>
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<td>NOTE</td>
<td>VARIABLES FOR INVENTORY AND</td>
</tr>
<tr>
<td>NOTE</td>
<td>ORDERING EQUATIONS</td>
</tr>
<tr>
<td>NOTE</td>
<td>FOR THE FACTOR - LABOR **********</td>
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<tr>
<td>A</td>
<td>CMN.K(1,S)=2</td>
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<td>A</td>
<td>APPN.K(1,S)=PPF.K(1,S)<em>40</em>52</td>
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<tr>
<td>A</td>
<td>PPF.K(1,S)=4.0*(1+STEP(FICW,STCW))</td>
</tr>
<tr>
<td>C</td>
<td>FICW=0</td>
</tr>
<tr>
<td>C</td>
<td>STCW=1</td>
</tr>
<tr>
<td>NOTE</td>
<td>VARIABLES FOR INVENTORY AND</td>
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<tr>
<td>NOTE</td>
<td>ORDERING EQUATIONS</td>
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<tr>
<td>NOTE</td>
<td>FOR THE FACTOR - CAPITAL **********</td>
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<td>A</td>
<td>CMN.K(2,S)=0</td>
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<tr>
<td>A</td>
<td>APPN.K(2,S)=PPF.K(2,S)</td>
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<td>NOTE</td>
<td>DELETE FOR MODELS CONTAINING CAPITAL SECTOR</td>
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<tr>
<td>W</td>
<td>PPF(2,S)=(B320*PDP(2,1))/(PDP(1,1)+(MLF(2,1)+AIR(1))) (1+FFPC)</td>
</tr>
<tr>
<td>C</td>
<td>FFPC=0</td>
</tr>
<tr>
<td>NOTE</td>
<td>BTG13, JULY 21, 1976</td>
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<td>NOTE</td>
<td>BACKLOG TEST GENERATOR</td>
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<td>NOTE</td>
<td>FOR INVENTORY AND ORDERING EQUATIONS</td>
</tr>
<tr>
<td>L</td>
<td>BTG.K=BTG.J+(DT) (OTG.JK-ATG.J)</td>
</tr>
<tr>
<td>N</td>
<td>BTG=DBTG</td>
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<tr>
<td>A</td>
<td>ATG.K=BTG,K/DBTG.K</td>
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**TABLE A-2**

**EQUATION LISTING FOR CONSUMER GOODS SECTOR MODEL (Cont’d)**

<table>
<thead>
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<th>Equation</th>
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| R  
| DTLG.K = DDTG.K * KDITG.K  |
| A  
| DDTG.K = SITG.K * DDTG.K + (1 - SITG.K) * (SLITG.K * RITG.K)  |
| C  
| SITG.K = ITG.K * NLITG  |
| C  
| NLITG = 0.125  |
| A  
| RITG.K = TABLE (TMITG, CITG.K, SLITG.K, K)  |
| T  
| TMITG.K = 2.5/1/1.5/1.0/1.95/2  |
| A  
| CITG.K = (DITG.K - ITG.K) * (SCBTDG) * (DBTG.K * BTDG.K) / TCITG  |
| C  
| SCITG = 1  |
| C  
| TCITG = 1  |
| A  
| DDTG.K = SLITG.K * DBATG.K  |
| A  
| DBATG.K = KBATG.K * (PDBTG.K - KBATG.K) * CBATG  |
| C  
| KBATG.K = DDATG  |
| C  
| CUATG = 0.7  |
| L  
| PDBTG.K = (PDDT.G - PDATG.K) / (DT/TPDADT)  |
| C  
| PDATG = DDATG  |
| L  
| PDDT.G = 0.5  |
| A  
| RITG.K = TABLE (TMN, RDOTG.K, 1, 4, 5)  |
| A  
| RDOTG.K = 1 + (PDDT.K / RDOTG.K + 1)  |
| C  
| COITG = 1  |
| L  
| PDDT.K = (PDDT.G + PDATG.K) / (DT/TPDADT)  |
| C  
| PDATG = DDATG  |
| L  
| TPDADT = 0.5  |
| A  
| DITG.K = CDITG.K + (1 - SITG.K) * FLTG.K  |
| A  
| NLITG = CTG.K  |
| C  
| CTG.K = 100  |
| A  
| SITG.K = STEP (SFTG, STTG)  |
| C  
| SFTG = 0  |
| A  
| STTG = 1  |
| A  
| FLTG.K = STEP (1, PSTG) * FPTG*K SIN (6.283 * ((TIME.K - FLTG) / FPTG))  |
| C  
| PSTG = 0  |
| A  
| FPTG = 0  |
| A  
| FPTG = 0  |
| A  
| FPTG = 0  |
| A  
| RTTG = 0  |
| A  
| RITG.K = 1 + STEP (1, RSTG) * PKWS (RNGT, SDITG, TCITG)  |
| C  
| RNGT = 0  |
| C  
| SDITG = 0  |
| C  
| TCITG = 1  |
| A  
| RPTG.K = TABLE (TRPTG, RPTG.K, 0, 4, 5)  |
| A  
| TRPTG = 4/1.7/1.6/4/25/105/1.0/0.05  |
| A  
| RPTG.K = 1 + (PPTG.K / RPTG.K - 1) * CPTG  |
| C  
| CPTG = 1  |
| C  
| PPTG = 0  |
| C  
| PPTG = 0  |
| C  
| PPTG = 0  |
| A  
| DITG.K = ITG.K * NLITG  |
| L  
| ITG.K = ITG.K * (DT)  |
| C  
| ITG.K = ITG.K  |
| C  
| UTTG.K = SLITG.K * NUTG.K  |
| L  
| NUTG.K = TABLE (TRUTG, CITG.K, SLITG.K, 1, 2, 5)  |
| T  
| TRUTG = 1.5/1.2/1.0/0.85/75/7/7  |

**Note**

FLOT24, January 13, 1977
TABLE A-2

EQUATION LISTING FOR
CONSUMER GOODS SECTOR MODEL
(Cont'd)

NOTE
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TABLE A-3

ANALYZER LISTING OF
CONSUMER GOODS SECTOR MODEL
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ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL

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<td>70.1/RDS,A, 74/L,N, 92.1/PLOTS, 193.6</td>
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<td>76 A DESIRED SHIPMENTS FROM INVENTORY (OUTPUT UNITS/YEAR)</td>
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### Table A-3

**Analyzer Listing of Consumer Goods Sector Model**

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<td>FPPG, 180.3 C</td>
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### TABLE A-3

**ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL**

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<td>70 A LOSS OF INVENTORY (OUTPUT UNITS/YEAR)</td>
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### TABLE A-3

**ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL**

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<td>182.1 C NOISE START IN TEST GENERATOR (YEARS)</td>
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# TABLE A-3

## ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL

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TABLE A-3

ANALYZER LISTING OF
CONSUMER GOODS SECTOR MODEL
(Cont'd)

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TABLE A-3

ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL

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<td>S</td>
<td>9 ALL PRODUCTION SECTORS</td>
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<td>AF,A,13/ROB,A,16/DF,L,15/DP,H,15.1/OP,A,16/OP,L,17/OP,N,A</td>
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### TABLE A-3

**ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL**

(Cont'd)

<table>
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<td>179</td>
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<td>SDW</td>
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<td>STEP HEIGHT IN DELAY FOR WORKERS (YEARS)</td>
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<td>DDW,A</td>
<td>185</td>
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<td>SHIP</td>
<td>71</td>
<td>SHIPMENTS (OUTPUT UNITS/YEAR)</td>
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<td>179</td>
<td>A STEP IN INVENTORY IN TEST GENERATOR (DIMENSIONLESS)</td>
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<td>178</td>
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<td>SUPPLY LINE (FACTOR UNITS)</td>
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<td>SWITCH FOR LABOR (DIMENSIONLESS)</td>
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<td>95</td>
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<td>PF,A</td>
<td>180/EPD,W,140.1</td>
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<td>A SOCIAL SECURITY TAX RATE (DOLLARS/PERSON/YEAR)</td>
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<td>95</td>
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<td>STL</td>
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<td>PBF,A</td>
<td>161</td>
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### TABLE A-3

**ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL**

(Cont'd)

<table>
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<td>FUNCTION WHICH GIVES 0 AS OUTPUT IF TIME IS LESS THAN SECOND ARGUMENT AND GIVES FIRST ARGUMENT IF TIME IS EQUAL TO OR GREATER THAN SECOND ARGUMENT</td>
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<td>NUMBER OF PLOTS</td>
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<td>193.8</td>
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<td>190.1</td>
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TABLE A-3
ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL
(Cont'd)

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<td>119.2 C</td>
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<td>TIME TO PERCEIVE DELAY FOR ORDERS IN TEST GENERATOR (YEARS)</td>
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<td>TPPIR</td>
<td>TIME TO PERCEIVE PRODUCTION RATIO (YEARS)</td>
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TABLE A-3

ANALYZER LISTING OF CONSUMER GOODS SECTOR MODEL

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A.3. CHANGES IN PARAMETER VALUES

The parameter settings in the above equation listing predate the present research and do not include the statistical estimates obtained in the present study. Table A-4 presents changes in parameter values (relative to parameter values listed in Table A-2) made for model-behavior tests presented in Chapters 4 and 5. The first group of parameter changes listed correspond to nondurable manufacturing parameter estimates for the SDNM investment function. This first group of parameter values are repeated from Appendix A of Chapter 3 (see Table 3-9). Note that all parameters are designated by the terms used in the equation listing in Table A-2. For example, simulation with the estimated parameters for forming expected growth in shipments EGS requires setting fraction for smoothing input FSI to 0.2. Given FSI=0.2, the averaging time in forming short-term average shipments (average input number one \( S\text{AIN1} \)) equals 1 year, and the averaging time in forming average input number two \( S\text{AIN2} \) equals 4 years. The averaging times correspond to the estimates of time for short-term averaging of shipments TSTAS and time for long-term averaging of shipments TLTAS derived in Appendix A of Chapter 3.

\[ S\text{AIN1} \]

---

6 Equation (4.2) in Table A-2 gives the first averaging time, designated time for smoothing input $TSI$ in the trend macro, as the product of total trend TOTRND and $FSI$. $FSI$ equals FSI (Equation 4.3). TOTRND is assigned the value of time for long-term trend TLTT when the trend macro is called in the equation for long-term growth LTG (Equation 54). TLTT equals five years (Equation 122.4). The second averaging time, designated time for averaging smoothed input $TASI$ equals (TOTRND - $TSI$), or $(1-FSI) \cdot TOTRND$ (Equation 3.1).
The second group of parameter settings in Table A-4 correspond to parameters outside the investment function which were changed to correspond more closely to available empirical studies. The first four parameters in this second group concern the delay times in the supply line for labor and capital. Holt estimates the average delay in filling job vacancies to be on the order of one month (Holt 1969, p. 137). Mayer's (1958) survey of manufacturers provides similar information for capital acquisition. Mayer estimates that, for new plant, the average time for orders in planning is about 5 months and the average construction delay is about 1.5 years; delays in planning for and obtaining new equipment are generally shorter. For the present simulations, time for orders in planning and delivery delay for labor are each set at .1 years; time for orders in planning and delivery delay for capital (plant and equipment) are respectively set at .3 years and 1 year.

