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A Cointegration-Euler Approach

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Abstract

Cyclical contractions are often referred to as inventory cycles, in part because movements in inventories can amplify cyclical fluctuations in output. An unanticipated slowing in demand generally leads to an unintended buildup of inventories: only with a lag do firms adjust production and their actual holding of inventories relative to the desired level. A possible explanation for this accumulation is that the costs of adjusting inventory holdings outweigh the disequilibrium costs, i.e., the cost of temporarily deviating from the equilibrium level of inventories.

In this paper, the relative importance of the disequilibrium costs to adjustment costs of inventories is evaluated. An estimate of the rate of inventory adjustment towards its long-run equilibrium level is provided in the United States by means of a linear-quadratic model with integrated processes. A limited-information approach allows the time-series properties of the data to be exploited and consistent estimates of the structural parameters of the Euler equation obtained.

Evidence is provided that the actual level of U.S. inventories was generally above the target level during the past six recession periods and that inventories fell below their desired level following an economic downturn. Furthermore, the actual level of inventories appears to have been at desired levels between the 1960 and the 1969-70 recessions and since the last recession in 1990–1991—two periods of sustained economic growth. These findings support the view that inventory imbalances can amplify the business cycle. The empirical estimates also imply that adjustment costs are substantially more important than disequilibrium costs. The estimate of the speed of adjustment suggests that firms adjust their holdings of inventories slowly as it takes about a year for 95 per cent of the adjustment of the actual level to the target level to be completed.

Résumé

On invoque souvent le cycle des stocks pour expliquer le ralentissement conjoncturel de l’activité économique, en partie parce que l’évolution des stocks peut amplifier les fluctuations cycliques de la production. Un fléchissement inattendu de la demande provoque généralement un gonflement involontaire des stocks, les entreprises n’ajustant leur production et le niveau effectif de leurs stocks par rapport au niveau qu’elles souhaitent détenir qu’après un certain temps. Il se pourrait que ce gonflement soit dû au fait que les coûts d’ajustement des stocks sont plus élevés que les « coûts de déséquilibre » (coûts entraînés par un écart temporaire des stocks relativement à leur niveau d’équilibre).

L’auteure évalue l’importance relative des coûts de déséquilibre et des coûts d’ajustement des stocks. Elle estime la vitesse à laquelle les stocks s’ajustent vers leur niveau d’équilibre à long terme aux États-Unis à l’aide d’un modèle quadratique linéaire à processus intégrés. La méthode d’estimation à information limitée qu’elle utilise permet d’exploiter les propriétés temporelles des données et d’obtenir des estimations convergentes des paramètres structurels de l’équation d’Euler.

Selon les résultats présentés dans l’étude, le niveau effectif des stocks aux États-Unis a été en règle générale supérieur au niveau visé durant les six dernières périodes de récession et il est tombé au-dessous de ce niveau une fois la récession terminée. En outre, les stocks semblent s’être établis au niveau souhaité entre les récessions de 1960 et de 1969–1970 et depuis la dernière récession survenue en 1990–1991 — deux périodes de croissance économique soutenue. Ces résultats appuient l’hypothèse voulant que les déséquilibres des stocks amplifient les fluctuations économiques. Les estimations empiriques indiquent également que les coûts d’ajustement sont nettement supérieurs aux coûts de déséquilibre. S’il faut en croire la vitesse d’ajustement calculée par l’auteure, les entreprises modifient lentement le niveau de leurs stocks. En effet, il leur faut environ un an pour réaliser 95 % de l’ajustement total au niveau souhaité.

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1. Introduction

Modelling the behaviour of inventories is an important area of inquiry for empirical work in macroeconomics, in part because inventory cycles can amplify cyclical fluctuations in output. The change in real business inventories averaged 0.6 per cent of the change in total Gross Domestic Product (GDP) in the United States over the period 1958:1 to 1997:2. However, during cyclical contractions, inventories contributed disproportionally to the decline in GDP (see below). As a result, most cyclical contractions have been referred to as inventory cycles. These inventory cycles are characterized by an unanticipated slowing in demand that generally leads to an unintended buildup of inventories. One explanation is that firms adjust production and their actual holding of inventories relative to the desired level only with a lag. A reduction in production can exacerbate the downturn by reducing demand further. Although one cannot claim that inventory changes cause the business cycle, any imbalances that occur between expected and actual sales have an impact on inventories and these imbalances often amplify the cycle.

