INFORMATION TO USERS

This reproduction was made from a copy of a document sent to us for microfilming. While the most advanced technology has been used to photograph and reproduce this document, the quality of the reproduction is heavily dependent upon the quality of the material submitted.

The following explanation of techniques is provided to help clarify markings or notations which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting through an image and duplicating adjacent pages to assure complete continuity.

2. When an image on the film is obliterated with a round black mark, it is an indication of either blurred copy because of movement during exposure, duplicate copy, or copyrighted materials that should not have been filmed. For blurred pages, a good image of the page can be found in the adjacent frame. If copyrighted materials were deleted, a target note will appear listing the pages in the adjacent frame.

3. When a map, drawing or chart, etc., is part of the material being photographed, a definite method of "sectioning" the material has been followed. It is customary to begin filming at the upper left hand corner of a large sheet and to continue from left to right in equal sections with small overlaps. If necessary, sectioning is continued again—beginning below the first row and continuing on until complete.

4. For illustrations that cannot be satisfactorily reproduced by xerographic means, photographic prints can be purchased at additional cost and inserted into your xerographic copy. These prints are available upon request from the Dissertations Customer Services Department.

5. Some pages in any document may have indistinct print. In all cases the best available copy has been filmed.

University Microfilms International
300 N. Zeeb Road
Ann Arbor, MI 48106
INTEREST RATE VOLATILITY AND INVENTORY INVESTMENT:
A THEORETICAL AND EMPIRICAL STUDY

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

by

Yea-Mow Chen, B.A., M.A.

The Ohio State University
1984

Reading Committee: Approved by
William G. Dewald
Richard Jensen
Stephen A. McCafferty

William G. Dewald, Adviser
Department of Economics
To My Brother

Yih-Hsiung

Who Brings Me Up To What I Am
ACKNOWLEDGEMENTS

I wish to acknowledge the guidance and comments from my dissertation committee: William Dewald, Richard Jensen, Steve McCafferty, and Huston McCulloch. A special note of gratitude goes to William Dewald, my adviser. His comments and encouragement throughout all stages are invaluable. He also polishes my writing which greatly improves the quality of this dissertation.

This work was made much easier by the cooperation of my wife, Shu-Ru, in taking the burden of daily life and in typing the final draft. My daughter, Elaine, provides much happiness throughout the process.
VITA

April 12, 1953. . . . . . Born - Taiwan, Republic of China

1976. . . . . . . . . . . . . . . . . . . . . . . . B.A., National Taiwan University, Taipei, Taiwan, Republic of China

1976-1978 . . . . . . . . . . . . . . . . . . . . Graduate School, National Taiwan University, Taiwan, Republic of China

1978-1984 . . . . . . . . . . . . . . . . . . . . Teaching and Research Associate, The Ohio State University, Columbus, Ohio

1980. . . . . . . . . . . . . . . . . . . . . . . . M.A., The Ohio State University, Columbus, Ohio

FIELDS OF STUDY

Major Field: Monetary Theory

Minor Fields: International Trade and Finance
            Econometrics
            Mathematical Economics
TABLE OF CONTENTS

DEDICATION ........................................ ii
ACKNOWLEDGEMENTS ................................ iii
VITA .................................................... iv
LIST OF TABLES ....................................... vi
LIST OF FIGURES ...................................... vii

CHAPTER

I. INTRODUCTION ....................................... 1
   Data Sources ........................................ 4
   Inventory Investment: 1979-1982 .................... 5
   Interest Rate Behavior: 1979-1982 ................. 10
   Interest Rate Volatility and Inventory Investment .. 14

II. THE EFFECT OF INCREASED INTEREST RATE VOLATILITY
    ON INVENTORY INVESTMENT ........................ 19
   Introduction ....................................... 19
   Literature Survey ................................... 21
   The Model ........................................... 24

III. EMPIRICAL TESTING ................................ 40
   Estimating Equation ................................ 41
   A Survey on Current Research on Inventory Investment . 43
   Empirical Results ................................... 53

IV. CONCLUSION ......................................... 67

BIBLIOGRAPHY .......................................... 70
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1. Inventories in Constant Dollars and Their</td>
<td>6</td>
</tr>
<tr>
<td>Fundamental Determinants</td>
<td></td>
</tr>
<tr>
<td>1.2. Mean and Standard Deviation of Total Inventories</td>
<td>7</td>
</tr>
<tr>
<td>Before and After October 1979 from the Detrended</td>
<td></td>
</tr>
<tr>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>1.3. Level and Volatility of Real Interest Rates.</td>
<td>11</td>
</tr>
<tr>
<td>3.1. A Summary on the Real Interest Rate Specification.</td>
<td>46</td>
</tr>
<tr>
<td>3.2. A Summary on the Estimated Speed of Adjustment</td>
<td>51</td>
</tr>
<tr>
<td>and Sales Expectations</td>
<td></td>
</tr>
<tr>
<td>3.5. Sum of Squared Residuals and F Statistics.</td>
<td>63</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
</table>
CHAPTER I

INTRODUCTION

During the episode of 1979-82 there were two emerging phenomena that have drawn much attention from economists: highly volatile interest rates and the abnormality of inventory investment. Since the Federal Reserve changed its operating procedures on October 6, 1979, interest rates have been characterized by four- to five-fold increases in volatility, while inventories were liquidated, except for a short period of recovery in 1981. The purpose of this study is to examine how increased interest rate volatility affects investment in inventories.

Traditionally business firms finance their inventory holdings by external borrowing, either through lines of credit maintained with commercial banks, or through issuing corporate bonds. The financial environment in which external funds are raised is important to a business firm's inventory decisions. Increased interest rate volatility raises the risk of market-making to financial intermediaries, which reduces their positions taken. As a result, less loanable funds are raised through financial intermediaries for business firms to finance inventory holdings. Further, financial market makers may add a risk premium to the interest rate charged, or widen the spreads between bid
and ask prices of underwriting corporate bonds. Increased interest rate volatility therefore reduces the availability of external funds for inventory financing on the one hand and raises the cost of external borrowings on the other.

In the micro framework of investment under uncertainty developed in Chapter 2, these financial difficulties associated with increased interest rate volatility in inventory financing are taken into account by a convex cost function with respect to the level of the real interest rate. Under the assumption of rational expectations, an increase in interest rate volatility is shown to raise the cost of inventory financing, which in turn reduces inventory investment. It should be noted that the specification of the convex cost function is a key link through which disruptions of efficiency in financial intermediation caused by increased interest rate volatility are transmitted into inventory decisions. A convex cost function is also a sufficient condition for increased interest rate volatility to reduce inventory investment using the definition of increasing risk as represented by a mean-preserving spread.

Though theoretically the level of the real interest rate should have a negative impact on inventory investment, it has generally not been supported by empirical evidence. Not until recently have economists been able to obtain a significant, negative interest rate coefficient in inventory estimation, but others still find a positive effect. The effect of increased interest rate volatility is even harder to detect empirically. Chapter 3 extends the sample period into a
volatile interest rate period of 1979-82 in estimations based on a stock-adjustment model. Interest rate volatility is hypothesized to reduce the desired level of inventories and hence to reduce inventory investment. While we are able to obtain some evidence on the interest rate effect, the empirical results with respect to the volatility effect are mixed with significant coefficients obtained only in the retail sector.

Several factors contribute to the insignificance of interest rate volatility in affecting inventories. First, the effect of increased interest rate volatility may have been embodied in the level of the real rate. Increased interest rate volatility pushes up the level of the interest rate by adding a risk premium to it. Second, structural changes in the financial environment, such as the imposition of credit controls in 1980:II and III and other financial innovations and institutional changes to hedge against interest rate risk, may have induced structural changes in inventory policy. Third, that the two recessions in 1980 and 1981-82 came so close to each other may have led firms to pay more attention to business cycles and less to interest rate movements. Fourth, the period of increased interest rate volatility is so short that it limits the reliability of the empirical results.

Structural changes in the firm's inventory policy may also have undermined the significance of the volatility effect. Facing increasing uncertainty in obtaining external funds and an increasing cost of financing inventory holdings, business firms may have changed their inventory policies to require more frequent orders and faster inventory
adjustment. The intuition is that, from a cost-minimization point of view, increased interest rate volatility raises the costs of financing relative to the costs of ordering or adjusting inventories. It is therefore more profitable to hold a lower level of inventories and to order more often. This structural change in inventory policy can be detected empirically. First, the Chow tests show that there is a significant difference in inventory behavior before and after October 1979. Second, the speed of inventory adjustment has been largely increased when a sample period with more volatile interest rates is tested. The interest rate volatility effect therefore could be implicit in the increase in the speed of adjustment parameter.

In the remainder of this chapter, we document some stylized facts about inventory investment and the levels and volatility of real interest rates during the period of 1979-1982. During the period inventory investment was relatively low and volatile, while interest rates were high and volatile. The question is how these two phenomena might be linked to each other.

Data Sources

Data employed in this study are all from the Survey of Current Business, published by the Department of Commerce, except the 91-day Treasury bill rate which is from the Federal Reserve Bulletin, published by the Board of Governors of the Federal Reserve System. Data on real inventories and final sales are taken from three sources of national income and product accounts. Historical data for 1959-1976 are from the
The period of 1979-1982 was characterized by wide cyclical variations in real GNP. There were two business cycles in this short period. Real GNP had been rising since the 1974-75 oil shock and reached the first peak in 1980:1. The first recession came in the second quarter of 1980 and lasted only one quarter. In that quarter real GNP dropped by $35 billion, or 2.3 percent. The economy recovered right after the recession and reached a second peak in 1981:II. Real GNP grew by $64.4 billion, or 4.4 percent during these five quarters. After that the economy was hit by recession again from 1981:III to 1982:IV, during which real GNP plunged $45.1 billion, or 3.0 percent.

Inventory behavior during 1979-1982 can best be described by two stylized facts:

Fact one: Inventory holdings during the period were relatively lower and more volatile than earlier.