The shipping equation in the consumer-goods sector model includes one parameter -- the exponent for shipment ES. Recall that shipment $SHIP_t$ equals backlog $B_t$ divided by delivery delay $DD_t$

$$SHIP_t = B_t/DD_t$$  \hspace{1cm} \text{(Equation 4-2, repeated)}

where,

$$DD_t = NBC \cdot MDD_t$$  \hspace{1cm} \text{(Equation 4-3, repeated)}

$$MDD_t = \left(\frac{DSB_t}{DSI_t}\right)^{ES}$$  \hspace{1cm} \text{(A-5)}

$$DSB_t = B_t/NBC$$  \hspace{1cm} \text{(A-6)}

$$DSI_t = IO_t/NIC$$  \hspace{1cm} \text{(A-7)}
Interpreting the equations determining shipments, we see that desired shipments for backlog DSB gives the shipment rate the sector would like to maintain given current backlog. Likewise, desired shipments for inventory DSI gives the shipment rate that would allow inventory coverage to equal normal inventory coverage NIC. When DSB increases above DSI, signaling a desired shipments for backlog higher than can be supported by current inventory, MDD exceeds unity. When MDD exceeds unity, delivery delay DD rises above normal backlog coverage NBC, and shipments fall below what could be shipped if delivery delay equalled NBC. Conversely, DSI above DSB signals excess inventories and leads to a reduction in delivery delay and consequent increase in shipments.

Combining the above equations shows that the shipping equation has the following Cobb-Douglas form:

\[ \text{SHIP}_t = \left( \frac{B_t}{\text{NBC}} \right)^{1-ES} \left( \frac{I0_t}{\text{NIC}} \right)^{ES} \quad (A-8) \]

The above equation shows that the exponent for shipments determines whether shipments respond more rapidly to changes in inventories or backlog.

ES can be estimated by regression on a logarithmic transformation of Equation (A-8). (Note that data for B and IO measure end-of-period stocks; hence IO and B appear as lagged variables in equation A-9.) The equation for estimation is:
\[
\log \text{SHIP}_t = k_0 + (1-\text{ES}) (\log B_{t-1} - \log \text{IO}_{t-1}) + \log \text{IO}_{t-1} \quad (A-9)
\]

where \(k_0 = \log((1/\text{NBC})^{1-\text{ES}} (1/\text{NIC})^{\text{ES}})\) \quad (A-10)

However, implausible estimates are obtained when the regression is run using total nondurables data, apparently due to incomplete backlog data. Consequently, ES is estimated using data for household appliances, radio, and TV, a three digit industry group which represents a typical consumer-goods industry and appears to provide superior backlog and inventory statistics to those available for more aggregate industry groups. Results of the regression are given below (standard errors of estimates in parentheses):

\[
\log \text{SHIP}_t = 0.60 + 0.22 (\log B_{t-1} - \log \text{IO}_{t-1}) + \log \text{IO}_{t-1}
\]

(0.06) (0.07)

On the basis of the above results, a value of 0.75 for ES is chosen.\(^7\)

Such a value for ES suggests that shipments in a typical consumer-goods

\(^7\)Data for backlogs of unfilled orders for output are not collected for some nondurable industries (such as textile mill products) and only partial data are collected for other industries.

\(^8\)As a check on the consistency of the regression, the above estimate for ES can be combined with estimates for NIC and NBC obtained directly from the household appliances data to provide a second estimate of the intercept \(k_0\). The result is:

\[
k_0 = \log ((1/.28)^{.25} (1/.7)^{.75}) = 0.58
\]

which is quite close to the estimated intercept 0.60.
sector are considerably more responsive to changes in inventories than to changes in order backlogs (see Equation A-8). Greater responsiveness to inventories is consistent with the greater (short-term) costs to producers of holding excess inventories versus accumulating excess order backlogs.

Lastly, note that the delay in forming perceived ratio of labor return to cost TPRLRC, designated TPFRC(1) in Table A-3, is reduced from 1 year to 0.75 year. TPRLRC is reduced to keep the parameter shorter than time to perceive ratio of capital return to cost TPRCRC. The rationale for requiring TPRCRC to exceed TPRLRC stems from the greater managerial caution in adjusting capital intensity than in adjusting labor intensity. Managers tend to be more cautious in adjusting capital intensity due to greater expense and, given longer delays in adjusting capital than labor, the more enduring commitment implicit in adjustments in capital intensity.

The third set of parameter changes in Table A-4 correspond to simplifications in the SDNM production sector for the present study. BAF=1 forces the delay for backlog adjustment DBA to equal the perceived delay in the backlog PDB (perceived delivery delay for labor and perceived delivery delay for capital) rather than a weighted sum of PDB and the constant normal delivery delay for factor NDDF. Similarly, SMPF=1 forces DIF to respond to PRFRC rather than a weighted sum of PRFRC and unity. CMPR=1 forces the multiplier from production ratio MPR to respond to the full extent of departures of perceived production ratio
PPR from unity, rather than to respond to only a fraction of (PPR-1).
WIC and WBC equal zero cause desired inventory coverage DIC and desired
backlog coverage DBC to respectively equal the constant normal inventory
coverage NIC and normal backlog coverage NBC. NLI=0 forces loss of
inventory LI to equal zero, and the reduction in NPROD makes the
corresponding reduction in the initial value of production to guarantee
an initial inventory equilibrium. Lastly, the parameter settings for
SOTG and CDOTG simplify the test generator by respectively eliminating
feedback on orders in the test generator from inventory in the test
generator ITG and delivery delay DD in the consumer-goods sector.
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<th>New Value</th>
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<td>1.03 yr.</td>
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<tr>
<td>TPDB(2) Time to Perceive Delay for Backlog (for capital)</td>
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<td>Parameter</td>
<td>Original Value</td>
<td>New Value</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
<td>-----------</td>
</tr>
<tr>
<td><strong>Parameters Outside the Investment Function:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOP(1) Time for Orders in Planning (for labor)</td>
<td>0.25 yr.</td>
<td>0.1 yr.</td>
</tr>
<tr>
<td>NDDW Initial Delivery Delay for Workers</td>
<td>0.15 yr.</td>
<td>0.1 yr.</td>
</tr>
<tr>
<td>TOP(2) Time for Orders in Planning (for capital)</td>
<td>1.5 yr.</td>
<td>0.3 yr.</td>
</tr>
<tr>
<td>NDDC Initial Delivery Delay for Capital</td>
<td>1.5 yr.</td>
<td>1.0 yr.</td>
</tr>
<tr>
<td>ESN Exponent for Shipments in Nation</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>TPPRC(1) Time to Perceive Factor Return to Cost (for labor)</td>
<td>1 yr.</td>
<td>0.75 yr.</td>
</tr>
</tbody>
</table>

<p>| <strong>Parameters to Simplify Model</strong> |               |           |
| BAF(1) Backlog Adjustment for Factor (for labor) | 0.7 | 1 |
| BAF(2) Backlog Adjustment for Factor (for capital) | 0.7 | 1 |</p>
<table>
<thead>
<tr>
<th><strong>Parameter</strong></th>
<th><strong>Original Value</strong></th>
<th><strong>New Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SMPF(1)</strong></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Sensitivity to Marginal Productivity of Factor (for labor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SMPF(2)</strong></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Sensitivity to Marginal Productivity of Factor (for capital)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CMPR(1)</strong></td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Coefficient for Multiplier from Production Ratio (for sector)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WBC(1)</strong></td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Weight for Backlog Coverage (for sector)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WIC(1)</strong></td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Weight for Inventory Coverage (for sector)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NLI(1)</strong></td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>Normal Loss of Inventory (for sector)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NPROD(1)</strong></td>
<td>1030</td>
<td>1000</td>
</tr>
<tr>
<td>Normal Production (for sector)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SOTG</strong></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Switch for Ordering in Test Generator</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CDOTG</strong></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Coefficient for Delay in Ordering in Test Generator</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A.4. SIMPLIFICATIONS IN THE SDNM INVESTMENT FUNCTION FOR ESTIMATION

The equation listing in Table A-2 contains a more general investment function than that tested in the present research. The full investment function described in the production-sector equations includes influences on capital ordering omitted in the present study, as well as several nonlinearities not included when the investment function was estimated. These simplifications were made to facilitate statistical estimation and focus attention on feedback mechanisms involving real (that is, nonfinancial) variables which appear to have the greatest influence on behavior of the consumer-goods sector model. As background for future studies extending the investment function tested above, Table A-5 lists the simplifications required to derive the investment function presented in Chapter 2 from the investment function included in the production-sector model in Table A-2.