The typical inventory cycle starts with an unanticipated drop in demand that leaves firms with inventories above their desired levels. Production is reduced to lower inventory holdings and may result in layoffs and a further reduction in demand. As inventories fall back to their desired level and demand resumes, production may be insufficient both to meet demand and maintain the desired level of inventories. As a result, inventories can fall below their desired level, which in turn causes increased production to restore inventories. Table 1 shows the movements in business inventories compared to the peak-to-trough change in GDP, both in real terms, in the United States during the past six recessions since 1960. The change in business inventories as a percentage of the change in GDP has fluctuated between 23.2 per cent during the 1980 recession and 5.2 per cent during the 1973-75 recession with an average change of 11.8 per cent. This compares to an average change of 0.6 per cent over the entire period. From Table 1, it is evident that inventories have contributed significantly to the decline in GDP during cyclical contractions.

Table 1: Change in real business inventories during the six recessions since 1960

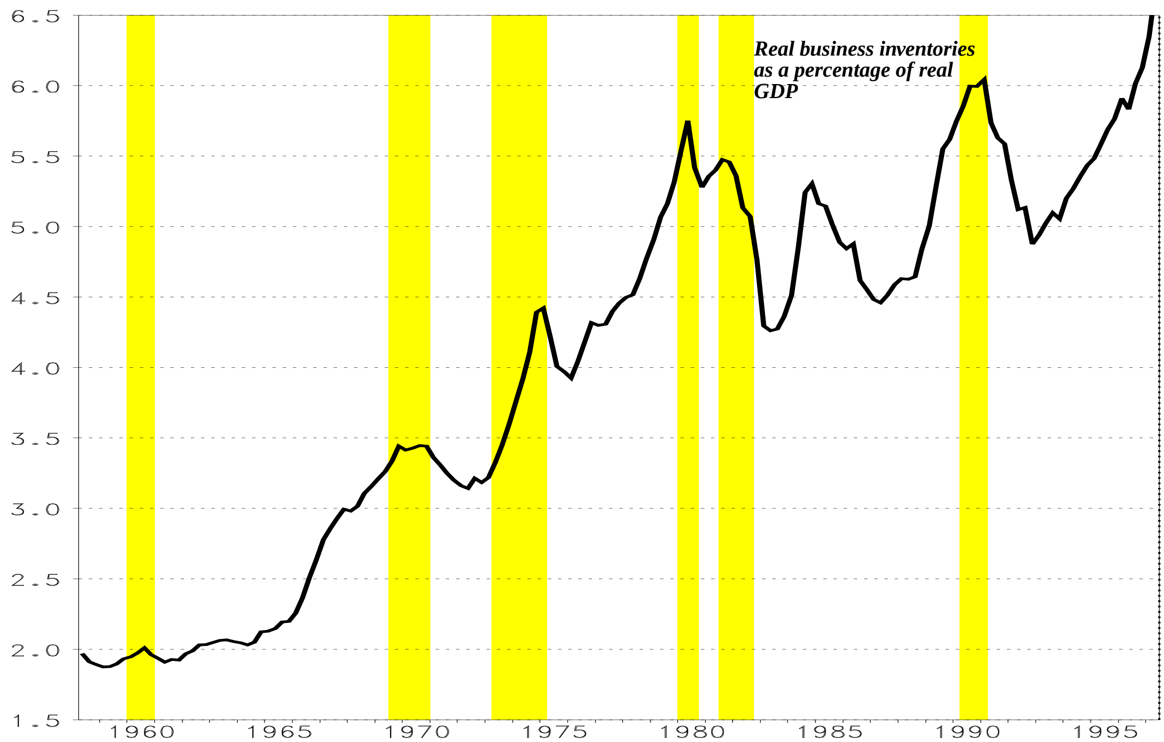
Recession period peak to trough[a]	Change in real GDP in billions of chain-weighted 1992 dollars	Change in real business inventories in billions of chain-weighted 1992 dollars	Change in real business inventories as a percentage of change in real GDP
1960:1 - 1960:4	-40.7	-3.0	7.3
1969:3 - 1970:4	-20.3	-4.5	22.0
1973:2 - 1975:1	-118.1	-6.2	5.2
1980:1 - 1980:3	-116.7	-27.1	23.2
1981:3 - 1982:3	-140.9	-10.4	7.4
1990:2 - 1991:1	-124.1	-6.7	5.4
Mean			11.8

a. The peak of the cycle is the first quarter prior to the first quarter of decline in real GDP. The trough is the last quarter of negative growth. Peaks and troughs of real GDP do not always coincide with the official National Bureau of Economic Research (NBER) recession dates.