Casual observation of inventory behavior, as depicted in Table 1.1, indicates that during 1979-1982 inventories were relatively lower than normal. The ratio of total inventories relative to final sales was the
### TABLE 1.1

INVENTORIES IN CONSTANT DOLLARS\(^a\) AND THEIR FUNDAMENTAL DETERMINANTS

<table>
<thead>
<tr>
<th>Period</th>
<th>Total Business Inventories</th>
<th>Changes in Inventories</th>
<th>Final Sales (^b)</th>
<th>Real GNP</th>
<th>Real Rate of Interest (^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979:1</td>
<td>339.5</td>
<td>12.9</td>
<td>103.3</td>
<td>1472.6</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>343.0</td>
<td>13.7</td>
<td>102.8</td>
<td>1469.2</td>
<td>1.13</td>
</tr>
<tr>
<td>3</td>
<td>344.2</td>
<td>4.8</td>
<td>104.6</td>
<td>1486.6</td>
<td>1.79</td>
</tr>
<tr>
<td>4</td>
<td>343.6</td>
<td>-2.3</td>
<td>105.4</td>
<td>1489.3</td>
<td>4.60</td>
</tr>
<tr>
<td>1980:1</td>
<td>343.5</td>
<td>-2.6</td>
<td>105.7</td>
<td>1496.4</td>
<td>4.54</td>
</tr>
<tr>
<td>2</td>
<td>342.9</td>
<td>-2.5</td>
<td>103.0</td>
<td>1461.4</td>
<td>-.51</td>
</tr>
<tr>
<td>3</td>
<td>340.4</td>
<td>-8.5</td>
<td>103.9</td>
<td>1464.2</td>
<td>.92</td>
</tr>
<tr>
<td>4</td>
<td>339.2</td>
<td>-6.2</td>
<td>104.9</td>
<td>1477.9</td>
<td>2.99</td>
</tr>
<tr>
<td>1981:1</td>
<td>340.0</td>
<td>2.4</td>
<td>106.6</td>
<td>1510.1</td>
<td>4.33</td>
</tr>
<tr>
<td>2</td>
<td>342.2</td>
<td>12.1</td>
<td>106.4</td>
<td>1512.5</td>
<td>8.99</td>
</tr>
<tr>
<td>3</td>
<td>346.2</td>
<td>16.5</td>
<td>106.8</td>
<td>1525.8</td>
<td>6.25</td>
</tr>
<tr>
<td>4</td>
<td>347.7</td>
<td>4.8</td>
<td>105.9</td>
<td>1506.9</td>
<td>3.38</td>
</tr>
<tr>
<td>1982:1</td>
<td>345.2</td>
<td>-15.4</td>
<td>105.8</td>
<td>1485.8</td>
<td>8.53</td>
</tr>
<tr>
<td>2</td>
<td>344.3</td>
<td>-6.9</td>
<td>105.5</td>
<td>1489.3</td>
<td>6.92</td>
</tr>
<tr>
<td>3</td>
<td>344.0</td>
<td>-1.3</td>
<td>105.1</td>
<td>1485.7</td>
<td>6.23</td>
</tr>
<tr>
<td>4</td>
<td>338.3</td>
<td>-22.7</td>
<td>106.6</td>
<td>1480.7</td>
<td>4.09</td>
</tr>
<tr>
<td>1983:1</td>
<td>334.5</td>
<td>-15.4</td>
<td>106.8</td>
<td>1490.1</td>
<td>2.72</td>
</tr>
<tr>
<td>2</td>
<td>333.1</td>
<td>-5.4</td>
<td>108.9</td>
<td>1525.1</td>
<td>5.22</td>
</tr>
<tr>
<td>3</td>
<td>334.1</td>
<td>3.8</td>
<td>110.3</td>
<td>1553.4</td>
<td>5.67</td>
</tr>
<tr>
<td>4</td>
<td>335.9</td>
<td>7.5</td>
<td>111.4</td>
<td>1563.0</td>
<td>4.95</td>
</tr>
</tbody>
</table>

\(a\). Inventories are seasonally adjusted quarterly totals, while changes in inventories are seasonally adjusted at annual rates. All variables, except the real rate of interest, are in billion constant dollars.

\(b\). Final sales are quarterly total at monthly rates.

\(c\). The real rate of interest is the ex post real rate. See definitions in the following section.
second lowest since 1959, only slightly higher than the ratio in 1963-66. Raw data on inventories and inventories/sales ratio also indicate that there was increased fluctuation in inventory holdings.

The phenomenon of comparative low but volatile inventory holdings after October 1979 can be seen clearly from detrended total business inventories. Figure 1.1 depicts the detrended total inventories since 1959 and Table 1.2 records means and standard deviations of detrended inventory holdings for three subperiods. These data support the observation that inventories during the period of 1979:IV - 1982:IV were both relatively smaller and more volatile than previously. Inventory volatility, as measured by its standard deviation, increased by 11 and 103 percent relative to the period of 1973:I - 1979:III and 1965:I - 1972:IV, respectively.

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965:1-1972:4</td>
<td>-.02</td>
<td>1.28</td>
</tr>
<tr>
<td>1973:1-1979:3</td>
<td>.94</td>
<td>2.34</td>
</tr>
<tr>
<td>1979:4-1982:4</td>
<td>-.31</td>
<td>2.60</td>
</tr>
</tbody>
</table>
FIGURE 1.1

DETFRENDED TIME SERIES OF TOTAL INVENTORIES\textsuperscript{a}

1959: I-1982: IV

\textsuperscript{a} Note that shaded areas indicate periods of recession.
Fact Two: The procyclical role of inventory investment in propagating GNP movements is no longer so clear, but it is still valid.

Inventory investment has long been recognized as a driving force in generating real GNP movements. It has been estimated that about 60 percent of decreases and 40 percent of increases in real GNP were due to inventory changes. This procyclical role of inventory investment is still valid for the period from 1979 to 1982. Total inventory investment was negative during the two recessions and positive during the recovery in 1980-1981. What makes inventory investment in this period unusual is that inventories were continuously liquidated a full two quarters after both the 1980 recession and 1981-82 recession were over. In addition, inventory investment was positive in the fourth quarter of 1981 when economic expansion was over and both real GNP and final sales were dropping. This counter-cyclical inventory investment was unusual compared with previous business cycles, in which inventory investment and real GNP tended to peak and trough in the same quarter.

Why did inventory holdings deviate so much from previous recessions? There are two arguments business executives have made to explain lower than usual inventory holdings. First, the recession in 1980 was expected in advance which prompted firms to liquidate their stock of inventories before the reduction in demand. This argument is supported by the fact that business firms started liquidating inventories one quarter (two quarters in the retail sector) before the
recession hit. Second, development of computer technology in inventory control has contributed to keeping inventory holdings low. Indeed, there has been a slightly decreasing trend in the ratio of total inventories to final sales since 1975. But why did inventory investment vary wider than earlier?

**Interest Rate Behavior: 1979-1982**

Two stylized facts about interest rate behavior during the episode of 1979-1982 can be documented:

**Fact One:** Interest rates, both nominal and real, were historically high.

The nominal interest rate, the 91-day Treasury bill rate used in this study, was in double digits throughout most of the period. It reached the historical high of 15.09 percent in 1981:III. The level of nominal rate was generally higher than the actual inflation rate, leading to a positive real rate. Table 1.3 presents mean levels of the real rate, both ex post and ex ante, for three subperiods, where the ex post real rate \( r_{EP} \) is calculated by subtracting the actual inflation rate from the nominal rate,

\[
r_{EP} = R_t - \Pi_t;
\]

where

- \( R_t = 91\text{-day Treasury-bill rate in period } t; \)
- \( \Pi_t = \text{The actual inflation rate in } t, \text{ calculated with the implicit GNP deflator.} \)
While the ex ante real rate ($r_{EA}^t$) is calculated by subtracting an inflation expectations measure from the nominal rate

$$r_{EA}^t = R_t - \Pi_{t+1}^e;$$

where $\Pi_{t+1}^e = \text{expected inflation at time } t+1;$

$$= (\Pi_t + \Pi_{t-1} + \Pi_{t-2} + \Pi_{t-3})/4.$$

Table 1.3 shows that the mean level of the real rate, both ex post and ex ante, were much higher for the period of 1979:IV - 1982:IV than for the other subperiods.

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean</th>
<th>Volatility as measured by</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r_{EP}$</td>
<td>$r_{EA}$</td>
<td>Standard Deviation</td>
<td>$r_{EP}$</td>
<td>$r_{EA}$</td>
<td>Mean Squared Deviation from a Moving Average</td>
</tr>
<tr>
<td>1965:1-1972:4</td>
<td>.92</td>
<td>.61</td>
<td>1.27</td>
<td>1.21</td>
<td>1.09</td>
<td></td>
</tr>
<tr>
<td>1973:1-1979:3</td>
<td>-.50</td>
<td>-.68</td>
<td>1.73</td>
<td>1.25</td>
<td>1.99</td>
<td></td>
</tr>
<tr>
<td>1979:4-1982:4</td>
<td>4.71</td>
<td>5.54</td>
<td>2.73</td>
<td>3.02</td>
<td>4.87</td>
<td></td>
</tr>
</tbody>
</table>
Fact Two: Interest rates, both nominal and real, were extremely volatile.

The sharp rise in the volatility of interest rates since late 1979 is widely recognized. For example, Walsh (1982) documented roughly four- to five-fold increases in standard deviations of five interest rates in the year after the Fed changed its operating procedures.

In Table 1.3, the sample period is divided into three subperiods. The first subperiod, 1965:I - 1972:IV, is thought to be interest rate stable. In fact the biggest change in the 91-day Treasury bill rate occurred in the first quarter of 1971 when it dropped 1.50 percentage point from 5.36 percent to 3.86 percent. During that period, except for two quarters, quarterly changes in 3-month Treasury bill rate fell within the range of plus or minus one percentage point.

Nominal interest rates in the subperiod of 1973:I - 1979:III remained rather stable, except the unusual variation during the period 1974:IV to 1976:I, which might have been prompted by inflation expectations changes. The standard deviation for this period is about 25 percent higher than that of the first subperiod. The largest change was a rise from 6.61 percent to 8.39 percent in the third quarter of 1973.

The behavior of nominal interest rates after October 1979 is a completely different story. It is characterized by sudden ups and downs. For example, the Treasury bill rate jumped 2.17 percentage points in the fourth quarter of 1979 when the Fed's change in control procedures was announced. It increased again in the first quarter of
1980, but fell by 3.41 percentage points a quarter after. In the last quarter of 1980, it jumped again by 4.47 percentage points. Total variation in the Treasury bill rate in the period 1979:IV-1982:IV, as measured by the standard deviation, is five times that for the period of 1965:I - 1972:IV, and three times the volatility in 1973:I - 1979:III.

While the nominal Treasury bill rate changed volatilley, the inflation rate during the episode of 1979:IV - 1982:IV did not behave very much differently from previous periods. The nominal Treasury bill rate and the inflation rate, however, did not move consistently in the same direction, which led to even larger variation in the real interest rate. For example, during 1979:IV, the quarter of the monetary policy changes, the Treasury-bill rate jumped 2.17 percentage points, while the inflation rate for the quarter decreased by .62 percentage points. The most prominent example occurred in 1981:II when the nominal rate increased by .87 percentage points while the inflation rate dropped by 4.17 percentage points, pushing the real interest rate to a historical high of 8.54 percent.

Table 1.3 also presents two measures of real interest rate volatility: the mean standard deviation of the ex ante real rate and a squared deviation from a moving average of the real rate of the past four quarters. The mean squared deviation from a moving average is obtained by calculated the moving average first, using an ex ante real interest rate,

\[ M\text{EAR}_t = \frac{1}{4} \left( r_{t}^{EA} + r_{t-1}^{EA} + r_{t-2}^{EA} + r_{t-3}^{EA} \right); \]
and then calculating the squared deviation by

\[ \text{MVEAR}_t = (r_{EA}^t - \text{MEAR}_t)^2. \]

As Table 1.3 shows, both measures indicate that real interest rate volatility during the episode of 1979:IV to 1982:IV increased by 140 percent compared with the subperiod of 1973:II - 1979:III, and about 150 to 350 percent relative to the period of 1965-1972.