The settings for MDO, MMO, and RIPEC identified in Table A-5 correspond to influences omitted from the investment function -- namely, long-term shifts in the availability of capital, liquidity, and expected price changes. These hypothesized influences are omitted entirely when the investment function is estimated in Chapter 3. The influences are inactive during simulations because the input variables (delivery delay for capital, liquidity in the sector, and prices) do not change.

The assumptions concerning TMNCN and TMFCN eliminate two nonlinear limiting conditions from the full investment function. In Table A-2, TMNCN and TMFCN restrict the rate of order starts for capital
TABLE A-5
SIMPLIFICATIONS OF INVESTMENT FUNCTION IN TABLE A-2

<table>
<thead>
<tr>
<th>Simplification in Terms of Model Symbols</th>
<th>Meaning of Simplification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDO = 1</td>
<td>Long-term shifts in availability of capital exert no influence on capital ordering</td>
</tr>
<tr>
<td>(Multiplier from Delay for Ordering)</td>
<td></td>
</tr>
<tr>
<td>MMO = 1</td>
<td>Insufficient or excess liquidity has no effect on capital ordering</td>
</tr>
<tr>
<td>(Multiplier from Money for Ordering)</td>
<td></td>
</tr>
<tr>
<td>TMNCN is linear with unity slope (Table for Multiplier for Negative Correction in Nation)</td>
<td>Capital ordering is not restricted by limits concerning how rapidly capital can be expanded or contracted.</td>
</tr>
<tr>
<td>TMPCN is linear with unity slope (Table for Multiplier for Positive Correction in Nation)</td>
<td></td>
</tr>
<tr>
<td>RIFEC = 1 (Ratio of Inventories of Factor for Expected Cost)</td>
<td>Expected changes in the price of capital does not influence desired capital.</td>
</tr>
<tr>
<td>NLI = 0 (Normal Loss of Inventory)</td>
<td>Producers do not have to replace lost output inventory as part of desired output.</td>
</tr>
<tr>
<td>TCI = TCB = TCIB (Time to Correct Inventory, Time to Correct Backlog)</td>
<td>Producers wish to adjust output inventory and backlog with equal rapidity.</td>
</tr>
<tr>
<td>WIC = 0 (Weight for Inventory Coverage)</td>
<td>Desired inventory coverage is a constant.</td>
</tr>
<tr>
<td>WBC = 0 (Weight for Backlog Coverage)</td>
<td>Desired backlog coverage is a constant.</td>
</tr>
</tbody>
</table>
OSC. For example, TMPCN restricts OSC (measured at a yearly rate) to not exceed the limit for expansion of capital (LRF(2) in Table A-2), which equals one tenth of the current stock of capital in the present model. Similarly, TMNCN restricts OSC to not go below 0.15 of replacement orders for capital (ROF(2) in Table A-2). The nonlinear limiting conditions embodied in TMNCN and TMPCN are omitted when the investment function is estimated, but they are present in simulations.

Assuming normal loss of inventory NLI equals zero eliminates replacement of lost inventory as a component of desired output and thereby simplifies the estimation equation.

Assuming TCI equals TCB reduces the number of parameters to be estimated. This simplification appears to be justified because the quality of available inventory and backlog data is inadequate to derive plausible estimates for the individual parameters TCI and TCB. Backlog data, in particular, are inadequate because order backlogs are not measured for some nondurable industries.

Lastly, setting WIC and WBC to zero forces desired inventory coverage DIC and desired backlog coverage DBC to respectively equal the constant normal coverages. This simplification eliminates two lag distributions from the estimated investment function by eliminating traditional inventory coverage TIC and traditional backlog coverage TBC as influences on DIC and DBC. TIC and TBC are formed as exponential averages of past inventory and backlog coverages in the investment function included in the full SDNM production sector.
This appendix lists all parameter settings and output statements necessary to generate the simulations in the present study. The parameter settings and output statements are grouped into a "rerun dataset," a set of commands which direct the DYNAMO III compiler in generating the desired simulations. When combined with the model equations presented in Appendix A, the rerun dataset generates all simulations presented in Chapters 4 and 5.\footnote{The rerun data set includes one parameter change not noted previously. This entails setting WIC and WBC to 0.3 for all noise runs. When WIC = WBC = 0.3, desired inventory coverage and desired backlog coverage are each determined as a weighted average of a constant normal coverage (normal inventory coverage NIC and normal backlog coverage NBC, respectively) and a traditional coverage (traditional inventory coverage TIC and traditional backlog coverage TBC, respectively). This change is made to decrease the cost of computation only and has little impact on behavior. Inclusion of the traditional coverages increases damping and reduces the amplitude of noise-driven fluctuations, thereby permitting a larger simulation interval (DT in Table A-2).}
TABLE B-1