Figure 1 plots real business inventories as a percentage of real GDP, on a quarterly basis, over the period 1958:1 to 1997:2, with recession periods shown by shaded bars; it reveals two interesting points. First, business inventories as a percentage of GDP reached a cyclical peak during the past six U.S. recessions and second, inventories as a percentage of GDP dropped off sharply after attaining the peak. The buildups in inventories during an economic slowdown probably reflect undesired accumulations.[1]

The stock-to-shipment ratio, which is defined as the total stocks divided by sales, gives some indication if movements in inventories were planned or undesired. If we assume that firms plan to maintain a constant stock-to-shipment ratio, we can conclude that an inventory accumulation that coincides with an increasing stock-to-shipment ratio is unintended. However, when an inventory accumulation coincides with a constant stock-to-shipment ratio, then the accumulation may be intended and in response to an anticipated increase in demand. The stock-to-shipment ratio is shown in Figure 2, with recession periods indicated by shaded bars. The ratio generally increased and peaked during the past six cyclical contractions, indicating that the

Figure 1:
Real business inventories as a percentage of real GDP
(1958:1 - 1997:2)

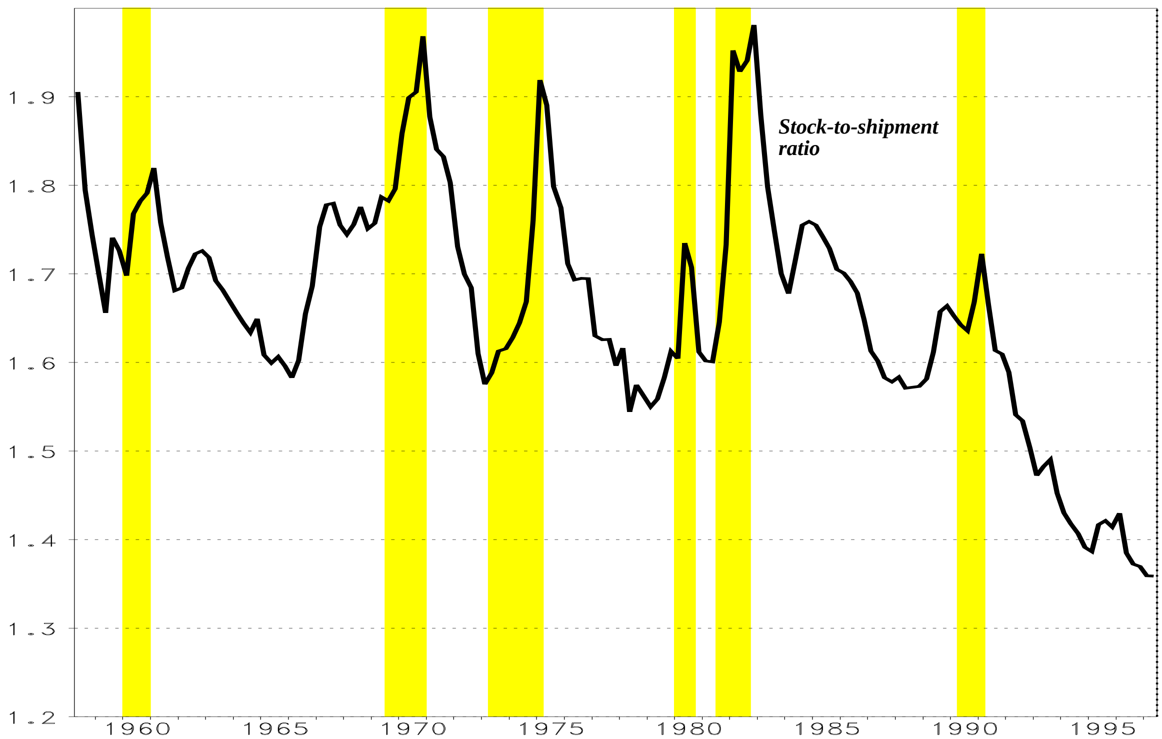


Recession periods are shaded.
Source: U.S. Department of Commerce, Bureau of Economic Analysis

1. The upward trend of real business inventories as a percentage of real GDP is probably the result of the rising share of retail inventories in total inventories (discussed later).

accumulations were likely unintended. The fact that U.S. firms maintained a level of inventories above their desired level during economic downturns supports the hypothesis that inventories are adjusted with a lag. A possible explanation is that there are costs to adjusting inventory holdings that outweigh the disequilibrium costs, i.e., the cost of temporarily deviating from the equilibrium level of inventories.