**Interest Rate Volatility and Inventory Investment**

Interest rate volatility might be expected to have had impact on inventory investment, in particular, for interest rate sensitive sectors, such as the automobile industry. As argued in Chapter 2, two effects arise when interest rates are moving volatilley. Both come from financial intermediaries through which business firms externally finance their inventory holdings. Increased interest rate volatility raises the risk of market-making by financial intermediaries, which reduces their lending, and leads them to charge a higher level of interest rates to borrowers. Note that in this process, there are two ways that interest rate volatility could affect inventory investment. One is through the reduction of loanable funds available for inventory financing; and the other is through raising the level of the interest rate and therefore the cost of inventory financing. Increased interest rate volatility could therefore be embodied in the level of the real rate in affecting inventory investment.

Before we investigate the effect of increased interest rate volatility, we briefly discuss how the level of the real rate might be
expected to affect inventory investment. Theoretically the level of interest rate should have an impact on inventory investment since it determines the cost of holding inventories. A higher interest rate pushes up inventory financing costs which in turn would lead to a decrease in inventory investment. Given the fact that real interest rates were historically high during the episode of 1979-1982, it may have contributed to relative low inventory holdings during the period. Inventory investment, however, did not behave consistently with movements of the real rate. Data from Table 1.1 indicate that inventory investment was negative during the period of 1980:I - 1980:III when the real rate was on a downward trend, and turned positive when rates were rising in 1981:I - 1981:III. Compared with the historical relationship between the two, in particular around business cycle turning points, this pattern is basically no different from other periods, i.e., inventory investment and interest rates are not in fact negatively correlated.

Descriptive statistics show that the correlation coefficient between total business inventories and the real rate of interest for the period after October 1979 is .36, which indicates a positive co-movement between total inventories and the real rate, a fact that contradicts theoretical expectations.

Turning to inventories and interest rate volatility, we can identify a negative relationship. Using the mean squared deviation from a four-quarter moving average of the real rate as a measure of interest rate volatility, total business inventories were negatively correlated
with interest rate volatility, with a correlation coefficient of -.12. For retail inventory investment, the correlation coefficient was -.17.

It should be noted that the above observations are quite tentative. The experience from October 1979 to 1982 spans too short an interval to support any conclusion with great confidence. Economic events that occurred after October 1979 may have played a part in affecting inventory decisions. Any interest rate volatility effect may have been blurred by the rise in the level of the real rate. In any event, further investigation requires a theoretical analysis and careful specification of the relationship between inventory investment and interest rate levels and volatility to which we turn next before attempting to identify an empirical relationship.
FOOTNOTES

1. Although it may make a difference, we do not distinguish between interest rate volatility and interest rate uncertainty in this study. Empirically they are measured by the standard deviation of the interest rate.

2. Lombra and Struble (1979) first argue that increased volatility has disrupted the functioning of financial market. This uncertainty then spreads over into the nonfinancial sector disrupting the saving-investment process. Deshmukh, Greenbaum, and Kanatas (1983) provide a theoretical justification in which an increase in interest rate risk leads financial intermediaries to reduce their positions.

3. Mascaro and Meltzer (1983) examine how increased interest rate volatility, due to more uncertain monetary growth, is transmitted into a higher level of interest rate. The key is a risk premium added to the level of the interest rate. Supporting evidence appears in Friedman (1982), Bodie and Friedman (1978), and Zwick (1979) in which the bid-ask spread in the high-grade corporate bond and government security markets has widened.

4. These are examples of the Lucas' critique (1976) which states that a policy changes will change the parameter values of a reduced form macro model. It is therefore impossible to use the existing model with given parameters for prediction after a policy regime switch.

5. For a detailed survey, see Chapter 4.

6. It would be interesting to analyze inventory investment by stages of fabrication, i.e., to analyze inventory investment in the form of raw
materials, work in process, and finished goods. However, data of inventory investment according to stages of fabrication are not available in real dollars in the Survey of Current Business.

7. Following Blinder's procedure (1981, 1984), real inventory stocks are all detrended according to a model of the trend component:

\[ \log I_t = a_0 + a_1 \text{TIme} + a_2 \text{DTIME} + \epsilon_t \]

where TIME is a linear time trend and DTIME is a linear time trend beginning at 1 in 1973:IV. Estimation is by generalized least squares, allowing for second-order autocorrelation in \( \epsilon_t \). The antilog of the fitted values from the detrending regression are subtracted from the actual data to define the detrended data.

8. For example, inventory liquidations accounting for 60-70 percent of the decrease in real GNP are reported by Blinder (1981), Bosworth (1971), and Feldstein and Auerbach (1976).

CHAPTER II

THE EFFECT OF INCREASED INTEREST RATE VOLATILITY ON INVENTORY INVESTMENT

Some economists contend that increased volatility of interest rates has disrupted the functioning of financial markets by increasing risks borne by lenders and borrowers. This uncertainty then spills over into the nonfinancial sector disrupting the saving-investment process, increasing the variability of prices, employment, and output. There is not much if any theoretical framework to justify this conjecture. In this chapter, we present a micro theoretical framework to investigate the adverse effect of increased interest rate volatility on the desired level of inventory investment.

Inventory holdings generally are recognized as a buffer stock to production in meeting unexpected demands. By drawing down or adding to the stock, inventories insulate production from unexpected changes in demand which avoids a large cost of rapid production adjustment. On the other hand, keeping inventories in stock needs to be financed. Traditionally most firms finance their inventory holdings through external borrowings. The financial environment in which loanable funds
are raised for inventory financing is important to firms' inventory decisions.

In a well developed financial market such as that of the United States, each decision about capital formation necessarily has a financial counterpart. The financial transactions are not merely a reflection of resource allocation of loanable funds. The financial setting in which capital formation takes place can also be a key determinant of the total amount of capital formation. Interest rate volatility is harmful in that financial market-makers may reduce the quantity and quality of their market-making services and raise the price of the services they provide. The cost of such developments would be a decline in the efficiency of financial markets, which could be expected to adversely affect the saving-investment process.

In a study examining how increased volatility has impaired the market mechanism for raising long-term business capital, Friedman (1982) argues that U. S. nonfinancial business corporations have raised less of their external funds in the form of long-term debt as a result of the increased interest rate volatility since October 1979. He also presents evidence that the financial markets have made corporations pay more for the underwriting and initial distribution of this debt. Other researchers such as Bodie and Friedman (1978), Johnson and others (1981), and Zwick (1979) have presented similar evidence.

In this chapter, we attempt to take into account the financial difficulties resulting from increased interest rate volatility on
inventory investment decisions. We model the financial difficulties imposed on inventory financing with a strictly convex cost function with respect to the level of the real interest rate in which the second moment is used to represent the volatility. In a profit-maximization investment model under increased uncertainty, an increase in interest rate volatility is shown to lead to a reduction in the desired level of inventory holdings.

It should be noted that the specification of the strictly convex cost function is the key link through which the efficiency-disruption effect of the increased volatility on financial markets is transmitted to the real sector. It is also a sufficient condition for increased uncertainty to have an adverse effect on desired inventory investment when a definition of increasing risk is introduced into the analysis.

In the next section we give a brief survey of the problems arising from demand or cost uncertainty in a firm’s pricing, investment, and output decisions. A theoretical framework of the effect of increased interest rate volatility on inventory investment follows. The model, with the assumption of rational expectations, is characterized by expectations revisions in the optimization process when new information emerges.

**Literature Survey**

Firms' investment, output and pricing decisions under uncertainty have generated much attention over the years. Mills (1959, 1962) and Karlin and Carr (1962) studied effects of demand uncertainty on the investment decisions of a firm. Mills examined a single period
monopolistic firm that sets both output and price, and showed that additive demand uncertainty leads to a lower price if marginal cost is constant. For both static and multiperiod cases with inventory carrying, Karlin and Carr confirmed that additive uncertainty tends to reduce the price and increase the output of a risk-neutral firm, while multiplicative uncertainty does the opposite.

Depending on the way in which the error term enters the demand function (additive, multiplicative, or nonlinear), other economists have shown that output could be higher and price lower given additive demand uncertainty with inventory carrying (Sandmo(1971), Baron(1970), Zabel(1972)), or output could be lower and price higher given multiplicative demand uncertainty and risk aversion (Sandmo(1971), Baron(1979), Leland(1972), and Zabel(1972)).

Cost uncertainty, along with price uncertainty, was first introduced by Hartman(1972) in a discrete-time model of a risk-neutral firm with adjustment costs. He showed that with a linear homogenous production function, increased output and wage rate uncertainties lead the competitive firm to increase investment. Due to the assumption of a homogenous production function and the nature of capital stock as a quasi-fixed factor in production, the investment decision is separated from pricing and wage rate determination. Current investment is independent of the capital stock and the investment functions for other periods. Increased volatility in investment costs therefore has no effect on fixed investment.
While those early studies were concerned with the way uncertainty for the current period entered the demand function, it is reasonable to argue that the firm should consider both current and future demand and cost uncertainties. Pindyck (1982) has analyzed investment behavior in a continuous time model in which both current and future demand and cost uncertainties are incorporated. By assuming that the price of output evolves according to an Ito process, he finds that price uncertainty leads to a higher target or expected rate of investment than under certainty if the marginal adjustment cost function is convex. If the marginal adjustment cost function is concave, the introduction of demand uncertainty reduces expected investment. Allowing the cost of capital or wage rate to evolve following an Ito process, stochastic fluctuations in the cost of capital have the same effect on output as demand uncertainty since both are expected to lead to comparable shifts in expected marginal cost over any length of time.

Stochastic fluctuations in the cost of capital are shown to increase the target rate of investment in Pindyck's paper. This result contradicts the invariant effect as obtained by Hartman. The reason, as admitted by the author himself, is the fact that his analysis focuses on how uncertainty affects the firm's target capital stock and output given current demand and factor costs, and says nothing about the behavior of investment at each point in time, nor about the existence or nature of any long-run stochastic equilibrium. As pointed out by Abel (1983) in a simplified framework, the target rate of investment may not be optimal.
By imposing restrictions that the production function be homogenous of degree one and adjustment cost function be of constant elasticity in the Pindyck's framework, Abel(1983) demonstrates that Hartman's results continue to hold. Investment is affected only to the extent that uncertainty affects the variance of the real wage rate because the marginal revenue product of investment is a function only of the real wage rate.

The multiperiod stochastic framework employed by Pindyck and Abel has a drawback in that the marginal variation of capital is expected to grow without bound as we look further and further into the future. This disquieting feature of the model is a consequence of the assumption that price or cost evolves according to a random process. A restriction on the stochastic process should be imposed. In the following section we present a multiperiod profit maximization model under uncertainty based on Lucas and Prescott(1971). This model is different from the stochastic framework as employed by Pindyck and Abel in that, instead of letting price or cost evolve without bound according to an Ito process, expectations about future prices or costs are based on available information about the structure of the optimizing model. This is more realistic in the sense that in a multiperiod dynamic model, firms revise their expectations concerning the future course of prices or costs as new information emerges. Without such a revision, a stochastic process that price or cost follows is sub-optimal.
The Model

In the analysis that follows we show how the profit-maximizing firm would optimize its inventory investment when increasing costs of inventory financing associated with interest rate volatility are taken into account. We first describe the cost function of inventory financing associated with levels and volatility of interest rates.