RERUN DATASET FOR SIMULATIONS IN CHAPTERS 4 AND 5

SENGE.RRN.DATA
00010 NOTE
00020 NOTE RERUN DATASET FOR SIMULATIONS PRESENTED IN "THE SDNM INVESTMENT
00030 NOTE FUNCTION: A COMPARISON TO THE NEOCLASSICAL INVESTMENT FUNCTION"
00040 NOTE DOCTORAL DISSERTATION SUBMITTED TO THE
00050 NOTE ALFRED P. SLOAN SCHOOL OF MANAGEMENT, MIT
00060 NOTE BY PETER M. SENGE
00070 NOTE
00080 NOTE
00090 NOTE PARAMETERS FOR INVESTMENT FUNCTION
00100 NOTE
00110 CP TASHIP=0.5/3
00120 CP TPFRC(2)=1.03
00130 CP TPDB(2)=1.34
00140 CP FSI=0.2
00150 CP TCIF(2)=1.07
00160 CP TCI=0.433
00170 CP TCB=0.433
00180 NOTE
00190 NOTE PARAMETERS OUTSIDE THE INVESTMENT FUNCTION
00200 NOTE
00210 CP TOP(1)=0.1
00220 CP NDDW=0.1
00230 CP TOP(2)=0.3
00240 CP NDDC=1.0
00250 CP ESN=0.75
00260 CP TPFRC(1)=0.75
00270 NOTE
00280 NOTE PARAMETERS TO SIMPLIFY MODEL
00290 NOTE
00300 TP BAF=1/1
00310 TP SMPE=1/1
00320 CP CMPR=1
00330 CP WEC=0
00340 CP WIC=0
00350 CP NLI=0
00360 CP NPROD=1000
00370 CP SOTG=1
00380 CP CDOTG=0
00390 NOTE
00400 NOTE PARAMETERS FOR STEP INPUT IN OTG
00410 NOTE
00420 CP SFTG=0.1
00430 NOTE
00440 NOTE PARAMETERS FOR SIMULATION OUTPUT
00450 NOTE
00460 CP LENGTH=10
00470 CP PLTP1=0.125
00480 CP SAVPER=0.125
00490 PLOTS (F,S), OS(F,S)=S, AF(F,S)=A, RF(F,S)=R/BF(F,S)=B/IF(F,S)=I,
00500 X DIF(F,S)=D/PR(F,S)=P, PRFRC(F,S)=2/DOUT(F,S)=#/GI(F,S)=G
00510 PLOTS (S), PROD(S)=P, SHIP(S)=S, OTG=0, DOUT(1,S)=D/PPR(S)=R/MPR(S)=M/
00520 X I(S)=I, DI(S)=3/B(S)=B, DB(S)=2
00530 RUN F42 (FIGURE 4-2)
00540 C SCI(2,1)=0
00550 C SCB(2,1)=0
00560 CPLT PR(2,1), PR(2,1).F42(0.9,1.3)/AF(2,1), AF(2,1).F42(-75,125)
00570 RUN F45 (FIGURE 4-5)
00580 C SCI(2,1)=0
00590 C SCB(2,1)=0
00600 PLOTS (F,S), OS(F,S)=S, AF(F,S)=A, RF(F,S)=R/BF(F,S)=B/IF(F,S)=I,
00610 X DIF(F,S)=D/PR(F,S)=P, PRFRC(F,S)=S/DOUT(F,S)=#/GI(F,S)=G
00620 PLOTS (S), PROD(S)=P, SHIP(S)=S, OTG=0, DOUT(1,S)=D/PPR(S)=R/MPR(S)=M/
00630 X I(S)=I, DI(S)=3/B(S)=B, DB(2)=2
00640 RUN F46 (FIGURE 4-6)
00650 C CSLA(2)=0
00660 CPLT DIF(2,1), DIF(2,1).F42(800,1200)/OS(2,1), OS(2,1).PMS
00670 RUN F47 (FIGURE 4-7)
00680 C CSLA(2)=0
00690 PLOTS (F,S), OS(F,S)=S, AF(F,S)=A, RF(F,S)=R/BF(F,S)=B/IF(F,S)=I,
00700 X DIF(F,S)=D/PR(F,S)=S, PRFRC(F,S)=2/DOUT(F,S)=#/GI(F,S)=G
00710 PLOTS (S), PROD(S)=P, SHIP(S)=S, OTG=0, DOUT(1,S)=D/PPR(S)=R/MPR(S)=M/
00720 X I(S)=I, DI(S)=D/B(S)=B, DB(2)=2
00730 RUN F48 (FIGURE 4-8)
00740 C SFTG=0
00750 CP RFTG=0.1
00760 CP LENGTH=40
00770 CP PLTP1=0.5
00780 PLOT DIF(2,1)=D, IF(2,1)=C/PR(2,1)=P
00790 RUN F49A (FIGURE 4-9A)
00800 C CGPF(2)=0
00810 PLOT DIF(2,1)=D,IF(2,1)=C/PR(2,1)=P
00820 RUN F49B (FIGURE 4-9B)
00830 C CGPF(2)=0
00840 PLOTS (F,S),OS(F,S)=S,AF(F,S)=A,RF(F,S)=R/EF(F,S)=B/IF(F,S)=I,
00850 X DIF(F,S)=D/PR(F,S)=P,PRFRC(F,S)=2/DOUT(F,S)=G/GI(F,S)=G
00860 PLOTS (S),PROD(S)=P,SHIP(S)=S,OTG=O,DOUT(1,S)=D/PPR(S)=R/MPR(S)=M/
00870 X I(S)=I,DI(S)=D,B(S)=B,DB(2)=2
00880 RUN F410 (FIGURE 4-10)
00890 C SPRFRC(1,1)=0
00900 C SPRFRC(2,1)=0
00910 CP RPTG=0
00920 CP SPTG=0.1
00930 CP LENGTH=10
00940 CP PLTP1=.125
00950 C PLOT DIF(2,1),DIF(2,1),F42(800,1300)/DIF(1,1),DIF(1,1),F42(700,1300)
00960 RUN F411 (FIGURE 4-11)
00970 C SPRFRC(1,1)=0
00980 C SPRFRC(2,1)=0
00990 PLOTS (F,S),OS(F,S)=S,AF(F,S)=A,RF(F,S)=R/EF(F,S)=B/IF(F,S)=I,
01000 X DIF(F,S)=D/PR(F,S)=P,PRFRC(F,S)=1/DOUT(F,S)=G/GI(F,S)=G
01010 PLOTS (S),PROD(S)=P,SHIP(S)=S,OTG=O,DOUT(1,S)=D/PPR(S)=R/MPR(S)=M/
01020 X I(S)=I,DI(S)=3/B(S)=P,DE(S)=2
01030 RUN F412 (FIGURE 4-12)
01040 CP WIC=0.3
01050 CP WBC=0.3
01060 CP DT=0.01
01070 CP SPF=0
01080 CP SDTG=0.05
01090 CP LENGTH=100
01100 CP PLTP1=1.25
01110 CP PRTP1=1
01120 CP SAVPER=0
01130 PRINT IF(2,1),AF(2,1),IF(1,1),PROD(1)
01140 RUN F5152 (FIGURES 5-1 AND 5-2)
01150 C SCI(2,1)=0
01160 C SCB(2,1)=0
01170 C CSLA(2)=0
01180 C CGPF(2)=0
01190 C SPRFRC(1,1)=0
01200 C SPRFRC(2,1)=0
01210 CP PLTP1=0
01220 RUN F510 (FIGURE 5-10)
01230 CP WIC=0
01240 CP WBC=0
01250 C DT=0.0625
01260 C SDNTG=0
01270 CP SPTG=0.1
01280 CP LENGTH=20
01290 CP SAVPER=0.25
01300 C PRTP1=0
01310 RUN F4220  (FIGURE 4-2, EXTENDED TO 20 YEARS)
01320 C SPRFRC(1,1)=0
01330 C SPRFRC(2,1)=0
01340 CP PLTP1=0.25
01350 C PLOT AF(2,1), AF(2,1), F4220(-75,125)/IF(2,1), IF(2,1), F4220(700,1100)
01360 X /IF(1,1), IF(1,1), F4220(950,1750)
01370 RUN F513  (FIGURE 5-13)
01380 C SPRFRC(1,1)=0
01390 C SPRFRC(2,1)=0
01400 C WIC=0.3
01410 C WBC=0.3
01420 C DT=0.01
01430 C SPTG=0
01440 C SDNTG=0.05
01450 C LENGTH=100
01460 C PLTP1=0
01470 C PRTP1=1
01480 C SAVPER=0
01490 RUN F514  (FIGURE 5-14)
01500 C SCI(2,1)=0
01510 C SCB(2,1)=0
01520 C WIC=0
01530 C WBC=0
01540 C SPTG=0.1
01550 C LENGTH=10
01560 C PLTP1=.125
01570 C SAVPER=0.125
01580 C PLOT DIF(2,1), DIF(2,1), F42(800,1300)/AF(2,1), AF(2,1), F42(-75,125)
01590 RUN F515  (FIGURE 5-15)
01600 C SCI(2,1)=0
01610 C SCB(2,1)=0
01620 C WIC=0.3
01630 C WBC=0.3
01640 C DT=0.01
01650 C SDNTG=0.05
01660 C LENGTH=100
01670 C PLTP1=0
01680 C PRTP1=1
01690 C SAVPER=0
01700 RUN P516     (FIGURE 5-16)
01710 C CSLA(2)=0
01720 C WIC=0
01730 C WBC=0
01740 C SFTG=0.1
01750 C LENGTH=20
01760 C PLTP1=0.25
01770 C SAVPER=0.25
01780 CPLOT OS(2,1),OS(2,1).F4220(-75,125)/AF(2,1),AF(2,1).F4220(0,200)
01790 RUN P517     (FIGURE 5-17)
01800 C CSLA(2)=0
01810 C WIC=0.3
01820 C WBC=0.3
01830 C DT=0.01
01840 C SDNTG=0.05
01850 C LENGTH=100
01860 C PLTP1=0
01870 C PRTP1=1
01880 C SAVPER=0
01890 RUN 518     (FIGURE 5-18)
01900 C CGPF(2)=0
01910 C WIC=0
01920 C WBC=0
01930 C SFTG=0.1
01940 C LENGTH=10
01950 C PLTP1=0.125
01960 C SAVPER=0.125
01970 CPLOT OS(2,1),OS(2,1).F42(-75,125)/GI(2,1),GI(2,1).F42(-.03,.05)
01980 X /IF(2,1),IF(2,1).F42(300,1300)
01990 RUN P519     (FIGURE 5-19)
02000 C CGPF(2)=0
02010 C WIC=0.3
02020 C WBC=0.3
02030 C DT=0.01
02040 C SDNTG=0.05
02050 C LENGTH=100
02060 C PLTP1=0
02070 C PRTP1=1
02080 C SAVPER=0
02090 RUN F520  (FIGURE 5-20)
02100 NOTE
02110 NOTE SENSITIVITY TEST NO.1
02120 NOTE
02130 CP TCIFF(2)=0.75
02140 CP NDDC=0.75
02150 CP TCIFF(1)=0.45
02160 CP NDDW=0.15
02170 CP TCI=0.6
02180 CP TCB=0.6
02190 CP WIC=0
02200 CP WBC=0
02210 CP SFTG=0.1
02220 CP LENGTH=20
02230 C PLTP1=0
02240 CP SAVPER=0.25
02250 RUN F5211  (SIMULATION WITH FULL SDNM INVESTMENT FUNCTION
02260 FOR FIGURE 5-21)
02270 C SPRFRC(1,1)=0
02280 C SPRFRC(2,1)=0
02290 C PLTP1=0.25
02300 C PLOT AF(2,1),AF(2,1).F5211(-175,125)/IF(2,1),IF(2,1).F5211(675,1175)
02310 X /IF(1,1),IF(1,1).F5211(950,1950)
02320 RUN F521  (FIGURE 5-21)
02330 CP WIC=0.3
02340 CP WBC=0.3
02350 CP DT=0.01
02360 CP SFTG=0
02370 CP SDNTG=0.05
02380 CP LENGTH=100
02390 CP PLTP1=0
02400 CP PRTP1=1
02410 CP SAVPER=0
02420 PRINT IF(2,1),AF(2,1)
02430 RUN F522A  (FIGURE 5-22A)
02440 C SPRFRC(1,1)=0
02450 C SPRFRC(2,1)=0
02460 RUN F522B (FIGURE 5-22B)
02470 NOTE
02480 NOTE SENSITIVITY TEST NO.2
02490 NOTE
02500 CP TCIFF(2)=1.5
02510 CP NDDC=1.5
02520 CP TCIFF(1)=0.2
02530 CP NDDW=0.075
02540 CP TCI=0.3
02550 CP TCB=0.3
02560 CP WIC=0
02570 CP WBC=0
02580 CP DT=0.25
02590 CP SDNTG=0
02600 CP SPTG=0.1
02610 CP LENGTH=20
02620 CP PRTP1=0
02630 CP SAVPER=0.25
02640 RUN F5231 (SIMULATION WITH FULL SDNM INVESTMENT FUNCTION
02650 FOR FIGURE 5-23)
02660 C SPRFRC(1,1)=0
02670 C SPRFRC(2,1)=0
02680 CP PLTP1=0.25
02690 CPLCT AF(2,1),AF(2,1).F5231(-175,125)/IF(2,1),IF(2,1).F5231(675,1175)
02700 X /IF(1,1),IF(1,1).F5231(950,1950)
02710 RUN F523 (FIGURE 5-23)
02720 CP WIC=0.3
02730 CP WEC=0.3
02740 CP DT=0.01
02750 CP SPTG=0
02760 CP SDNTG=0.05
02770 CP LENGTH=100
02780 CP PLTP1=0
02790 CP PRTP1=0
02800 CP SAVPER=0
02810 PRINT AF(2,1)
02820 RUN F524A (FIGURE 5-24A)
02830 C SPRFRC(1,1)=0
02840 C SPRFRC(2,1)=0
02850 RUN F524B (FIGURE 5-24B)
APPENDIX C: DATA

In order to estimate the SDMM investment function presented in Equation (3-4), data for the following variables are needed:

- order starts for capital
- capital
- shipments
- potential production
- ratio of capital return to cost
  -- price of output
  -- production
  -- cost of capital services
    -- price of capital
    -- normal loss of capital
    -- long-term interest rate
- backlog of unfilled orders
- inventory of output
- delay in the supply line for capital
- supply line for capital

The following presentation discusses the derivation of these data in three groups: capital ordering; capital stock and cost of capital services; and inventory, backlog, shipments, production, and potential production.