Figure 2:
Stock-to-shipment ratio - manufacturing
(1958:1 - 1997:2)



Recession periods are shaded.
Source: U.S. Department of Commerce, Bureau of the Census - “Manufacturers’ Shipments, Inventories, and Orders.”

The purpose of this paper is to evaluate the importance of adjustment costs relative to disequilibrium costs of U.S. inventories and to obtain an estimate of the speed of adjustment of the actual level of inventories to their target level. The target level of inventories is defined as the long-run equilibrium level of inventory holdings. The innovation to the existing empirical work on inventories, introduced in this paper, is the methodology that is applied. Earlier studies have obtained results that are difficult to reconcile with the data or that vary substantially and one possible explanation is the estimation techniques used.

In this paper, we estimate the adjustment costs of inventories and the rate of adjustment of inventories to their long-run equilibrium by means of a linear-quadratic model with integrated processes. We follow Amano’s 1995 application of the cointegration-Euler approach to Canadian labour demand.[2] More specifically, we are able to obtain a measure of the relative importance of the disequilibrium to adjustment costs of inventories as well as an estimate of the rate of inventory adjustment towards their equilibrium level.

Amano (1995) points out several attractive features of the linear-quadratic model. The linear-quadratic model subsumes a wide range of dynamic models. These include, for instance, partial-adjustment and error-correction models. A further advantage is that the linear-quadratic model has well-understood properties when variables that are non-stationary processes are included in the estimation. Another feature is that, although the model incorporates forward-looking elements in the decision process, it is relatively straightforward to solve when using an Euler equation approach. This approach allows the optimization problem to be solved recursively, i.e., the time path of inventories is independent of whether the entire future stream of the expected marginal return to inventory holdings or the optimal trade-off this period and next period are considered. The cointegration-Euler approach, moreover, uses a limited-information procedure. Earlier empirical studies on the behaviour of inventories often estimated the model's parameters using a full-information approach that required an explicit solution for the model's control variables in terms of the forcing processes. Applying the limited-information approach allows us to exploit the time-series properties of the data and to obtain consistent estimates of the inventory adjustment costs.

Applying the cointegration-Euler approach to quarterly U.S. real inventory data yields several interesting results. We find that, during recession periods, the actual level of U.S. inventories generally has been above the target level, which is expressed as a function of manufacturing new orders, capacity utilization, raw material prices, and the yield spread. As inventories fall back to their desired level and demand resumes following a recession, production appears insufficient to meet demand and maintain the desired level of inventories. As a result, inventories fall below their desired level. Moreover, the actual level of inventories appears to have been more or less in line with the target level between the 1960 and the 1969–70 recessions and since the last recession in 1990–91. These two periods coincide with periods of sustained economic growth. We also find that the adjustment cost is substantially more important than the disequilibrium cost. Finally, our estimate of the speed of adjustment implies that firms adjust their holdings of inventories slowly. Contrary to the findings of many earlier studies, our estimate of the speed of adjustment is not implausibly low. The estimate implies that it takes about a year for 95 per cent of the adjustment to be completed.

The paper has four further sections. In Section 2 we briefly review the literature on inventory behaviour. Section 3 outlines the linear-quadratic inventory model. Section 4 discusses the estimation procedure and presents the empirical results, while Section 5 summarizes the results and contains some suggestions for further research.

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2. The cointegration-Euler approach was proposed by Cooley and Ogaki (1996).

2. A short review of the literature on inventory behaviour

Inventory behaviour has been an important area of research in the literature.[3] Various empirical approaches to inventory modelling have been pursued, based on different views of why firms hold inventories. One model that continues to be important in the empirical research on inventories is the linear-quadratic production-smoothing model proposed by Holt, Modigliani, Muth, and Simon (1960). The basic assumption of the model is that firms hold inventories of finished goods primarily to smooth production levels given fluctuating demand and convex cost functions. However, the production-smoothing model is unable to reconcile the theory with the data as it predicts that sales are more volatile than output over time—the opposite of what the empirical evidence suggests.

As a result, a variety of authors have modified the traditional production-smoothing model. One such modification is that firms hold inventories primarily to smooth production costs, rather than production levels. Ramey (1991) relaxes the assumption of convex cost functions of the production-smoothing model and allows for non-convexities in the technology facing firms. She shows that, if imperfectly competitive firms operate in a region of declining marginal costs, then cost-minimizing firms will choose to make production more variable than sales—this is suggested by the empirical evidence.