Generally a linear inventory financing cost is specified in early studies:

\[ C_t = r_t I_t; \]

where \( C_t \) is the financing cost; \( r_t \), the real rate of interest; and \( I_t \) is inventories in stock. Inventory financing cost depends linearly on the level of the real rate. Except in so far as increased interest rate volatility could push up the level of the real rate, this specification is unable to capture the financial difficulties associated with increased interest rate uncertainty.\(^5\),\(^6\) An alternative specification is needed to capture the credit squeeze effect on inventory investment. Here we specify the inventory financing cost as a quadratic function of the real rate of interest:

\[ C_t = (1 - r_t + r_t^2) I_t. \tag{2.1} \]

The term of the second moment is used to capture the financial difficulties in financing inventories caused by the increased volatility in interest rates. When expectations are taken on equation (2.1) as in our maximization process, the term of second moment can be justified...
from a mean-variance theory in which the quadratic term represents the variability. An increase in the volatility increases the cost of financing directly.

Equation (2.1) in fact can be derived from the classical Fisherian interest rate theory. In a one good, two-period certainty model, competitive price-taking firms maximize the welfare of their owners by accepting all investment projects that earn a rate of return at least as high as the one period interest rate. In equilibrium, a firm's marginal cost is set to equal the cost of capital. Denoting the cost of capital by $P$, we have

$$P_t = \frac{1}{1 + r_t}.$$  

Expanding this around $r_t = 0^7$ by Taylor's expansion and neglecting those terms higher than second order yields

$$P_t = 1 - r_t + r_t^2.$$  

The cost of capital is approximated by a second order polynomial function of the one-period interest rate. This approximation should hold for a multi-period relationship between the cost of capital and the rate of interest rate.

One particular aspect concerning decisions under uncertainty is that expectations about future variation could have effects on current decision-making. More specifically, expectations revision after new information emerges could change the optimal path taken by firms in longer term planning. Analysis of decisions under uncertainty with
random variables following an Ito process such as specified by Pindyck (1982) and Abel (1983) would not be able to capture the impact of expectations revision in the maximization process. It is therefore suboptimal. In this model multiperiod optimization with rational expectations is presented.

The model developed here is based on the neoclassical theory of investment under uncertainty as formulated by Lucas and Prescott (1971). The problem is specified as a stochastic dynamic optimization in which there is uncertainty about future values of the exogenous variables facing firms. This framework is chosen because firms should be concerned about the evolution of future interest rates and their impact on inventory financing costs when interest rates are increasing volatile. It turns out that the solution for future inventory demand depends on the past levels of inventory stock and the expected course of future interest rates when a backward solution technique is applied.

The problem is a classic one in which the firm, in anticipating future demand and interest rates, makes a decision about the optimal level of inventory holdings. In the model, we assume that the price sequence is known to the firm and therefore can be assumed to be constant. \(^8\) Profit opportunity arises for firms with holdings of inventories whenever demand is unusually strong. If the firm does not hold sufficient inventories, it will lose sales and customers. The high cost of rapid ordering prevents the firm from meeting the unexpected demand profitable in a short period. In keeping inventories, two costs
are incurred. First, there are inventory carrying cost specified as equation (2.1), which captures the credit squeeze effect of increased interest rate volatility. Second, there is an increasing adjustment cost associated with changes in inventories due to unanticipated sales or interest rate fluctuations.

\[ C_t^2 = d/2 (I_t - I_{t-1})^2. \]  

Equation (2.2) measures the increasing cost of adjusting inventories, both planned and unplanned, as actual sales and interest rates evolve. This increased cost of adjustment prevents firms from fully adjusting to meet unanticipated demand. Lucas (1967) has shown that the imposition of non-linear costs of varying capital yields both the desired capital stocks and the optimal path of adjustment. In this model we simplify by assuming that the firm orders to stock and to meet unexpected demand without engaging in production decisions.

The object of the firm is to choose a stochastic inventory process \( \{I_{t+j}\} \) \( j=0, 1, 2, ... \) to maximize the expected present value of profits over the time horizon; that is, to choose \( I_{t+j} \) to

\[
\text{Max } v_t = E_t \sum_{j=0}^{\infty} b^j \{P_{t+j}S_{t+j} - C_{t+j}^1 - C_{t+j}^2\}. \]  

(2.3)

Subject to: \( I_{t-1} \) given; and

\[ I_{t+j} - I_{t+j-1} = y_{t+j} - S_{t+j} \]  

(2.4)
based on all information available at time t+j. In the maximization problem, $S_{t+j}$ is the sales of goods in time t+j; and $y_{t+j}$ is the amount of commodity ordered. We assume that orders only take place at the beginning of each period. Equation (2.4) governs the dynamic accumulation of inventories. It states that inventory accumulation is the difference between the amount ordered and the amount sold in the current period.

There are two special features of the model. First, although this is a dynamic stochastic control problem, it is of the linear quadratic form and therefore satisfies the certainty equivalence assumptions, that is, one can replace the random variables by their expectations and solve the problem as if it were deterministic. Second, each period's decision determines only one future period inventory investment as implied by the optimization principle in dynamic programming theory. These two characteristics of the model imply that one can obtain an analytic solution by differentiating with respect to each of the decision variables, $I_{t+1}$, $I_{t+2}$, ..., and setting the derivatives equal to zero.

Before solving the dynamic optimization problem under uncertainty, we briefly describe the basic characteristics of inventory adjustment mechanism. Equation (2.4) states that inventory will be accumulated if the amount ordered is greater than the amount sold in the current period, while it will be decumulated if sales are greater than the amount ordered. Equation (2.4) is in fact an identity. How much to
order, we assume, depends positively on expected sales and negatively on the level of inventories carried over,

$$y_t = \lambda_1 S^e_t - \lambda_2 I_{t-1}, \quad \lambda_1, \lambda_2 > 0. \quad (2.5)$$

Upon substitution from equation (2.5), equation (2.4) can be written as

$$I_t - I_{t-1} = (\lambda_1 - 1)S_t - \lambda_2 I_{t-1} + \lambda_1(S^e_t - S_t);$$

or

$$S_t = \phi_1(I_t - I_{t-1}) + \phi_2 I_{t-1} + \phi_3 u_t \quad (2.6)$$

in a more general form. In equation (2.6), $u_t = S_t - S^e_t$ is the sales shock. Equation (2.6) is substituted into equation (2.3) for optimization.

In this problem, the information set $\Omega_t$ at time $t$ that the firm uses in inventory decision consists of at least

$$\{I_t, I_{t-1}, \ldots; S_t, S_{t-1}, \ldots; u_t, u_{t-1}, \ldots; r_t, r_{t-1}, \ldots\}.$$ 

Stochastic processes $\{u_{t+j}\}_{j=0}^\infty$ and $\{r_{t+j}\}_{j=0}^\infty$ are assumed to be of exponential order less than $1/b$ to guarantee a stable solution. $b$ is a discount factor.

Substituting $S_t$ from equation (2.6) into equation (2.3) yields

$$\text{Max } v_t = \mathbb{E}_{t} \sum_{j=0}^\infty b^j \left[ \phi_1(I_{t+j} - I_{t+j-1}) + \phi_2 I_{t+j-1} \right. \left. + \phi_3 u_{t+j} \right] - (1 - r_{t+j} + r^2_{t+j}) I_{t+j}$$
The Euler equations for optimization are

\[ \phi_1 P_{t+j} - (\phi_1 - \phi_2)b E_{t+j} P_{t+j+1} - (1 - r_{t+j} + r_{t+j}^2) \]

\[ -d(I_{t+j} - I_{t+j-1}) + db E_{t+j} (I_{t+j+1} - I_{t+j}) = 0, \quad j = 0, 1, 2, \ldots \quad (2.8) \]

and the transversality condition is

\[ \lim_{t \to \infty} E b^T \{ (\phi_1 - \phi_1 b + \phi_2 b) P_{t+T} - (1 - r_{t+T} + r_{t+T}^2) \]

\[ -d(I_{t+T} - I_{t+T-1}) \} = 0. \quad (2.9) \]

The Euler equations state that the net gain from storing an additional unit of commodity is zero at time \( t+j \). The gain is the sum of revenue from sales and the discounted value of the savings in future costs of adjustment net of the cost of not being able to meet the unexpected demand, inventory carrying, and inventory adjustment at \( t+j \).

To solve the Euler equations, which are second order difference equations, two boundary conditions are needed. One boundary condition is supplied by the initial level of inventory, \( I_{t-1} \), and the other by the transversality condition of equation (2.9), which is a necessary condition for optimality.

Sargent(1979) has shown that sufficient conditions for the transversality condition (2.9) to hold are that all the sequences of
\( u_{t+j}, r_{t+j} \) and the solution trajectory \( I_{t+j} \) are of exponential order less that \( 1/b \). Further the transversality condition compels us to solve the stable root backward and the unstable root forward. Here we apply the solution technique for linear difference equations as described in Sargent (1979, chapter 14 in particular). First rewrite the Euler equations as

\[
be_{t+j}(I_{t+j+1}) - (1+b)I_{t+j} + I_{t+j-1} = d^{-1}[(1 - r_{t+j} + r_{t+j}^2) - (\phi_1(1-b) + \phi_2 b)P]. \tag{2.10}
\]

Let \( z_{t+j} = d^{-1}((1 - r_{t+j} + r_{t+j}^2) - (\phi_1(1-b) + \phi_2 b)P). \) Denote \( s = t+j+1 \), the Euler equations can further be written as

\[
b - (1+b)B + B^2 E_{s-1}I_s = E_{s-1}z_{s-1}; \tag{2.11}
\]

where the backward operator \( B \) is defined as \( B^j E_{s-1}I_s = E_{s-1}I_{s+j} \) for all \( j \). The above equation can be rewritten as

\[
b(1 - \theta_1 B)(1 - \theta_2 B) E_{s-1}I_s = E_{s-1}z_{s-1}; \tag{2.12}
\]

where \( b - (1+b)B + B^2 = b(1 - \theta_1 B)(1 - \theta_2 B) \), which is the factorization of the difference equation. The two roots \( \theta_1 \) and \( \theta_2 \) can be solved as \( \theta_1 = 1 \) and \( \theta_2 = 1/b \).

The solution to the optimization problem is obtained by substituting the two characteristic roots back into the Euler equations to yield
Thus, the expected inventory stock depends on the past inventories and the future course of stochastic interest rates. Since $0 < b < 1$, the effect of any disturbances in interest rates will persist over time. If there were no uncertainties in interest rates, the expected inventory for the coming period would be very close to the level that the firm holds in the current period.