C.1. CAPITAL ORDERING

Order Starts. Two possible sources of quarterly data for order starts exist: capital appropriations data compiled by the Conference Board (1953 and later) and "order starts" data compiled by the US Commerce Department, Bureau of Economic Analysis. Both sets of data are available for one- and two-digit industry groups (such as total nondurables, total
durables, electrical machinery and equipment, and textile mill products). The present study utilizes capital appropriations data because it seems to more nearly match the stage of the investment process reflected by "order starts" in the SDNM. Actually, the BEA's "order starts" data corresponds more closely to orders placed for capital OPC in the SDNM (see Figure 1). As Jorgenson (1965) notes, the appropriation decision precedes the actual placing of orders, and therefore comes closest to the order starts decision in the SDNM.¹

The Conference Board appropriations survey estimates appropriations, cancellation of appropriations, unspent appropriations, and capital expenditures for the 1000 largest manufacturing companies (ranked by total assets) based upon reports from approximately two-thirds of those companies. In order to have these data represent entire industry groups, they are scaled by the ratio of BEA investment expenditures data to the Conference Board investment expenditures. For example, data on capital appropriations for all durable manufacturers \(CA_{\text{DUR}}\) are scaled by the ratio of BEA expenditure data for durable manufacturers \(BEA_{\text{DUR}}\) to Conference Board expenditure data for durable

¹One means of verifying that the capital appropriations data measure an order flow which precedes the flow measured by the BEA order starts data is by comparison of the accumulated difference between each and capital expenditures. These data are available as "backlog of unspent capital appropriations" (net of cancellations of appropriations) and "carry-over," respectively. If appropriations precedes order starts, the backlog of capital appropriations should exceed carry-over, which is exactly the case. For the first quarter of 1975, the appropriation backlog exceeded carry-over by factors ranging from 1.2 to 1.8 for various industry groups.
manufacturers CBI\textsubscript{DUR}:

\[
\frac{CAS_{DUR}}{CA_{DUR}} = \frac{BEA_{DUR}}{CBI_{DUR}}
\]  \hspace{1cm} (C-1)

The appropriation data are seasonally adjusted, and deflated to constant 1972 prices by an investment goods price deflator described below.

**Supply Line of Unfilled Orders for Capital.** Data for the supply line of unfilled orders for capital are computed from Conference Board data for backlog of unspent capital appropriations. The unspent appropriations data are scaled and deflated in the manner described above for appropriations data.

**Delay in the Supply Line for Capital.** Data for delay in the supply line for capital are computed as the ratio of supply line of unfilled orders for capital to capital expenditures (BEA data). Underlying this computation is the assumption that expenditures are contemporaneous with arrivals of the new capital. For capital projects in which costs must be met prior to completion (such as many structures), this will underestimate the delivery delay. For projects in which payment lags delivery (such as much equipment), it will overestimate the delivery delay.
C.2. CAPITAL STOCK AND COST OF CAPITAL SERVICES

Capital Stock. Capital stock data for industrial groups can be constructed in a variety of ways. In earlier investment studies using industry-level data, Jorgenson has based capital stock estimates on the BEA Capital Goods Studies (see Wasson et al. 1970) and the IRS's Statistics of Income (see US Department of Treasury). The former contains various yearly estimates of gross and net (i.e., net of depreciation) capital stock for total manufacturing. The latter contains summary balance sheets for each industry group. Jorgenson computes capital stock from the following recursive relationship:

$$\text{CAP}_{t+1} = I_t + (1 - \delta)\text{CAP}_t$$  \hspace{1cm} (C-2)

where $I_t$ is deflated investment expenditures and $\delta$ is the (constant) rate of replacement. He computes the rate of replacement for each industry group by using Equation (C-2) to interpolate between initial and terminal values of capital stock for each group at the beginning of year 1948 and 1960. The initial and terminal values are derived by allocating data on capital stock for all manufacturing (BEA data) to industry groups according to the proportion of manufacturing's depreciable assets within that industry (IRS data).\(^2\)

The present study derives capital stock in a slightly different manner because, at least for the historical period covered by the present

\(^2\)See the statistical appendix to Jorgenson and Stephenson (1967a).
study, the rate of replacement $\delta$ seems to be far from constant. For example, if, following the procedure described by Jorgenson, one uses Equation (C-2) to interpolate between estimates for capital stock in nondurable manufacturing in 1953 and 1968, the value of $\delta$ required to meet the terminal condition causes capital to diminish in absolute terms until 1963! Although capital stock fluctuates about its growth trend, no evidence exists for continuous absolute decline in capital from 1953 to 1963.

Rather than compute capital based on an assumed constant rate of replacement, the present study derives annual estimates of capital for each industry group based on the BEA capital stock data from 1953 to 1968. Capital stock data for all manufacturing are allocated to each industrial category in accordance with its proportion of total depreciable assets in that year. Quarterly data are derived by interpolating between annual values. Data for capital stock and expenditures are then used to compute a variable $\delta$ for each quarter 1953,1 to 1967,4 (using Equation C-2). (The resulting series for total nondurable manufacturing varies between 2.8% per quarter and 5.3% per quarter, underscoring the inappropriateness if assuming a constant rate of replacement.) To obtain estimates for industry capital from 1968 to 1975, Equation (C-2) was projected forward from the first quarter of 1968 using the average $\delta$ for each industry from 1960,1 to 1967,4. Capital stock data are deflated to constant 1972 prices.
Cost of Capital Services. Hall and Jorgenson (1967) define the rental cost of capital as a function of a price deflator for investment goods q, the rate of replacement of capital $\delta$, the (opportunity) cost of capital r, and aspects of the corporate tax structure. Bischoff (1971) and others have included capital gains due to the rate of inflation in computing the rental cost of capital. The present study ignores the taxation variables and inflation and simply defines CCS as follows:

$$CCS_t = q_t(\delta_t + r_t)$$

(C-3)

where r is a corporate bond rate (Moody's AAA corporate bond rate).

The price deflator for investment goods q is computed as a weighted average of the implicit deflators for producer's durables and for structures from the US National Income and Product Accounts. From 1959,1 on, the weights used to construct q come from quarterly data on the Proportion of Appropriations for Plant, as estimated by the Conference Board. For the period 1953,1 to 1958,4, Jorgenson's procedure of forming weights based on annual BEA estimates of equipment and plant investment (see Jaszi et al. 1962) is followed. The investment deflator equals 1 in 1972.

C.3. INVENTORY, BACKLOG, PRICE OF OUTPUT, SHIPMENTS, PRODUCTION, AND POTENTIAL PRODUCTION

Quarterly data on inventories of product, backlogs of unfilled orders for product, and shipments of product are compiled by the Bureau of the Census and are published monthly in the Survey of Current Business.
The data are deflated to constant 1972 dollars by the Labor Department's wholesale price indices for the respective industry groups considered in the present study (nondurable manufactured goods, durable manufactured goods, textile mill products and electrical machinery and equipment). The same price indices are used to measure price of output in computing ratio of capital return to cost. It should be noted that data for backlogs of unfilled orders for product are unavailable for some nondurable industries, such as textile mill products. Consequently, the backlog correction which influences desired output in the SDNM investment function is omitted in regressions for textile mill products.

Data for production are based on the Federal Reserve Board's production index. The index equals 100 in 1967. In order to convert the production index into a measure which can be compared directly to data for inventory, backlog, and shipments, the production index is scaled by the mean ratio of value added (in 1972 dollars) to the production index. That is, production data are formed as the product of the Federal Reserve Board production index $Q_{FRB}$ and a constant $k$. $k$ equals the mean value of the ratio of value added $VA$ to $Q_{FRB}$. Value added $VA$ equals shipments plus change in inventory output $IO$:

$$\text{PROD}_t = Q_{FRB}_t \cdot k$$  \hspace{1cm} (C-4)

$$k = \text{mean} \frac{VA_t}{Q_{FRB}_t}$$  \hspace{1cm} (C-5)
\[ \text{VA}_t = \text{SHIP}_t + \Delta(\text{IO}_t) \]  
(C-6)

Equation (C-4) gives production measured in 1972 dollars, the same unit of measure for inventory, backlog, and shipments.

Data for potential production PP are constructed from data for production and an index of capacity utilization \( U(U = 1.0 \text{ implies full utilization}) \):

\[ \text{PP}_t = \frac{\text{PROD}_t}{U_t/\text{NU}} \]  
(C-7)

\[ \text{NU} = \text{mean } (U_t) \]  
(C-8)

where NU denotes normal utilization. The above measure of potential production is consistent with the definition of potential production in the SDNM (see Equation 4-1). In the SDNM, potential production equals the amount of production achieved when all factors of production are normally utilized.\(^3\) In Equation (C-7), data for potential production exceed production data whenever utilization \( U \) is below normal utilization NU. Data for PP fall below PROD data whenever \( U \) is above NU. Hence, potential production is measured as the rate of production after correcting for non-normal capacity utilization.