Blinder (1986) and Christiano and Eichenbaum (1987) propose a production-cost-smoothing model in which the assumption of convex cost functions is retained. However, the authors allow for shocks to technology and to the costs of producing output. Within this framework, firms will use inventories to shift production to periods in which production costs are relatively low. Eichenbaum (1989) presents a model that includes unobserved shocks to the costs of producing output. He also finds that cost shocks are important; however, his results depend upon the assumption that the unobserved cost shocks follow an autoregressive process of order one (AR(1)).

Although production-cost-smoothing models are able to explain and model the behaviour of inventories, they produce empirical estimates of the production and inventory holding costs that vary substantially with different specifications of the model. One possible explanation proposed by West and Wilcox (1994) for the disparity of results is the specification or estimation technique. The models used generally differ in their treatment of unobserved serial correlation, observable measures of factor costs, and in the choice of instruments.

Other authors have developed models that retain the assumption that firms hold inventories to smooth production levels. Blanchard (1983) revived the target inventory model used by many macroeconomists in the 1950s and 1960s. He defines the target inventory stock as the level of inventories where costs are minimized. Blanchard argues that firms will realize increasing costs when maintaining less than the target inventory level as they will be faced with an increasing probability of realizing stockout costs. A stockout occurs when a firm faces a potential buyer, but has no inventory stock or current output on hand and therefore loses the sale. Stockout avoidance behaviour implies that firms will try to always have some inventory at hand. Eichenbaum (1984)

3. For an extensive review of the literature on modelling inventory behaviour, see Thurlow (1994).

and West (1986) include an “accelerator target inventory level.” Within this framework, it is assumed that firms do not immediately adjust actual stocks to their desired levels, but remove a fraction of any discrepancy between actual and desired stocks. Arguments used to justify this partial adjustment include inertia on the part of firms and the cost of adjusting output.[4]

These models, however, are also difficult to reconcile with the data. Stockout avoidance models imply very small inventory stocks—an implication that is not supported by the empirical evidence. Accelerator target inventory models, on the other hand, yield very low estimates of the adjustment speed. Maccini and Rossana (1984) argue that a possible reason for the low estimates of the adjustment speed is that inappropriate procedures, which fail to correct for autocorrelation, are used.

In this paper, we pursue the line of empirical research on the adjustment costs of inventories. Firms are assumed to maintain a desired level of inventories, which is defined as the long-run equilibrium level. Deviation from this target level of inventories results in two kinds of costs, the disequilibrium costs and the adjustment costs.

3. The linear-quadratic inventory model

This section describes the linear-quadratic model used to estimate the adjustment costs relative to the disequilibrium costs and the rate of adjustment of inventory holdings towards their long-run level. The derivation of the estimated equations is taken from Amano (1995).

A representative firm is assumed to control the level of inventories, inv_t, and to choose the optimal level of inventories, inv_t^{τ}, such that the expected present value of the adjustment and the disequilibrium costs are minimized, i.e.,

$$minE_t \sum_{i=t}^{\infty} \beta^{i-t} [\Upsilon(inv_i - inv_i^{\tau})^2 + (inv_i - inv_{i-1})^2] \tag{1}$$

for $i \geq t$, subject to a law of motion between the target level of inventories and some observable economic variables. Equation (1) is composed of the two types of costs, where $(inv_i - inv_i^{\tau})$ represents the disequilibrium costs and $(inv_i - inv_{i-1})$ the adjustment costs. Expectations are assumed to be formed rationally. E_t is the mathematical expectations operator, conditional on the information set available at time t, I_t. The parameter β is the firm’s subjective discount factor, $\beta \in (0, 1)$, and $\Upsilon > 0$ is a weighting factor that determines the importance of the disequilibrium costs relative to the adjustment costs. The target level of inventories is assumed to follow the law of motion,

$$inv_t^{\tau} = X_t'\alpha + \upsilon_t , \tag{2}$$

where υ_t is a white-noise process known to the firm, but unknown to the econometrician, X_t is a $k \times 1$ vector of forcing variables, and α is a $k \times 1$ vector of unknown parameters.

4. Kahn (1987) formally shows that the accelerator effect arises when modelling the stockout avoidance motive for accumulating inventory.