In order to analyze how increased interest rate volatility affects inventory investment, we have to look into a comparative static analysis to see how an increase in interest rate variability affects the equilibrium level of inventories.\textsuperscript{10} For this purpose, we adopt the definition of increasing risk as suggested by Rothschild and Stiglitz(1970) which is represented by a mean preserving spread of the probability distribution.

In the one dimensional case, a mean-preserving spread involves taking some of the probability mass close to the center of a distribution and putting it further out in the tails in such a manner that the mean remains unchanged. As a distribution undergoes such a mean-preserving spread, the variance increases. The definition can be extended to multidimensional cases.
Rothschild and Stiglitz have shown that, operationally, a mean-preserving spread can be obtained by adding a random variable with conditional mean zero to the original random variable. Applying this definition, Hartman (1972) demonstrated that

**Lemma:** The expected value of a real-valued, convex function increases or remains unchanged when the joint distribution of the arguments undergoes a mean-preserving spread.

**Proof:** Let $H(\cdot)$ be a real-valued, convex function of an $n$-dimensional vector. Let $X$ and $U$ be random vectors of dimension $n$ with joint distribution function $F_{XU}(x,u)$. Let $F_{U/X}(u)$ be the conditional distribution of $U$ given $X$, and let $F_X(x)$ be the marginal distribution function of $X$. Suppose that $E(U/X) = 0$, then

$$E_{XU}H(X + U) = \int H(x+u) \, dF(x,u)$$

$$= \int \{ H(x + u) \, dF_{U/X}(u) \} dF_X(x)$$

$$\geq \int \{ H[x + E(u/X)] \} \, dF_X(x)$$

$$= \int H(x) \, dF_X(x)$$

$$= E_XH(x).$$

Q.E.D.

Note that strict inequality will hold if $H(\cdot)$ is a strictly convex function of its arguments. Otherwise, for a linear function $H$, equality will hold.

Now apply this lemma to our study. We let variable $r_{s+1}$ undergo a mean-preserving spread by adding a random variable $\varepsilon_{s+1}$ to $r_{s+1}$, where
\(E(c_{s+1}/r_{s+1}) = 0\). Note that the real-value variable \(z_{s+1}\) is a quadratic function and therefore is a strictly convex function of \(r_{s+1}\). Applying the Lemma, we have

\[E \bar{z}_{s+1} > E z_{s+1};\] \quad (2.14)

where \(E \bar{z}_{s+1}\) represents the value of the \(E z_{s+1}\) after the interest rate \(r_{s+1}\) undergoes a mean-preserving spread, i.e., after we add \(\varepsilon_{s+1}\) to \(r_{s+1}\). The inequality is due to the fact that \(z_{s+1}\) is a strictly convex function of \(r_{s+1}\). This strict convexity stems from our assumption of a quadratic inventory financing cost function. With a linear inventory financing cost function as specified in conventional literature,

\(E \bar{z}_{s+1} = E z_{s+1}\). That is, increased interest rate volatility would not have any effect. The quadratic cost function is therefore a sufficient condition for any direct effect of interest rate volatility.

Substituting equation (2.14) back to equation (2.13), we have

\[E_{s-1} I_s < E_{s-1} I_s\] \quad (2.15)

Thus, by utilizing the definition of increasing risk in terms of the mean-preserving spread, we have shown that an increase in interest rate volatility will decrease the desired level of inventory holdings.

It is interesting to compare our results with those derived by Hartman(1972) and Pindyck(1982). Hartman analyzes the effects of price and cost uncertainties on output and investment. He found that price
and wage rate uncertainties increase expected future profits and thus increase current investment and output. Interest rate uncertainty on the other hand does not have any effect on future profits and hence does not affect investment. This particular feature mainly stems from his assumption of a homogenous production function and the separation of the short-run labor employment decision from the long-run investment decision. As a consequence, only future prices and wage rates enter into the expectations formation in the investment decision, leaving the cost of investment goods as irrelevant. Variation of the price of investment goods therefore will not have an effect on current investment.

In Pindyck's setup (1982), the cost of capital is no different from the wage rate in determining expected marginal cost and future profits. Both are assumed to evolve following the same stochastic process. When optimization is restrained to achieve a target rate of investment, interest rate uncertainty is shown to have the same effect on output as wage rate uncertainty since both lead to comparable shifts in expected marginal cost over any length of time.

In our model we impose additional financial constraints on inventory financing under the circumstance of increasing uncertainty in interest rates. The financial constraints limit the extent to which external funds can be raised and increase the costs of inventory financing. As a consequence investment in inventories is limited which implies a negative association between inventory investment and interest rate volatility.

2. A detailed survey appears in the following section. Note that our analysis on the effect of increasing cost uncertainty on inventory investment is different from that on fixed investment. One is a short-term phenomenon, while the other is long-term. In a recent paper Maccini(1984) integrates both fixed and inventory investment in a framework to determine price and output responses.

3. Deshmukh, Greenbaum, and Kanata(1983) provide a theoretical framework to show that an increase in interest rate risk leads financial intermediaries to reduce their positions taken.

4. If the real rate of interest is log-normally distributed and its expected rate of change is constant, we can assume that the real rate is generated by an Ito process

\[ \frac{dr_t}{r_t} = \mu dt + \sigma_r dz \]

where \( dz \) is a Wiener process with zero mean and unit variance.

5. In a study of effects of monetary variability on the levels and variability of interest rates, Mascaro and Meltzer(1982) show that interest rate risk increases with the variability of unanticipated changes in monetary growth, which in turn increases the levels of interest rates at all maturities. Their empirical evidence supports
this conjecture that the risk premium explains the high level of nominal and real interest rates.

6. The linear specification on inventory carrying cost is attacked by Blinder (1982). He argues that, as long as stock-outs are avoided, this extreme assumption leads to the conclusion that production is totally unresponsive to fluctuations in demand.

7. In perhaps the most extensive study of actual nominal and real returns, Ibbotson and Sinquefield (1982) analyzed Treasury bills, long-term government bonds, long-term corporate bonds, and common stocks over the period 1926-1981. They found that over the entire period, Treasury bills provided a zero real return compounded annually. Even if we expand it around a positive constant $r_t$, the result is not changed.

8. The possibility of speculation with respect to future prices was discussed by Muth (1961) in his famous article on rational expectations. Here we assume the main role played by inventory is to meet unanticipated demand and to smooth production. Though speculation may be important, to our knowledge, no one has attempted to identify a separate link between interest rate movements and speculative inventory holdings.

9. Note that we assume that the price sequence is known to the firm. For simplicity, it is assumed to be constant over time, i.e., $P_{t+j} = P$ for all $j$.

10. Equation (2.13) implies our result that interest rate volatility adversely affects inventory investment because the second term on the
right hand side of equation (2.13) is a negative function of interest rate volatility. This result is only made possible with approximation by the Taylor's expansion in which the second moment of the interest rate is included. A general implication can be obtained by using the definition of increasing risk, as presented below.
CHAPTER III

EMPIRICAL TESTING

Theoretical investigation in the preceding chapter indicates that increased interest rate volatility would be expected to reduce the desired holdings of inventories and to speed up inventory adjustment. A sufficient condition for this relationship to be valid is that costs associated with inventory financing should increase with interest rate volatility. Unfortunately data on inventory financing costs are hard to obtain and therefore the theory can not be tested directly. In this chapter we propose a reduced form equation for estimation based on the stock-adjustment theory, in which both the level and volatility of the real rate of interest are specified as determinants of desired inventories. We first give a detailed survey of current research on inventory investment with focus on interest rate effects and structural changes in the speed of inventory adjustment. Empirical results are provided with different specifications of expected sales and expected inflation.

One should bear in mind that early research on inventory investment generally had difficulty in identifying an interest rate effect. This may stem from the fact that the level of the real rate did not fluctuate enough until recently to capture the attention of business executives;
or it may result from incorrect specification of the real rate of interest. Even though some economists have been able to uncover a significant interest rate coefficient by extending the sample period into 1980s, a period in which interest rates fluctuated more widely, and by a more careful specification of the real rate, this conclusion is not apparent to others. Given that the effect of the level of the real rate on inventory investment is unsettled, it is not surprising that it is difficult to detect a volatility effect empirically. Further, the significance of interest rate volatility effect could be hidden in the level of real rate since increased volatility tends to push up the level of the real rate.

**Estimation Equation**

Empirical studies of inventory behavior basically follow the theory of stock-adjustment as developed by Lovell (1961), which is shown by Darling (1965) to be consistent with the cost-minimization argument by Holt, Modigliani, Muth, and Simon (1960). The stock adjustment model decomposes changes in inventories into a planned adjustment toward the level of desired stock and an unexpected accumulation or depletion due to unexpected changes in demand. Specifically,

\[
\Delta I_t = \alpha_0 (I_t^* - I_{t-1}) + \alpha_1 (S_t - S_t^e); \quad (3.1)
\]

where \( I_t \) = aggregate level of inventories at the end of period \( t \);

\( \Delta I_t = I_t - I_{t-1} \);
According to the stock adjustment model, each firm attempts only a partial adjustment towards the desired level of inventories within any one period. This implies $0 < \alpha_0 < 1$.2

Unexpected sales deplete inventory holdings. At the beginning of each period, the firm makes a projection about the demand for its product and orders or produces to stock accordingly. Unexpected demand will force the firm either to deplete its inventories or to increase production depending on the cost of adjusting production relative to the cost of adjusting inventories.3 If production is more costly to adjust, and inventory is used to cushion unexpected demand, $\alpha_1$ should be close to $-1$; otherwise $-1 < \alpha_1 < 0$.

Traditionally the desired level of inventories is hypothesized to be determined by expected sales, inventory carrying costs, and cyclical business conditions:

$$I_t^* = \beta_0 + \beta_1 S_t^e + \beta_2 r_t + \beta_3 Y_t; \quad (3.2)$$

where $r_t = \text{the real interest rate in period } t$; $Y_t = \text{the cyclical factor}$. 
Substituting (3.2) to (3.1) yields

\[ \Delta I_t = a_0 + a_1 I_{t-1} + a_2 S_t^e + a_3 (S_t - S_{t-1}) + a_4 r_t + a_5 Y_t; \]

where

- \( a_0 = \alpha_0 \beta_0 > 0; \)
- \( a_1 = -\alpha_0 < 0; \)
- \( a_2 = \alpha_0 \beta_1 > 0; \)
- \( a_3 = \alpha_1 < 0; \)
- \( a_4 = \alpha_0 \beta_2 < 0; \)
- \( a_5 = \alpha_0 \beta_3 > 0. \)

Equation (3.3) is the reduced form equation generally used for empirical testing. It states that changes in inventories should be positively associated with higher expected sales and a rising economic condition; while a larger initial stock of inventories, unexpected sales, and a higher real interest rate will dampen investment in inventories.

Different specifications on the unobservable expected sales and ex ante real rate of interest have been tried in estimating equation (3.3) which lead to different empirical results. In the next section we survey recent empirical studies on inventory investment that are based on equation (3.3).
Current studies on inventory behavior focus on the real interest rate effect and the speed of adjustment.