\(^3\) The term "potential production" is a misnomer in the present model because it implies a maximum rate of production, yet PP equals the rate of production at normal factor utilization. This inconsistency disappears in the full SDNM production sector because factor utilization is determined for each factor individually prior to combining the factors in the Cobb-Douglas production function.
Two data sources were employed to construct data for capacity utilization: (1) quarterly indices for capacity utilization in total durable and total nondurable manufacturing published by the Wharton Econometric Forecasting Agency and (2) quarterly data for capacity utilization in two digit industry groups collected by the U.S. Department of Commerce. The Wharton data span from 1947 to the present but are unavailable for two-digit industry groups such as textile mill products and electrical machinery and equipment manufacturers. The Commerce Department data measure utilization in two-digit industry groups but are available only since 1968. For the years 1953 to 1968, nondurable manufacturing data must be substituted for textile mill products data, and durable manufacturing data must be substituted for electrical machinery and equipment data. To make the Commerce Department data from 1968 on compatible with the Wharton data, the Commerce data are scaled by the mean ratio of the Wharton data to the Commerce data from 1968 on. For example, data for capacity utilization in textile mill product manufacturers from 1953 to 1968 equal data for capacity utilization in total nondurables. From 1968 on, data for capacity utilization in textile mill products $U_{\text{TEX}_t}$ equal Commerce Department utilization data $\text{COMU}_{\text{TEX}_t}$ multiplied by a scale factor $k$ which equals the mean ratio of Wharton nondurable utilization rates $\text{WHARU}_{\text{NONDUR}_t}$ to $\text{COMU}_{\text{TEX}_t}$.
1968--

\[ U_{TEX_t} = COMU_{TEX_t} \cdot k \quad \text{(C-9)} \]

\[ k = \text{mean} \left( \frac{WHARU_{NONDUR_t}}{COMU_{TEX_t}} \right) \quad \text{(C-10)} \]

The scale factor \( k \) serves to adjust for differences in the two sources of utilization data.\(^4\)

\(^4\) Differences apparently exist between the way capacity utilization is defined by the Commerce Department and Wharton. For example, the mean value of \( U \) for total nondurables from the first quarter of 1968 to the fourth quarter of 1976 equaled 0.942 as measured by Wharton and 0.836 as measured by the Commerce Department.
APPENDIX D: ESTIMATION PROBLEMS POSED BY THE DELAY STRUCTURE OF SYSTEM DYNAMICS MODELS

The complex delay structure of the SDNM investment function presents estimation problems which are common to system dynamics models. In particular, system dynamics models typically include multiple delayed variables and nonlinear combinations of delayed variables. Such formulations arise because of the "available information" principle in system dynamics which requires that only information actually available to decision-makers can serve as inputs to decision-points in a model (see Section V of Chapter 2). Though the principle is important for understanding observed behavior, it leads to difficult distributed lag estimation problems.

This Appendix identifies the types of estimation problems which arise in the SDNM investment function, discusses why they arise, and considers the applicability of conventional econometric distributed lag techniques for such formulations. The discussion serves as a general introduction to the problems of distributed lag estimation of system dynamics models.
D.1 ESTIMATION PROBLEMS POSED BY THE SDNM INVESTMENT FUNCTION

Chapter 3 stated that the SDNM investment function can be expressed for estimation as follows (with parameters grouped as coefficients $K_1, K_2, K_3, K_4$):

$$\text{OSC}_t = K_1 \cdot \text{CAP}_t \cdot (\text{ASHP}_t/\text{PP}_t) \cdot \text{PRCRC}_t + K_2 \cdot \text{CAP}_t \cdot \left(\frac{(B_t - I_0_t)}{\text{PP}_t}\right) \cdot \text{PRCRC}_t$$

$$+ K_3 \cdot \text{CAP}_t + \text{CAP}_t \cdot \text{EGS}_t + K_4 \cdot \left(\text{CAP}_t \cdot [\text{NLC} + \text{EGS}_t] \cdot \text{PDSLCl}_t - \text{SLC}_t\right) + \varepsilon_t$$

(Equation 3-1)

where $\varepsilon_t$ represents a stochastic error process.

**Multiple Delayed Variables.** The SDNM investment function shown above includes five separate delayed variables. Multiple delays occur as a result of the system dynamics modeling principle which requires that only information actually available to decision-makers can be inputs to decision points in a model. The available information principle leads to identifying variables such as shipments, the ratio of capital return to cost, delivery delay for capital, and long-term trends in shipments which, because of imperfect information on current conditions and caution in reacting to perceived changes in conditions, only influence investment decisions after appreciable delays. However, as will be shown below, multiple delayed variables alone do not pose especially difficult estimation problems. The difficulties for estimation posed by the SDNM investment function stem from the ways in which delayed variables combine to influence capital ordering.
Products of Delayed and Contemporaneous Variables. Several coterms in Equation (3-1) include the products of delayed and contemporaneous variables.\(^1\) For example, the cterm of \(K_2\) includes the product of capital \(CAP\), backlog \(B\) minus inventory of output \(IO\) divided by potential production \(PP\), and perceived ratio of capital return to cost \(PRCRC\). The last variable \(PRCRC\) represents perceptions of the nonoptimality of current factor proportions. Because beliefs that current factor proportions should be adjusted in a particular way respond only slowly to changes in optimal factor mix or to departures from unchanged optimal conditions, \(PRCRC\) is formed as a delayed or smoothed value of the ratio of capital return to cost \(RCRC\) (the a priori smoothing time equals 2 years in the SDNM). Delays in perceiving other variables entering the cterm of \(K_2\), such as output inventory and backlog conditions, are much shorter than delays in perceiving nonoptimal factor proportions. Therefore, current values of the other variables multiply \(PRCRC\) in the cterm. Other products of delayed and contemporaneous variables occur in the \(K_1\) and \(K_4\) coterms and in the product of capital and expected growth in shipments (which enters the equation with a unity coefficient).

\(^1\) A cterm is the combination of variables which multiplies a coefficient to be estimated. For example, the cterm for the coefficient \(K_1\) in Equation (3-1) is \(CAP_t \cdot (ASHIP_t / PP_t) \cdot PRCRC_t\).
Multiple Occurrences of Delayed Variables. Equation (3-1) includes two delayed variables, perceived ratio of capital return to cost PRCRC and expected growth in shipments EGS, which enter more than one coterms. PRCRC enters the K1- and K2 coterms as a consequence of expressing the nonlinear SDNM formulation for desired capital (Equation 2-6) in a "linear-in-the-parameters" format convenient for statistical estimation. EGS enters the equation in two places because the SDNM formulation hypothesizes two influences of growth expectations--an influence on the desired rate of capital expansion and an influence on the desired backlog of unfilled orders for capital.

Products of Delayed Variables. Equation (3-1) includes two products of delayed variables. The coterms of K1 includes the product of average shipments ASHIP and the perceived ratio of capital return to cost PRCRC. The coterms of K4 includes the product of expected growth in shipments EGS and perceived delay in the supply line for capital PDSLC. In both cases, capital ordering responds to the product of two separate delayed variables (rather than to a delayed value of the product) because the delayed variables represent distinct inputs to investment decision-making. Consider the product of ASHIP and PRCRC in the K1 coterms as an example. Average shipments represents investor's production goal in the absence of output inventory and backlog imbalances and perceived growth trends. Perceived ratio of capital return to cost, on the other hand, reflects desires to produce with a more profitable factor mix. Because the two variables represent separate influences on investment decision-
making, they enter Equation (3-1) as separate delayed variables.

**Ratios of Delayed Variables.** Expected growth in shipments EGS, as determined in the SDNM, depends on the ratio of two delayed variables, short-term average shipments STASHIP and long-term average shipments LTASHIP:

\[
E_{GS_t} = \frac{1}{T_{LTAS}} \frac{STASHIP - LTASHIP}{LTASHIP} 
\]

(Equation 2-20, repeated)

where \( T_{LTAS} \) equals the time for long-term averaging of shipments, the delay time involved in forming LTASHIP from STASHIP. Because EGS enters into two coterms in Equation (3-1), each coterms implicitly includes the ratio of two delayed variables.
D.2 APPLICABILITY OF DISTRIBUTED-LAG ESTIMATION TECHNIQUES FOR THE SDNM INVESTMENT FUNCTION

This section considers the applicability of conventional distributed-lag estimation techniques for each of the estimation problems posed by the SDNM investment function. The analysis considers the two most widely used econometric distributed lag techniques, the Koyck method and the polynomial-distributed lag (PDL) method developed by Almon (1965), and an approach proposed by Bischoff (1971a) which estimates an approximation to the product of two lag distributions. The analysis shows that all the techniques apply only to a limited extent for the SDNM lag structure. Both the Koyck and PDL approaches can be used to estimate the product of a delayed variable and contemporaneous variables, but only the PDL approach can be applied with confidence to multiple products of delayed and contemporaneous variables. Neither approach readily applies to multiple occurrences of a delayed variable in different coterms, or to products or ratios of delayed variables. The approach proposed by Bischoff for estimating the product of two lag distributions has limited applicability to the present study because it fails to provide estimates of the individual distributions.

Koyck Estimation. The Koyck approach to distributed-lag estimation constrains the lag weights \( w_1 \) which characterize a lag distribution

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2 The following presentations provide only a brief overview of the Koyck and PDL methods. For a more detailed survey of alternative distributed-lag estimation techniques see Griliches (1967).
\[ \sum_{i=1}^{\infty} w_i X_{t-i} \] to decline geometrically:

\[ \sum_{i=0}^{\infty} \lambda (1-\lambda)^i X_{t-i} \] (D-1)

When a Koyck lag occurs in a linear equation, the equation can be transformed to eliminate the distributed lag:

\[ Y_t = \beta_0 + \beta_1 \sum (\lambda)(1-\lambda)^i X_{1_{t-i}} + \beta_2 X_{2_t} \] (D-2)

\[ Y_{t-(1-\lambda)Y_{t-1}} = \beta_0 \cdot \lambda + \beta_1 \cdot \lambda \cdot X_{1_t} + \beta_2 \cdot X_{2_t} - \beta_2 (1-\lambda)X_{2_{t-1}} \] (D-3)

Moving \( Y_{t-1} \) to the right-hand side of Equation (D-3) allows one to directly estimate the "Koyck parameter" \((1-\lambda)\), though consistent estimation may require an estimator other than ordinary least squares. From the estimate \((\hat{\lambda})\), one can derive an estimate of the "mean lag" for the Koyck distribution (see Johnston 1972, p. 299):

\[ \text{mean lag} = \frac{\sum w_i \cdot t}{\sum w_i} = (\hat{\lambda})^{-1} - 1 \]

By constraining a lag distribution to decline geometrically, the Koyck method has both strengths and weaknesses. The geometrically declining pattern implies that, in an equation such as Equation (D-2), the greatest impact on \( Y \) of a change \( \Delta X_1 \) occurs in the first period after the change occurs. The effect of \( \Delta X_1 \) on \( Y \) then declines progressively in future periods. Econometricians often view the geometrically declining effect of \( \Delta X_1 \) on \( Y \) as an excessive constraint
to impose on the data. Model-builders often prefer a more "flexible" lag distribution which allows "the data to determine" the shape of a distributed lag. However, imposition of the geometrically declining constraint on the data may lead to a more robust estimate of the mean lag of the distribution than that obtained with more flexible distributed lag techniques, such as the PDL estimation. The robustness of the Koyck method is especially useful in the presence of errors in specifying the equation under consideration or measurement errors in the data.³

The Koyck method has limited applicability for the estimation problems posed by the SDNM investment function. The Koyck method applies to multiple delayed variables only if they enter an equation in a strictly linear manner, or if they enter different coterms multiplied by the same variables, neither of which is the case in the SDNM.⁴ The

³ In a synthetic-data experiment to test the robustness of the Koyck and PDL techniques, I have used both approaches to estimate a lag distribution in an equation similar in format to the SDNM investment function. The estimation equation was perfectly specified. When modest (5%) measurement errors were added to the synthetic data, many statistically significant estimates for the PDL distribution had the incorrect sign, but OLS estimates of the Koyck parameter \((1-\lambda)\) were accurate to within 25% and an IV estimator was accurate to within 8%. (Results available upon request from author.)