The first-order necessary condition for minimization of equation (1) is given by the Euler equation

$$\Delta inv_t = \beta E_t \Delta inv_{t+1} - \Upsilon(inv_t - inv_t^{\tau}) \tag{3}$$

and the transversality condition is given by

$$\lim_{T \to \infty} E_t[\beta^T(\Upsilon(inv_T - inv_T^{\tau}) + \Delta inv_T)] = 0. \tag{4}$$

The forward solution to equation (3) can be derived as

$$inv_t = \lambda inv_{t-1} + (1-\lambda)(1-\beta\lambda)E_t \sum_{i=t}^{\infty} (\beta\lambda)^{i-t} inv_i^{\tau} \tag{5}$$

where λ, with $\lambda < \frac{1}{\sqrt{\beta}}$, measures the speed of adjustment of the inventory stock to the target level and is the smallest stable root of the Euler equation that satisfies the condition

$$\beta\lambda^2 - (1 + \beta + \Upsilon)\lambda + 1 = 0. \tag{6}$$

Equations (2) and (5) imply that the control variable inv_t will inherit any stochastic trend in the forcing variables. Suppose that X_t is an independent random walk, i.e.,

$$(1-L)X_t = e_t \tag{7}$$

where $E_{t-1}e_t = 0$. Substituting equation (2) into (5) and (7) yields

$$(1-\lambda L)inv_t = (1-\lambda)X_t'\alpha + (1-\lambda)\upsilon_t. \tag{8}$$

The root λ lies inside the unit circle and it follows from equation (8) then that the endogenous variable, inv_t, must be integrated of order one, I(1), and that the error term, υ_t, is white noise, i.e., I(0). This implies that inv_t and X_t are cointegrated with the cointegration vector $(1, \alpha)$ and that the cointegration restriction is implied by the linear-quadratic model.

A Euler equation that can be estimated is obtained by substituting equation (2) into (3), i.e.,

$$\Delta inv_t = \beta E_t \Delta inv_{t+1} - \Upsilon(inv_t - X_t'\alpha) + \Upsilon\upsilon_t \tag{9}$$

and then replacing $E_t\Delta inv_{t+1}$ by its realization Δinv_{t+1}. Re-writing equation (9) yields

$$\Delta inv_t = \beta\Delta inv_{t+1} - \Upsilon(inv_t - X_t'\alpha) + \eta_{t+1} \tag{10}$$

where $\eta_{t+1} = \beta u_{t+1} + \Upsilon\upsilon_t$, such that $E_t\eta_{t+1} = 0$. The disturbance, η_t, is thus a composite error term that can be re-written as a first-order moving-average (MA(1)) process, under the assumption that the structural error term, υ_t, is white noise. Equation (10) may be interpreted as a forward-looking error-correction model. Since the model implies that inv_t and X_t are cointegrated, a two-stage procedure for estimating the parameters in equation (10) is applied as suggested by Dolado, Galbraith, and Banerjee (1991).

4. Estimation procedure and results

This section discusses the data and presents the empirical results from the estimation of the target level of inventories. As well, the procedures used to estimate the weighting factor, Υ, that determines the importance of the disequilibrium costs relative to the adjustment costs and the speed of adjustment term, λ, are discussed and the empirical results are presented.

4.1 The data

To implement the two-step approach, the forcing variables, X_t, that influence the target level of inventories, inv_t^{τ}, are specified. The target stock of U.S. inventories is expressed as a linear function of new orders, capacity utilization in the manufacturing sector, raw material prices, and the yield spread (the differential between the ten-year Treasury bond yield and the three-months T-bill rate),

$$inv_t^{\tau} = \alpha_0 + \alpha_1 orders_t + \alpha_2 caput_t + \alpha_3 raw_t + \alpha_4 spread_t + \zeta_t \tag{11}$$

where $\zeta_t = (1-\lambda L)^{-1}(\lambda\gamma\nu_t - \lambda\alpha e_t)$.[5] New orders are used as a measure of expected sales and the comovement between desired inventories and new orders should be positive. Capacity utilization is included to capture technology shocks. Finn (1996) notes that a positive technology shock enhances the productivity of the factors of production, including capital, and thereby increases their usage. The increase in the marginal productivity of capital utilization should lead to an increase in capacity utilization and production and a lower level of target inventories. The comovement of capacity utilization and desired inventories is expected to be negative. Raw material prices are used as a measure of factor costs and a positive price shock should reduce the level of inventories producers are willing to hold. The yield spread is a measure of the monetary policy stance and captures the availability of credit to firms. An easing of monetary policy, i.e., the spread between long and short rates widens, increases credit availability. This, in turn, lowers the opportunity cost of holding inventories and should raise the desired level of inventories. Moreover, the yield spread, as the difference between two nominal rates, provides a measure of a change in real interest rates that results from a shift in inflation expectations that is embedded in the term structure. An upward shift in inflation expectations should increase the desired level of inventories and the comovement between the spread and the target level of inventories is expected to be positive.