Theoretically a higher interest rate leads to a lower level of desired holding of inventories through raising the cost of carrying inventories. This relationship is predicted by every theoretical work. It is not until recently, however, that economists have been able to uncover some interest rate effects on inventory investment. Others still find that the interest rate effect is insignificant. In a comment on the Feldstein and Auerbach's study, Lovell (1976) states that "... the probability of obtaining an interest rate coefficient with negative sign is 50 percent."

Factors that cause the insignificance of the estimated interest rate coefficient have been investigated by Irvine (1980, 1981b). Three factors are identified. First, sample periods for early studies were characterized by stable nominal interest rates and inflation rates. Real interest rates were not moving much. Second, as Feldstein and Auerbach (1976) pointed out, the nominal interest rate and expected inflation rate are moving together theoretically but have coefficients of opposite sign in inventory equation (3.3). Omission of either will tend to bias the coefficient of the included variable toward zero. We should point out that speculation on future price changes may be important in inventory decisions. Speculation may lead firms to stock more inventories even when interest rates go up with the expected
inflation rate. Finally, econometric techniques employed may account for the failure to find a significant effect of interest rates on inventories.

Extending the sample period into a more volatile interest rate episode and employing a more relevant specification on the real interest rate have enabled several economists to estimate a significant, negative interest rate effect on inventory holdings. Examples are Akhtar(1983), Irvine(1981a, b, c, d), Lieberman(1980) Pearce and Wisley(1983), and Rubin(1979/80). This finding is not universal. For example, Blinder(1981, 1984) and Maccini and Rossana(1981) continue to conclude that inventories are insulated from interest rate fluctuations.

Table 3.1 summarizes specifications that lead to a significantly negative interest rate coefficient and those that do not. The real interest rate is generally calculated by subtracting a measure of the expected inflation rate from the nominal interest rate. Since inventory is held a relatively short period of time, both the nominal rate and expected inflation rate should be for a relatively short time span. While the nominal rate is generally represented by the bank prime rate or the short-term commercial paper rate, expected inflation follows quite different schemes of expectations formation. Three common specifications for forming inflationary expectations are:

1. Static(Naive) Expectations: $P^e_t = P_{t-1}$;

2. Adaptive Expectations or Distributed Lag Formation:

$$P^e_t = \delta P^e_{t-1} + (1-\delta)P_{t-1};$$

where $0 < \delta < 1$;
### TABLE 3.1
A SUMMARY ON THE REAL INTEREST RATE SPECIFICATION

<table>
<thead>
<tr>
<th>Regression with a significant interest rate coefficient:</th>
<th>Sample Period</th>
<th>Industry</th>
<th>Nominal Interest Rate</th>
<th>Inflation Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akhtar(1983)</td>
<td>1965:III-1981:II Total Business</td>
<td>4-6 month CP rate</td>
<td>( P_t^e = 1/4 \cdot \sum_{j=1}^{4} P_{t-j} )</td>
<td></td>
</tr>
<tr>
<td>Irvine(1981b)</td>
<td>1958:3-1974:12 Retail</td>
<td>bank prime rate</td>
<td>( P_{t+1}^e = \frac{P_t - P_{t-12}}{P_{t-12}} \times 100 )</td>
<td></td>
</tr>
<tr>
<td>Pearce and Wisley (1983)</td>
<td>1971:3-1979:12 Retail</td>
<td>short-term CP rate</td>
<td>( (1-B)P_t = (1-B)(P_t - P_{t-1}^e) )</td>
<td></td>
</tr>
<tr>
<td>Lieberman(1980)</td>
<td>1957-1976 Heavy Machinery and Textile</td>
<td>a weighted average of after-tax cost of debt, preferred and common stocks</td>
<td>actual inflation rate</td>
<td></td>
</tr>
<tr>
<td>Rubin(1979/80)</td>
<td>1965:III-1978:II Total Business</td>
<td>short-term CP rate</td>
<td>percentage change in the inventory stock deflator</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regression without a significant interest rate coefficient:</th>
<th>Sample Period</th>
<th>Industry</th>
<th>Nominal Interest Rate</th>
<th>Inflation Expectations</th>
</tr>
</thead>
</table>
(3) Rational Expectations with Perfect Foresight:

\[ P_t^e = P_{t+1}, \quad i > 1. \]

Table 3.1 shows that the specification of the expected rate of inflation, which determines the real rate of interest, is a key determinant in whether one can derive a statistical significant interest rate coefficient. An appropriate specification is the one that would be able to take into account the seasonal effect on price expectations, such as the relative inflation rate expected over the same month last year by Irvine (1981a, b, c, d), or an ARIMA model of the form \((1-B)P_t = (1-B)v_t\) by Pearce and Wisley (1983) where the projection is done by a method similar to a moving average, or the adaptive expectations over the last four period prices with equal weights by Akhtar (1983). The specification of the expected rate of inflation as a distributed lag (Maccini and Rossana (1981)) or autoregression (Blinder (1981, 1984)) of past inflation rates tends to lead to insignificant results. This may stem from the fact that inventory investment is a short-term decision. Expectations formation according to a distributed lag or autoregressive mechanism tends to distribute the effect of variations in interest rates over time which weakens the initial impact of real rate changes on inventory decisions. Another reason is that demand for inventories has a seasonal pattern associated with the seasonal sales pattern. The inflation rate in the same quarter last year is more relevant than inflation rates in the other quarters in forming inflation expectation.
This observation that the real interest rate specification matters in obtaining a significant interest rate effect is further confirmed by Lieberman (1980). He used a different concept of cost of capital measure by taking into account the effect of taxation and the firm's specific risk. The cost of capital measure is a weighted average of each firm's after tax cost of debt, preferred stock, and common stock. In accompanying with the actual inflation rate, he was able to obtain strong evidence that total inventories, and, in particular, work in process inventories, are sensitive to the firm's cost of capital. When an alternative cost of capital, specifically a short term commercial paper rate, is substituted as a measure of inventory carrying cost, the interest rate coefficient becomes insignificant. The actual inflation rate is used as a proxy for the expected inflation rate throughout his study and its coefficients in all regressions are insignificant.

It is important to include both the nominal interest rate and the expected inflation rate in estimation. As mentioned, the nominal interest rate and expected inflation rate are moving together theoretically but have coefficients of the opposite sign in the inventory investment equation. Omission of either one will tend to bias the coefficients of the included variable toward zero. Irvine (1981b) has tested this hypothesis by excluding the expected inflation rate from regressions. The estimated coefficients for the prime interest rate are all of wrong sign for total retail, retail durable, and retail non-durable sectors.
In sum, evidence provided by recent research on inventory behavior offers some confirmation that inventory financing costs matter. Early studies that generally failed to uncover an interest rate effect may have reflected specification errors with respect to the real rate or simply that interest rates were too stable to identify an effect. In addition, specifications on inflation expectations are important to successfully obtain a significant interest rate coefficient. An appropriate specification is the one that allows for seasonality effects, such as a weighted average of the inflation rate the same quarter last year.

The second focus of recent research is on the speed of adjusting actual inventories to the desired level. It started with the Feldstein and Auerbach's examination (1976) of manufacturing inventory behavior in which they observed an unreasonable slow speed of adjustment. Often the estimated speed of adjustment is less than 10 percent per quarter. As they argued this is implausible when even the largest swings in inventories in a given quarter amount to less than one day's production. Alternatively they proposed a target-adjustment model in which firms are closing the gap between current stock of inventories and the desired one within any period; while the target level is slowly adjusted to fundamental determinants. The estimation based on this target-adjustment model is consistent with the estimated parameter values and with the basic characteristics of inventories and sales expectations.

Maccini and Rossana (1981) tested Feldstein and Auerbach theory by including a real wage rate, real resource cost, and/or real interest
rate as fundamentals in determining the speed of adjustment. With the inclusion of expected sales only, the model fits very poorly, and the estimated speed of adjustment is extremely low. Lengthening the lag on industry orders (which is used to represent expected sales) resulted in an improved fit of the model and an increase in the estimated speed of adjustment. When real wage rate and real resource prices are added into the basic model in conjunction with a search for the optimal lag combination, the point estimates on the adjustment speed rise substantially, and the overall statistical significance of the adjustment speed was increased. These findings indicate that firms close the gap between actual and desired inventories very quickly; though desired inventories respond only slowly to changes in actual magnitudes of economic variables.

The stock-adjustment model does not totally fail in yielding a reasonable speed of adjustment estimate. Irvine (1981b) and Pearce and Wisley (1983) estimate that adjustments to the desired level could be completed within two months, though not as fast as implied by the target-adjustment model. Examination of both theories and specifications indicates that the difference in the results may lie in the specification of sales expectations. Specifying sales expectations is important in determining the speed of adjustment because it appears in the desired inventory equation. Formulating expectations of sales to depend on relevant determinants, such as sales in the same period last year, tends to boost the speed of adjustment estimate in comparison with
<table>
<thead>
<tr>
<th>Source</th>
<th>Methodology and Data Source</th>
<th>Estimated Speed of Adjustment</th>
<th>Sales Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldstein and Auerbach (1976)</td>
<td>Target-Adjustment model</td>
<td>.940 (Durable Manufacturing)</td>
<td>Survey estimates</td>
</tr>
<tr>
<td>Blinder (1981)</td>
<td>(S,s) model</td>
<td>.67 (all retail)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.459</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.374</td>
<td></td>
</tr>
</tbody>
</table>

S^e_t = a(L)S^e_{t-1} + b(L)P_t + c(L)P^e_t + \epsilon_t

where a(L)= fourth-order distributed lag;

P_t = industry's relative price;
P^e_t = real personal income.

S^e_t = S^e_{t-12}\left[\frac{1}{3}\left(\frac{S^e_{t-1}}{S^e_{t-13}} + \frac{S^e_{t-2}}{S^e_{t-14}} + \frac{S^e_{t-3}}{S^e_{t-15}}\right)\right]

ARIMA: S^e_t = (1-B^{12})(1-B)S_t

Narrowly rational: (1-B^{12})(1-B)(1-\phi^3)S_t = (1-\phi_1 B)(1-\phi_2 B^{12})(S_t - S^e_t)

Naive: S^e_t = S_{t-12}

Perfect foresight: S^e_{t+1} = S_{t+1} + \epsilon_{t+1}
<table>
<thead>
<tr>
<th>Study</th>
<th>Estimated Speed of Adjustment</th>
<th>Sales Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akhtar (1983)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Quarterly, 1965:IV-1981:II)</td>
<td>.61 (total business)</td>
<td>Naive expectations: $S^e_t = S_{t-1}$</td>
</tr>
<tr>
<td>(Quarterly, 1972:I-1981:II)</td>
<td>.59 (total business)</td>
<td></td>
</tr>
<tr>
<td>Feldstein and Auerbach (1976)</td>
<td>.057 (durable manufacturing)</td>
<td>Naive expectations: $S^e_t = S_{t-1}$</td>
</tr>
<tr>
<td>Blinder (1981)</td>
<td>.06 (all retail)</td>
<td>Distributed lag function as specified for the $(S,s)$ model</td>
</tr>
<tr>
<td>(Monthly, 1960:2-1980:II)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Unless specified, all studies employ a stock-adjustment model as a theoretical foundation.
naive expectations based on sales last period or a simple distributed lag expectations specification.