⁴ This and the following discussions of distributed lag estimation techniques consider a technique to be applicable to a particular estimation problem if the techniques allows estimates of the parameters of interest using a linear estimator. (That is, all parameters must be recoverable from coefficient estimates of a linear-in-the parameters equation.)
method applies to multiple occurrences of a delayed variable, or to products of delayed variables only as an approximation, and does not apply to the ratio of delayed variables.

The one feature of the SDNM lag structure for which the Koyck method does apply is the product of a delayed variable and contemporaneous variables. Application of the Koyck method in such a case requires a slight modification of the standard Koyck transformation. To illustrate the modified Koyck transformation, consider the following equation containing the product of a contemporaneous variable \( X_{1t} \) and a distributed lag of past values of \( X_{2t} \):

\[
Y_t = \beta_0 + \beta_1 X_{1t} \cdot \sum(\lambda)(1-\lambda)^i X_{2t-i} + \beta_2 X_{3t} \tag{D-4}
\]

The Koyck transformation fails to eliminate the distributed lag in \( X_{2t} \) unless both sides of the lagged equation are multiplied by

\[
Z_t = \frac{X_{1t}}{X_{1t-1}}
\]

\[
Y_t - (1-\lambda) \cdot Z_t \cdot Y_{t-1} = \beta_0 - \beta_0 \cdot (1-\lambda) \cdot Z_t + \beta_1 \cdot \lambda \cdot X_{1t} \cdot X_{2t} + \beta_2 \cdot X_{2t}
\]

\[
-\beta_2 \cdot (1-\lambda) \cdot Z_t \cdot X_{2t-1} \tag{D-5}
\]

\[
Z_t = \frac{X_{1t}}{X_{1t-1}}
\]

Estimation of the modified Koyck equation leads directly to an estimate of the Koyck parameter \((1-\lambda)\) which characterizes the lag distribution for \( X_{2t} \).
If one attempts to apply the Koyck method to multiple products of a delayed variable and contemporaneous variables, or to multiple occurrences of a delayed variable, an approximation must be made. To see the possible errors induced by the approximation consider the following equation with two products of delayed and contemporaneous variables:

\[ Y_t = \beta_0 + \beta_1 X_{1t} \cdot \sum (1-\lambda)^i X_{2t-i} + \beta_2 X_{3t} \cdot \sum (1-\alpha)^i X_{4t-i} \]  

(D-6)

After a modified Koyck transformation, Equation (D-6) can be expressed as follows:

\[ Y_t - (1-\lambda) Z_{1t} \cdot Y_{t-1} = \beta_0 - \beta_0 (1-\lambda) Z_{1t} + \beta_1 \lambda X_{1t} X_{2t} + \]

\[ + \beta_2 X_{3t} \cdot \sum (1-\alpha)^i X_{4t-i} \]

(D-7)

\[ Z_{1t} = X_{1t} / X_{t-1} \]

In Equation (D-7), the lag distribution for \( X_4 \) appears in two different coterms. A second modified Koyck transformation fails to eliminate both occurrences of the \( X_4 \)-lag distribution unless one assumes that

\[ Z_{1t} \cdot X_{3t} = X_3 \text{, or } \frac{X_{1t}}{X_{t-1}} = \frac{X_{3t}}{X_{3t-1}} \]

If such an assumption is made, an equation of the following form is estimated:
\[
Y_t = [(1-\lambda)Z^{1}_{t} + (1-\alpha)Z^{2}_{t}]Y_{t-1} + (1-\lambda)(1-\alpha)Z^{1}_{t}Z^{2}_{t}Y_{t-2} = \\
= \beta_0 - \beta_0(1-\lambda)Z^{1}_{t} - \beta_0(1-\alpha)Z^{2}_{t} + \beta_0(1-\lambda)(1-\alpha)Z^{1}_{t}Z^{2}_{t} \\
+ \beta_1\lambda X^{1}_{t}X^{2}_{t} - \beta_1\lambda(1-\alpha)Z^{2}_{t}X^{1}_{t-1}X^{2}_{t-1} \\
+ \beta_2\alpha X^{3}_{t}X^{4}_{t} - \beta_2(1-\lambda)\alpha Z^{3}_{t}X^{3}_{t-1}X^{4}_{t-1} \\
\text{(D-8)}
\]

\[
Z^{1}_{t} = \frac{X^{1}_{t}}{X^{1}_{t-1}} \\
Z^{2}_{t} = \frac{X^{3}_{t}}{X^{3}_{t-1}}
\]

If the above assumption is not strictly correct, Equation (D-8) holds only as an approximation, and the terms in the two lag distribution (in Equation D-7) which fail to cancel become subsumed into the error process. The resulting error process will be highly autocorrelated and correlated with current and lagged values of most coterms.\(^5\) (Note that the above analysis also applies to equations with multiple occurrences of a delayed variable, which happens in Equation D-7).

\(^5\)If one attempts to estimate the transformed equation with an instrumental variable estimator, such an error process makes selection of appropriate instruments extremely difficult. Only the \(X^{1}_{t} \cdot X^{2}_{t}\) and \(X^{1}_{t-1} \cdot X^{2}_{t-1}\) coterms can be used in constructing instruments since current and past values of all other coterms are highly correlated with the error process.
If the errors induced by estimating Equation (D-8) are not too great, or if another method is available to estimate multiple products of a delayed variable and a contemporaneous variable, the Koyck method can be applied to the product of delayed variables. By applying a second type of modified Koyck transformation, a product of two Koyck lag distributions can be transformed into an additive combination of the distributions. To illustrate the modified transformation, consider the following equation with the product of two Koyck lag distributions:

\[ Y = \beta \cdot \Sigma \lambda \cdot (1-\lambda)^i X_{1, t-i} \cdot \Sigma \alpha \cdot (1-\alpha)^i X_{2, t-i} \]  

(D-9)

The following transformation converts the Equation (D-9) into an additive combination of the \(X_1\) and \(X_2\) lag distributions:

\[ Y_t - (1 - \alpha)(1 - \lambda)Y_{t-1} = \sum_{i=0}^{\infty} \alpha(1-\alpha)^i X_{1, t-i} \cdot \sum_{i=0}^{\infty} \lambda(1-\lambda)^i X_{2, t-i} \]

\[ - \sum_{i=0}^{\infty} \alpha(1-\alpha)^{i+1} X_{1, t-1-i} \cdot \sum_{i=0}^{\infty} \lambda(1-\lambda)^{i+1} X_{2, t-1-i} \]

\[ = \alpha \cdot \lambda[X_1 \cdot \sum_{i=0}^{\infty} (1-\lambda)^i X_{2, t-i} \]

\[ + X_2 \cdot \sum_{i=0}^{\infty} (1-\alpha)^i X_{1, t-i} - X_1 \cdot X_2 \]

\[ + \sum_{i=1}^{\infty} (1-\alpha)^i X_{1, t-i} \cdot \sum_{i=1}^{\infty} (1-\lambda)^i X_{2, t-i} \]

\[ - \sum_{i=0}^{\infty} (1-\lambda)^{i+1} X_{1, t-1-i} \cdot \sum_{i=0}^{\infty} (1-\lambda)^{i+1} X_{2, t-1-i} \]  

(D-11)
(cancelling the last two summands in Equation 3-11)

\[ Y_t - (1 - \alpha)(1 - \lambda)Y_{t-1} = \alpha \cdot \lambda \cdot X_{1_t} \cdot \sum_{i=0}^{\infty} (1 - \alpha)^i X_{2_{t-i}} \]

\[ + \alpha \cdot \lambda \cdot X_{1_t} \cdot \sum_{i=0}^{\infty} (1 - \alpha)^i X_{2_{t-i}} \]

\[ = \alpha \cdot \lambda \cdot X_{1_t} \cdot \sum_{i=0}^{\infty} (1 - \alpha)^i X_{2_{t-i}} \]  \hspace{1cm} (D-12)

The lag structure in Equation (D-12) belongs to the class discussed above—multiple products of delayed and contemporaneous variables. As noted above, such a formulation can be estimated by the Koyck method only by making a simplifying assumption. Estimation of such a formulation by the PDL approach is discussed below.