Inventories are in real terms and include finished goods, work-in-process inventories as well as production inputs. Inventories, new orders, and capacity utilization are for the manufacturing

5. Other variables that were initially considered include: suppliers delivery index, employment in the goods-producing sector, stocks-to-sales ratio, and investment in machinery and equipment. These variables were either not statistically significant or had the wrong expected signs. Results are not included, but are available upon request.

sector. New orders and raw material prices, measured by the price of intermediate materials less foods and feeds, are deflated by the producer price index for finished consumer goods excluding food. All variables are seasonally adjusted and measured in logarithms, with the exception of the yield spread. Capacity utilization is also included in levels. We use quarterly data for the period 1958:1 to 1997:2.[6] The choice of the sample period is dictated by the availability of new orders and the seasonal frequency by the availability of the inventory data.[7] Details regarding the data are presented in Appendix 1.

4.2 Tests for integration

The time-series properties of the data are examined using both the augmented Dickey and Fuller (1979) test and a modified version of the Phillips and Perron (1988) Z_α test proposed by Stock (1991). Both the ADF test and the modified Phillips-Perron Z_α (MZ_α) test allow us to test formally the null hypothesis that a series is I(1) against the alternative that it is I(0). The results from the tests of the time-series properties of the data can be found in Table 2 in Appendix 2. ADF critical values are generated to account for the finite-sample distribution of the series by performing Monte Carlo simulations with 5,000 replications for the level of inventories, the level of new orders, capacity utilization, the price of raw materials and the yield spread.[8] Before conducting the experiment, we accounted for the possibility that the variables follow an autoregressive moving-average process. Schwert (1987) provides evidence that the presence of moving-average components leads to different critical values than the tabulated Dickey-Fuller critical values reported in Fuller (1976). Evidence was found that capacity utilization contains a moving-average component, while the yield spread appears to follow an autoregressive moving-average process.[9]

Table 2 (Appendix 2) indicates that both the ADF and the MZ_α tests suggest that inventories, new orders, and raw material prices are non-stationary or I(1) processes in levels. The ADF test rejects the null hypothesis of a unit root in the level of the yield spread at conventional levels of significance and also provides evidence that capacity utilization is characterized as a stationary or I(0) process. Both the ADF and the MZ_α tests suggest that inventories, new orders, and raw material prices are stationary or I(0) processes in first-differences at the 1 per cent level of significance.

6. In an earlier version of this paper, we used monthly data. However, no real inventory data were available on a monthly basis. Deflating nominal inventories by the producer price index did not yield results that were comparable to the quarterly real data published by official U.S. statistical agencies.
7. The price of intermediate materials is used instead of raw material prices due to availability of the data. The food and feed component is excluded from the price measures as it is expected to impact farm, but not non-farm, inventories.
8. Corrected critical values were not generated for first-differences due to the time involved in conducting the experiment.
9. The conclusion was based on the Akaike and Schwartz criteria. Results are not included but are available upon request.

4.3 Estimation of the desired level of inventories

4.3.1 Tests for cointegration

An implication of the linear-quadratic model is that, if inv_t, $orders_t$ and raw_t are integrated of the highest order, i.e., I(1), then X_t should form a cointegrating relationship with inv_t. Equation (11) is estimated and the residuals are examined to determine whether or not the variables in X_t and the endogenous variable inv_t share a stochastic trend. The Engle and Granger (1987) and the Stock and Watson (1993) tests for cointegration are applied. The results of the ADF and the MZ_{α} tests from the Engle-Granger and the Stock-Watson procedures are presented in Table 3 in Appendix 3.

Table 3 (Appendix 3) indicates that the ADF test rejects the null hypothesis of no cointegration at the 10 per cent level and the MZ_{α} test at the 1 per cent level for the Stock-Watson cointegration test. The less-powerful Engle-Granger test provides less evidence of a cointegrating relationship between the variables. One should note, however, that if the adjustment costs are high relative to the disequilibrium cost, i.e., γ is small; then the λ that satisfies the condition in equation (6) approaches unity and the error term in equation (11), ζ_t, becomes nearly integrated. Evidence consistent with cointegration is therefore more difficult to detect.