Empirical Results

To test the effect of increased interest rate volatility on investment in inventories, we follow the device of Maccini and Rossana (1981) to include interest rate volatility as a key determinant of desired inventories. That is, we assume that

\[ I_t^* = \lambda_0 + \lambda_1 s_t^e + \lambda_2 r_t + \lambda_3 o_r^2; \]  

(3.5)

where \( o_r^2 \) = interest rate volatility;

\[ \lambda_1 > 0, \quad \lambda_2, \lambda_3 < 0. \]

This specification is consistent with our theoretical finding from the micro model of inventory investment discussed in Chapter 2. As in the micro theory, we require that \( \lambda_3 \) be negative to reflect the adverse impact on inventory demand of increasing cost in holding inventories associated with increased interest rate volatility. Following the traditional specification, the desired level of inventories is formulated to respond positively to expected sales and negatively to the level of the real rate of interest.

Substituting (3.5) into (3.1), we have

\[ \Delta I_t = b_0 + b_1 I_{t-1} + b_2 s_t^e + b_3 (s_t - s_t^e) + b_4 r_5 + b_5 o_r^2; \]

(3.6)

where \( b_0 = \alpha_0 \lambda_0 > 0; \)
Equation (3.6) is the reduced form equation for empirical estimation. Before we are able to perform any estimations, two unobservable variables require careful specification. In this study, we test the hypotheses that both the level and volatility of the real interest rate matter in inventory investment using two specifications of expected sales and three specifications of the real interest rate and associated variances.

Evidence provided by Maccini and Rossana (1981) and Pearce and Wisley (1983) indicates that ARIMA forecasts of sales generally convey more relevant information than expectations of sales from a distributed lag model. Based on this finding, we follow an ARIMA procedure in forecasting sales for the coming period and search for appropriate lag combinations to reach an ARIMA(2,0.1) model as

$$S^e_t = \delta_1 S_{t-1} + \delta_2 S_{t-2} + \varepsilon_t - \xi \varepsilon_{t-1}.$$  \hspace{1cm} (3.7)

This yields a prediction closer to the actual sales than any other lag combination of ARIMA models.
A naive sales expectations formulation, allowing only for seasonal adjustment, is shown by Irvine (1983) and Akhtar (1983) to fit as well as an ARIMA model. Accordingly we also employ such a naive model with

\[ S_t^e = S_{t-1}. \] (3.8)

Three specifications on the real rate of interest and associated variances are tested:

1. ARIMA(1,0,1): \[ P_t^e = \xi_1 P_{t-1} + \nu_t + \tau_1 \nu_{t-1}; \]
2. Naive: \[ P_t^e = \left( P_{t-1} + P_{t-2} + P_{t-3} + P_{t-4} \right)/4; \]
3. Narrowly Rational: \[ r_t = (1-\eta) \sum_{k=1}^{\infty} (\eta)^{t-k}(1-\Pi_{t-k}), \]
where \( \eta = 0.94871. \)

Of the three specifications, the real interest rate forecasted according to a narrowly rational expectations scheme requires some explanation. The optimal forecasting rule is proposed by Muth (1960) which is an exponentially weighted sum of past levels of the real rate. The distinct feature of this forecasting rule is that the weighting coefficient \( \eta \) depends on the variance of the permanent component in the real interest rate relative to the variance of its transitory part. According to Garbade and Watchel's study (1978) on the constancy of the real interest rate, \( \eta \) takes the value of 0.94871.

Interest rate volatility based on the exponentially weighted forecasting rule is represented by a weighted absolute forecasting error:

\[ EP^3 = \phi \sum_{j=1}^{N} (1-\phi)^{t-j} \epsilon_{t-j}. \]
where $\varepsilon_t = r_t - (i_t - \Pi_t)$, which is the difference between the real rate of interest forecasted by the narrowly rational expectation model, $r_t$, and the realized real interest rate, $(i_t - \Pi_t)$. $\phi$ is the speed of adjustment of the real interest rate expectations to its expectation error. McCulloch (1983) has shown that a representative value for $\phi$ is one-six, which corresponds to an average lag of 6 months in the adjustment of real rate expectations to its forecasted error.

The expected inflation rate generated by the ARIMA or Naive model is calculated by

$$\Pi^e_t = \log(P^e_t/P^e_{t-1});$$

and the real rate of interest is calculated as

$$r_t = i_t - \Pi^e_{t+1}.$$

Note that in calculating the real rate, special care has been taken to line up the nominal interest rate to the expected inflation rate over the next period so that the calculated value is consistent with the definition of the real interest rate.

Interest rate volatility is represented by the deviation of the real rate generated by the ARIMA or Naive model to its respective time trend. That is we first fit a trend real interest rate based on the values of $r_t$ generated above and calculate interest rate volatility as

$$\sigma_r^2 = (r_t - r^T_t)^2.$$
Our sample period runs from 1965:I through 1982:IV based on seasonally adjusted quarterly data published in the *Survey of Current Business*. Ideally seasonally unadjusted data should be employed to reflect the instantaneous impulse of changes in economic determinants on inventory holdings. However not all variables are published as seasonally unadjusted and therefore a seasonally adjusted series is used. A priori, due to the inertia in adjusting inventories, one would expect that quarterly data on inventories would display serially correlated errors. The Durbin-Watson statistic calculated for estimates of equation (3.3) based on the ordinary least square method confirms this. To correct for serial correlation, a Cochrane-Orcutt adjustment is employed.  

Table 3.3 and 3.4 summarize estimated results under different specifications for the period of 1965:I - 1982:IV and 1973:I - 1982:IV, respectively. The results indicate that specifications based on the Naive and ARIMA formulations tend to yield better estimates than are obtained with a narrowly rational expectation formulation. Both the overall explanatory power and estimated coefficients are more significant for the Naive or ARIMA formulation of expectations than for the rational formulation. This result confirms previous findings that a rational expectation formulation tends to distribute the effect of surprises over a long period which weakens its instant impact on inventory investment decisions, while a Naive or an ARIMA model reflect shocks more strongly and quickly.
### TABLE 3.3

INVENTORY INVESTMENT ESTIMATIONS

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Naive Total</th>
<th>ARIMA Total</th>
<th>Narrowly Rational Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Business</td>
<td>Retail</td>
<td>Business</td>
</tr>
<tr>
<td>Current Sales</td>
<td>-.01</td>
<td>.34</td>
<td>-2.04</td>
</tr>
<tr>
<td></td>
<td>(.01)</td>
<td>(3.64)</td>
<td>(2.65)</td>
</tr>
<tr>
<td>Lagged Sales</td>
<td>2.73</td>
<td>.21</td>
<td>2.20</td>
</tr>
<tr>
<td></td>
<td>(3.24)</td>
<td>(.48)</td>
<td>(2.81)</td>
</tr>
<tr>
<td>Lagged Inventories</td>
<td>-.39</td>
<td>-.48</td>
<td>-.24</td>
</tr>
<tr>
<td></td>
<td>(2.47)</td>
<td>(2.40)</td>
<td>(2.17)</td>
</tr>
<tr>
<td>The Rate of Interest</td>
<td>-.78***</td>
<td>-.51**</td>
<td>-.36**</td>
</tr>
<tr>
<td></td>
<td>(1.41)</td>
<td>(2.07)</td>
<td>(1.40)</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>-.07</td>
<td>-.17*</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>(.60)</td>
<td>(2.99)</td>
<td>(.41)</td>
</tr>
<tr>
<td>New Orders</td>
<td>.54</td>
<td>.58</td>
<td>.60</td>
</tr>
<tr>
<td></td>
<td>(7.75)</td>
<td>(6.41)</td>
<td>(9.19)</td>
</tr>
</tbody>
</table>

R²                     | .55         | .50         | .50                     | .48         | .53      | .42    |
S.E.                   | 4.99        | 2.98        | 5.26                    | 3.06        | 5.06     | 3.22   |
D.W.                   | 1.90        | 2.03        | 1.86                    | 2.08        | 1.92     | 2.19   |
Rho                    | .29         | .19         | .18                     | .18         | .27      | .38    |

Note: a. Absolute values of t-statistics are in parentheses.

b. When an ARIMA model is used, forecasted sales and sales forecast error are substituted for current sales and lagged sales, respectively.

c. *: significant at 1% level;
   **: significant at 5% level;
   ***: significant at 10% level.
### TABLE 3.4

**INVENTORY INVESTMENT ESTIMATIONS**


<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Naive</th>
<th>ARIMA</th>
<th>Narrowly Rational</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Business</td>
<td>Retail</td>
<td>Total Business</td>
</tr>
<tr>
<td>Current Sales</td>
<td>-1.73 (1.68)</td>
<td>-.14 (.27)</td>
<td>.54 (.88)</td>
</tr>
<tr>
<td>Lagged Sales</td>
<td>3.24 (2.61)</td>
<td>1.30 (2.65)</td>
<td>.02 (.03)</td>
</tr>
<tr>
<td>Lagged Inventories</td>
<td>-.64 (2.19)</td>
<td>-1.78 (3.15)</td>
<td>-.35 (2.13)</td>
</tr>
<tr>
<td>The Rate of Interest</td>
<td>-1.14*** (1.34)</td>
<td>-.58*** (1.42)</td>
<td>-.78** (1.79)</td>
</tr>
<tr>
<td>Interest Rate Volatility</td>
<td>.02 (.14)</td>
<td>-.15 (1.93)</td>
<td>-.02 (.24)</td>
</tr>
<tr>
<td>New Orders</td>
<td>.58 (5.49)</td>
<td>.58 (4.49)</td>
<td>.74 (5.07)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.56</td>
<td>.54</td>
<td>.53</td>
</tr>
<tr>
<td>S.E.</td>
<td>6.14</td>
<td>3.21</td>
<td>6.35</td>
</tr>
<tr>
<td>D.W.</td>
<td>1.90</td>
<td>2.37</td>
<td>1.88</td>
</tr>
<tr>
<td>Rho</td>
<td>.29</td>
<td>.66</td>
<td>.19</td>
</tr>
</tbody>
</table>

See notes to Table 3.3.
Our main concern is on the significance of the real interest rate coefficient and interest rate volatility coefficient. Table 3.3 indicates that the real interest rate had a significant effect on inventory behavior over the years of 1965 through 1982, at least in the retail sector, under either the Naive or the ARIMA specification. A percentage increase in the real interest rate will decrease inventory investment by .36 to .78 billions dollars in the economy. The response is even greater when only the sample period from 1973:I to 1982:IV is considered. The coefficient increases to .78, or to 1.14 for the economy under the Naive and ARIMA specifications, respectively. This result supports the recent finding that the real rate of interest is important in explaining inventory holdings, which contradicts the earlier findings that inventory investment is insulated from changes in the real interest rate.