**Polynomial-Distributed Lag (PDL) Estimation.** The PDL approach constrains the lag weights \( w_i \) of a lag distribution to lie along a polynomial of a specified degree \( n \):

\[ w_i = \gamma_0 + \gamma_1 \cdot i^1 + \gamma_2 \cdot i^2 + \ldots + \gamma_n \cdot i^n \]  \hspace{1cm} (D-13)

Applying the PDL approach to a linear equation containing a lag distribution with \( N \) terms,

\[ Y_t = \beta_0 + \beta_1 \cdot \sum_{i=0}^{N} w_i \cdot X_{1_{t-i}} + \beta_2 \cdot X_{2_t} \]  \hspace{1cm} (D-14)

leads to the following equation for estimation:

\[ Y_t = \beta_0 + \beta_1 \cdot \left[ \gamma_0 \cdot \overline{X}_t^0 + \gamma_1 \cdot \overline{X}_t^1 + \gamma_2 \cdot \overline{X}_t^2 + \ldots + \gamma_n \cdot \overline{X}_t^n \right] + \]

\[ + \beta_2 \cdot X_{2_t} \]  \hspace{1cm} (D-15)
where

\[
\begin{align*}
\bar{X}_t^0 &= X_{t} + X_{t-1} + \ldots + X_{t-N} \\
\bar{X}_t^{-1} &= X_{t-1} + 2 \cdot X_{t-2} + \ldots + N \cdot X_{t-N} \\
\bar{X}_t^{-2} &= X_{t-2} + 2^2 \cdot X_{t-3} + \ldots + N^2 \cdot X_{t-N} \\
& \vdots \\
\bar{X}_t^{-n} &= X_{t-n} + 2^n \cdot X_{t-(n+1)} + \ldots + N^n \cdot X_{t-N}
\end{align*}
\]

Because the "scrambled variables" \(\bar{X}_t^0, \ldots, \bar{X}_t^{-n}\) can be formed prior to estimation, PDL reduces the number of distributed-lag parameters to be estimated from \(N+1\), the number of lag weights, to \(n\), the degree of the polynomial. If the parameter \(\beta_1\) is known, the PDL parameters \(\gamma_0, \gamma_1, \ldots, \gamma_n\) can be estimated directly in Equation (D-15), and the lag weights \(w_i\) can be computed using Equation (D-13). If \(\beta_1\) is unknown, the products \(\beta_1 \cdot \gamma_0, \beta_1 \cdot \gamma_1, \ldots, \beta_1 \cdot \gamma_n\) can be estimated from Equation (3-15) and the products \(\beta_1 \cdot w_i\) can be computed. (In most cases, the constraint \(\sum w_i = 1\) can be imposed to then compute \(\beta_1\).)

The PDL approach has a great advantage in flexibility over the Koyck approach. Given a polynomial of sufficiently high degree, PDL estimation can fit any possible pattern of lag weights. Moreover, as will be shown below, PDL is more able than the Koyck approach to accommodate nonlinear combinations of delayed and contemporaneous variables and multiple delayed variables. However, when applying the PDL approach, the gain in flexibility may be nullified by loss in
robustness. Because no constraints are imposed on the shape of the
PDL lag distribution, PDL results can be quite sensitive to errors in
data or model specification (see footnote #3 above). Schmidt and
Waud (1973) have shown similar sensitivity of PDL results to changes in
the assumed degree \( n \) and length \( N \) of the lag distribution.

Relative to the estimation problems posed by the SDNM investment
function, PDL estimation is somewhat more versatile than the Koyck
approach. In particular, PDL estimation applies readily to single or
multiple occurrences of products of delayed and contemporaneous variables.

For example, PDL estimation of an equation of the form

\[ Y_t = \beta_0 + \beta_1 \cdot X_{1t}^{\text{N}} \cdot \sum_{i=1}^{N} w_i \cdot X_{2t-1}^{\text{M}} + \beta_2 \cdot X_{3t}^{\text{M}} \cdot \sum_{i=1}^{M} v_i \cdot X_{4t-1}^{\text{M}} \]  \hspace{1cm} (D-16)

results in the following equation for estimation:

\[ Y_t = \beta_0 + \beta_1 \cdot \left[ \gamma_0 \cdot X_{1t}^{\t \text{0}} + \gamma_1 \cdot X_{1t}^{\t \text{1}} \cdot X_{2t}^{\t \text{1}} \right] + \cdots + \gamma_n \cdot X_{1t}^{\t \text{n}} \cdot X_{2t}^{\t \text{n}} \]

\[ + \beta_2 \cdot \left[ \mu_0 \cdot X_{3t}^{\text{0}} \cdot X_{4t}^{\text{0}} + \mu_1 \cdot X_{3t}^{\text{1}} \cdot X_{4t}^{\text{1}} \right] + \cdots + \mu_m \cdot X_{3t}^{\text{m}} \cdot X_{4t}^{\text{m}} \]  \hspace{1cm} (D-17)

where \( \gamma_0, \ldots \gamma_n \) and \( \mu_0, \ldots \mu_m \) are the PDL parameters and
\( X_2^0, \ldots X_2^n \) and \( X_4^0, \ldots X_4^m \) are the respective scrambled variables for
the \( X_2^- \) and \( X_4^- \) lag distributions. Equation (D-17) is no more
difficult to estimate than the linear case, Equation (D-15).

If the same delayed variable appears in two different coterms,
PDL estimation is more difficult to apply because the two lag distribu-
tions must be constrained to lie along the same polynomial. In
general, estimating such a formulation by PDL leads to a nonlinear
estimation problem.

Nonlinear estimation likewise generally results from application of the PDL method to a product of two lag distributions. Given an equation of the form

\[ Y_t = \beta_1 \sum_{i=0}^{N} \omega_i X_{1,t-i} \cdot \sum_{i=0}^{M} \nu_i X_{2,t-i} \]  \hspace{1cm} (D-18)

the PDL approach leads to the following equation for estimation:

\[ Y_t = \beta_1 [\gamma_0 \cdot \bar{X}_{1_t}^0 + \gamma_1 \cdot \bar{X}_{1_t}^1 + \ldots + \gamma_n \cdot \bar{X}_{1_t}^n ] \cdot [\mu_0 \cdot \bar{X}_{2_t}^0 + \mu_1 \cdot \bar{X}_{2_t}^1 + \ldots + \mu_m \cdot \bar{X}_{2_t}^m ] \]  \hspace{1cm} (D-19)

If one converts equation (D-19) into a linear-in-the-parameters form, there will be \((n+1)\cdot(m+1)\) coefficients (such as \(\beta_1 \cdot \gamma_0 \cdot \mu_0\)) to estimate. Moreover, it will not in general be possible to recover unique estimates of the individual PDL parameters, \(\gamma_0, \ldots, \gamma_n\) and \(\mu_0, \ldots, \mu_m\), from the coefficient estimates. Hence, the PDL approach will generally require nonlinear estimation to uniquely identify the weights for the individual lag distributions.

As an alternative, one might combine the PDL approach with the modified Koyck transformation presented above to estimate the product of two lag distributions. Recall that, by applying a modified Koyck transformation, the product of two lag distributions can be converted into a sum of two distributions, with each multiplied by a different contemporaneous variable (e.g., Equation D-12). The preceding discussion shows that PDL estimation can be applied directly to such an equation.
(Equations D-16, D-17). The usefulness of the combined Koyck-PDL approach has not been explored in the present approach because the two polynomially distributed lags applied to an equation of the form of Equation (D-12) should, in principle, be constrained to have geometrically-declining weights. Imposing such a constraint leads to a nonlinear estimation problem. PDL estimation, like the Koyck approach, is unable to estimate the ratio of lag distributions without resorting to a nonlinear estimation technique.

Other Techniques. Charles Bischoff's study of alternative investment-function lag distributions (Bischoff 1971a) warrants attention here because of the similarity between estimation problems posed by the SDNM investment function and estimation problems considered by Bischoff. Specifically, Bischoff considered an investment function involving the product of two lag distributions—one reflecting changes in desired output and one reflecting changes in desired capital-output ratio. Bischoff's approach to estimating the product of the two lag distribution entails estimating two distributed lags of products of the underlying variables.
To illustrate the approach, consider that the product of two lag distributions

\[ \sum_{i} w_{i} \cdot X_{1,t-i} \cdot \sum_{j} v_{j} \cdot X_{2,t-j} \]

is a special case of the more general "second-order lag distribution":

\[ \sum_{ij} u_{ij} \cdot X_{1,t-i} \cdot X_{2,t-j} \]

where \( u_{ij} = w_{i} \cdot v_{j} \)

Recognizing that estimation of the second-order lag distribution is not generally possible, Bischoff estimates the following sum of two lag distributions:

\[ \sum_{i} w'_{i} \cdot X_{1,t-i} \cdot X_{2,t-j} + \sum_{j} v'_{j} \cdot X_{1,t-j} \cdot X_{2,t-(j-1)} \]

The value of Bischoff's approach lies in the test provided for the hypothesis of separate distributed lags for \( X_{1} \) and \( X_{2} \). Consider the case if the hypothesis is wrong—that is, if the hypothesized product of separate lag distributions for \( X_{1} \) and \( X_{2} \) should be replaced by a single distributed lag for the product of \( X_{1} \) and \( X_{2} \):

\[ \sum_{i} w''_{i} \cdot X_{1,t-i} \cdot X_{2,t-i} \]

If the hypothesis of separate lag distributions is incorrect, all "off-diagonal" weights in the second-order lag distribution -- \( u_{ij} \), \( i \neq j \) -- equal zero. This implies that the weights \( v'_{j} \) in Bischoff's estimated sum
of lag distributions are likewise zero. Hence, by estimating the sum of two distributed lags of products of the underlying variables $X_1$ and $X_2$, where one of the two distributed lags involves only products of the form $X_{1_{t-1}} \cdot X_{2_{t-1}}$, one can test the hypothesis of separate lag distributions of $X_1$ and $X_2$.

Although Bischoff's approach provides a test for the hypothesis that two lag distributions combine multiplicatively, it does not lead to estimates of the individual lag distributions. For this reason, the approach has only limited usefulness for the present study. In order to utilize estimation results in subsequent simulations of the SDNM production-sector model, estimates of individual lag distributions are required. Estimates for the individual lag distributions are necessary because several delayed variables in the SDNM investment function, such as average shipments and expected growth in shipments, influence production-sector decisions other than capital ordering.


<table>
<thead>
<tr>
<th>Author(s) (Year)</th>
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