Estimates of the effect of interest rate volatility generally do not confirm the hypothesis that an increase in interest rate volatility reduces inventory investment. Although we estimate four negative interest rate volatility coefficients out of six regressions, only one is significant at the 1 percent level and two are significant at close to the 10 percent level of significance. The coefficients for interest rate volatility are smaller relative to estimated coefficients for the real interest rate in all regressions.

The effect of increases in interest rate volatility is more significant when only the retail sector is estimated. For the full sample period, the estimated coefficients are significant at the 1
percent level of significance with the Naive expectations specified and close to the 10 percent level under the ARIMA specification. With a subperiod 1973:1 to 1982:IV that includes more volatile interest rates, the estimated coefficients are significant at the 5 percent significance level for both expectation specifications.

The fact that we are unable to detect a significant interest rate volatility effect on total business inventory investment does not necessarily imply that interest rate volatility does not matter in firms' inventory management. Its effect may be blurred because firms changed their inventory strategy. Higher interest rate volatility to some extent implies a structural change in the financial sector of the economy which in turn causes behavioral changes in firms' financing and hence in their inventory strategy. A comparison of the coefficients for lagged inventories, which measures the speed of adjustment, in Table 4.3 and 4.4 indicates that the speed of adjustment has increased 100 to 300 percent since 1973. Firms appear to be closing any gaps between the desired and actual levels of inventories within a month or two, which is much faster than was estimated in previous research.

The high speed of adjustment estimated in the stock-adjustment model, when interest rate volatility is included, may be due to the structural changes in inventory behavior, instead of the notion that the desired inventory is slowly adjusted to its fundamental determinants. To the extent that the target-adjustment model is correct, interest rate volatility should have a lagged effect on the desired inventory accumulation or decumulation, while the gap between the desired and
actual inventories is closed quickly. This is not supported when we lengthen the lag on interest rate volatility in regressions. The sum of the estimated coefficients for interest rate volatility is of the wrong sign or insignificant. That there is a faster speed of adjustment in conjunction with inventory investment not reacting to past levels of interest rate volatility leads us to believe that the faster speed of adjustment is caused by a structural change in inventory behavior.

The hypothesis that more volatile interest rates has induced a structural change in firms' inventory behavior, in particular for the period after October 1979, is further supported by Chow-test statistics in Table 3.5. The calculated F statistics based on estimates in Table 3.3 and 3.4 are not significantly different from $F(13,52) = 2.00$ at the 5 percent level of significance. The division of the whole sample period at 1973:I does not yield evidence of structural change. If we divide the sample at 1979:IV and reestimate the equation, the calculated F statistics are significant, in particular with the Naive specification. This suggests that there may have been a structural change in firms' inventory behavior since October 1979.

The effect of increased interest rate volatility may be further blurred since the increased volatility tends to push up the level of the real rate. There may be a risk premium added to the real rate when the real rate is volatile. The association between the level and volatility of the real rate of interest causes a multicollinearity problem in estimations when both the level and volatility are included. As a
### TABLE 3.5

**SUM OF SQUARED RESIDUALS AND F STATISTICS**

<table>
<thead>
<tr>
<th>Period</th>
<th>Naive Total</th>
<th>Naive Retail</th>
<th>ARIMA Total</th>
<th>ARIMA Retail</th>
<th>Narrowly Rational Total</th>
<th>Narrowly Rational Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Business</td>
<td></td>
<td>Business</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965:I-1972:IV</td>
<td>226.82</td>
<td>137.66</td>
<td>265.22</td>
<td>156.99</td>
<td>239.28</td>
<td>142.15</td>
</tr>
<tr>
<td>1973:I-1982:IV</td>
<td>1244.74</td>
<td>359.87</td>
<td>1330.60</td>
<td>345.95</td>
<td>1280.05</td>
<td>389.15</td>
</tr>
<tr>
<td>1965:I-1982:IV</td>
<td>1617.21</td>
<td>587.58</td>
<td>1795.36</td>
<td>616.95</td>
<td>1661.03</td>
<td>684.75</td>
</tr>
<tr>
<td></td>
<td>.79</td>
<td>1.96</td>
<td>1.00</td>
<td>2.19</td>
<td>.87</td>
<td>2.79</td>
</tr>
<tr>
<td>1965:I-1979:III</td>
<td>714.11</td>
<td>329.52</td>
<td>865.83</td>
<td>497.17</td>
<td>981.31</td>
<td>505.66</td>
</tr>
<tr>
<td>1979:III-1982:IV</td>
<td>332.37</td>
<td>63.87</td>
<td>532.36</td>
<td>37.94</td>
<td>136.30</td>
<td>37.42</td>
</tr>
<tr>
<td>1965:I-1982:IV</td>
<td>1617.21</td>
<td>587.58</td>
<td>1795.36</td>
<td>616.95</td>
<td>1661.03</td>
<td>684.75</td>
</tr>
<tr>
<td></td>
<td>4.52</td>
<td>4.93</td>
<td>2.36</td>
<td>1.53</td>
<td>4.03</td>
<td>2.61</td>
</tr>
</tbody>
</table>
consequence, the estimated coefficients for both variables tend to have large sampling errors, and thus the actual estimates may be far from the true parameter values. Further, estimated coefficients may be sensitive to addition or deletion of a few observations or the deletion of an apparently insignificant variable. Here we test this by not including interest rate volatility in estimations. When the level of the real interest rate is included alone, it is more significant than when volatility is also included.

In summary, even though the estimations do not yield clear cut evidence with regard to the effect of increasing interest rate volatility, there may be an effect implicit in changes in the speed of adjustment reflecting that firms have adapted to more volatile interest rates by adjusting actual inventories to the desired level more quickly. In addition, an interest rate volatility effect may have been hidden by the rise in the level of the real rate, a fact that is hard to sort out in empirical tests.
1. The other inventory theory that is famous in management science but does not generate much attention in empirical economics is the two-bin \((S, s)\) model. Only Blinder (1981) implemented the theory in empirically testing inventory investment in the retail industry.

2. As suggested by Feldstein and Auerbach (1976) and Maccini and Rossana (1981), firms are actually adjusting to the desired levels very fast, while adjusting the desired level slowly according to its fundamental determinants. This implies that the speed of adjustment \(\alpha_0\) is close to unity.

3. In addition, firms can adjust their prices based on information extracted from excess demand. A permanent increase in demand more likely leads the firm to increase its production and prices; while a temporary increase only leads to a decumulation of inventories. Another subject of recent investigation on inventory behavior is to show how inventory holdings affect price adjustment. For a detail survey, see chapter 2.

4. Exceptions are provided by Liu (1963, 1969). For a detailed survey of early studies, see Eisner and Strotz (1963), and Rowley and Trevedi (1975).

5. Four specifications are tested by Irvine (1981b): Naive, AR(2), polynomial distributed lag, and rational expectations. He concludes that a capital cost measure based on a naive expectations formulation yields the best result. The same test has been performed by
Akhtar (183). Of the three specifications tested: static, adaptive, and rational, the formulation of adaptive expectations of prices in the previous four quarters is judged best.

6. Whether the nominal rate and the expected inflation rate should be separated in estimation is another subject of controversy; but results will not be changed as long as both are included.

7. Additional impact of interest rate volatility is on the speed of adjustment $\alpha_0$ in equation (4.1). We expect that $\alpha_0$ would be larger for the period with highly volatile interest rates.

8. Betancourt and Kelejian (1981) argue that the Cochrane-Orcutt estimation procedure is inconsistent when the lagged dependent variables are presented.

9. Other factors that might cause the structural change include the use of computer, expectations of the 1980 recession, a credit control implemented in 1980:II and III, and innovations in financial markets.

10. Other econometric solutions to the multicollinearity problem include obtaining additional or better data, imposing exact linear constraints, and imposing stochastic linear restrictions. For details, see Judge, Hill, Griffiths, Lutkepohl, and Lee (1982) or Maddala (1977).
This study focuses on two phenomena: relatively low and volatile inventory investment and high and volatile interest rates during 1979-1982. Increased interest rate volatility is shown to first disrupt the capital raising mechanism both by decreasing loanable funds available and by raising the cost of external inventory financing. Optimization for business firms requires an inventory policy that balances the costs of financing inventory holdings relative to the costs of inventory ordering and adjustment. Increases in interest rate volatility raise the costs of inventory holdings which in turn, in a comparative static analysis applying the definition of increasing risk, decrease inventory holdings of business firms.

The negative impact of increased interest rate volatility on inventory investment is different from the invariant effect on business fixed investment obtained by Hartman (1972) or the positive effect derived in Pindyck (1982) of increased volatility in the cost of capital. The difference stems from the inherently different roles played by capital and inventories in the firm's decision process. Inventories are buffer stocks which absorb random fluctuations in demand and influence the firm's expected sales. Capital, on the other hand, is a quasi-fixed
factor which enters the firm's production process and thus affects output. Increased interest rate volatility therefore has different implications on fixed investment and inventory investment. It would be interesting to integrate both capital and investment in finished goods into a theoretical framework, such as the one by Maccini(1984), to study their relative adjustments to exogenous shocks.

It is common not to find significant interest rate effects on inventory investment empirically. It is even harder to detect the impact of increased interest rate volatility. Indeed so it is in this study when we tried to test the theory empirically. Some confirming evidences have been obtained, but not all. Several factors contribute to reduce the significance of the interest rate variability, such as credit controls in 1980:II and III, and financial innovations that were developed to hedge against interest rate risk. One particular factor that can be identified in blurring the effect is that the interest rate volatility effect has been embodied in the level of interest rate. That this has likely occurred is evidenced by the fact that when the level of the real interest rate is included alone in estimation, it is more significant than when volatility is also included.

Any interest rate volatility effect is further blurred by structural change in inventory policy and increases in the speed of inventory adjustment. In this study we are able to identify a structural change in inventory policy before and after October 1979 by the Chow test. In addition, the speed of adjusting inventories has been increased by 100 to 200 percent. Whether the structural change in
inventory policy can be attributed to increased interest rate volatility is not tested in this study and should be an interesting subject for further research.

Future extention includes developments of different theories for inventory investment according to stages of fabrication or for different sectors in the economy. Since time series data show different patterns of inventory behavior in different sectors, especially around cyclical turning points, separate analysis is needed.

Theoretically inventory investment serves as a buffer stock to production. How much it contributes to output variation is an empirical issue. The subject, though not well exploited so far, could provide important insight into the business cycle.

Finally both inventory investment and labor employment to some extent are affected by a firm's decisions on investment in inventories. By building up inventories or delaying layoffs during a period of recession, firms invest in storing useable resources with which future profits could be realized. The subject has been studied by Topol(1983). The interaction between inventory investment and labor layoffs could influence the timing of a policy effect when the government attempts to stimulate the economy.


Irvine, F. O., (1981b), "Retail Inventory Investment and the Cost of


Lombra, R. E. and B. Struble (1979), "Monetary Aggregate Targets and the Volatility of Interest Rates," Journal of Money, credit, and Banking 11, August, 284-300.


Mills, E. S. (1962), Price, Output, and Inventory Policy, New York; John Wiley & Son.