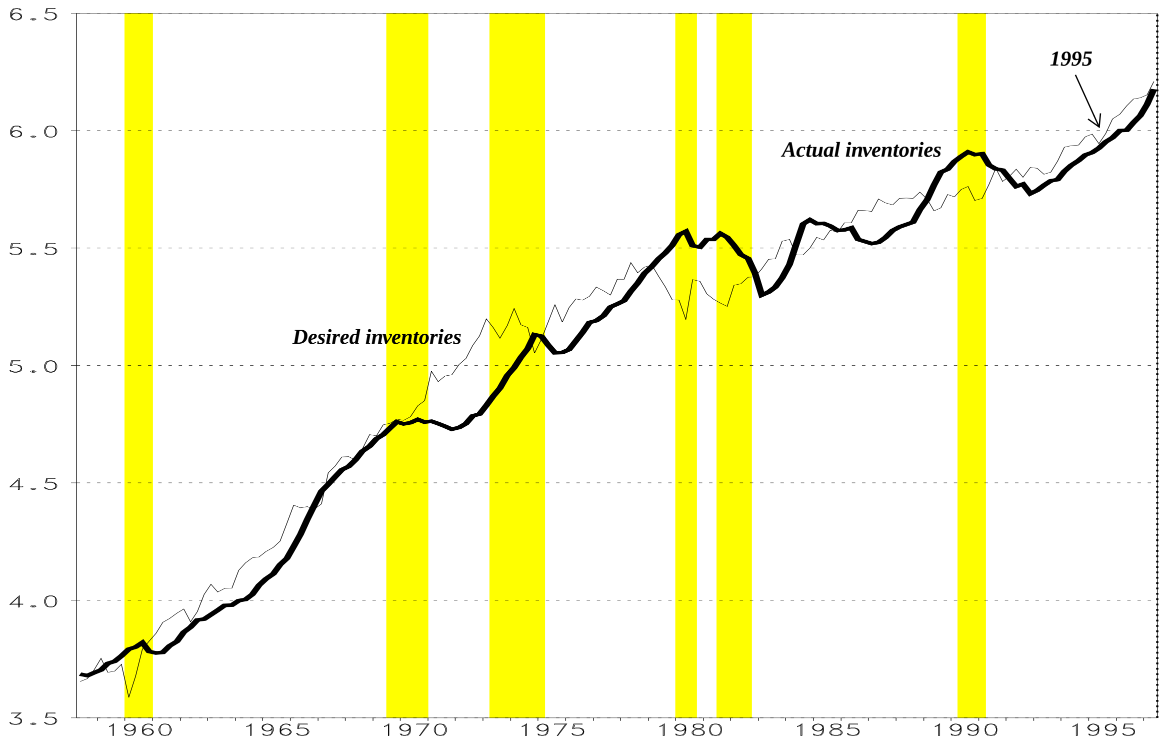
4.3.2 Estimation of the cointegrating vector

The super-consistent and asymptotically efficient estimates of the long-run parameter α that are obtained from the cointegrating regression using the Stock-Watson procedure can also be found in Table 3 (Appendix 3). Although the Engle-Granger method also yields super-consistent estimates of the long-run parameter α, the estimates are not asymptotically efficient. Their distribution depends upon nuisance parameters as a result of serial correlation in the error term and endogeneity of the regressor matrix. The asymptotically optimal estimates of the long-run parameter, $\hat{\alpha}$, reported in Table 3, have the expected signs. The estimated parameter on new orders is positive, in line with our prior expectations of an increase in anticipated demand to raise the desired level of inventory holdings. The coefficient on capacity utilization is negative and suggests that an increase in capacity utilization, which reflects a positive technology shock, lowers the desired level of inventories. The estimated parameter on raw material prices is negative and indicates that an increase in the price of an input to production will induce firms to hold a lower stock of inventories. The estimated coefficient on the yield spread is positive and suggests that an easing in monetary policy, i.e., widening the spread between long and short rates, increases credit availability. This, in turn, lowers the opportunity cost of holding inventories and should raise the desired level of inventories. Moreover, an upward shift in inflation expectations also increases the desired level of inventories.

4.3.3 The actual and the desired levels of inventories

Figure 3 plots the actual and the target level of inventories, while Figure 4 shows the gap between the two levels for the period 1958:1 to 1997:2. Figure 3 indicates that the actual level of inventories exceeded the desired level over the past recessions, with the exception of the 1973–75 recession. Interestingly, the target level fell below the actual level *before* the 1980 and 1990–91 recessions; this supports the view that firms adjust their actual holding of inventories relative to the desired level with a lag. At the beginning of the 1981-82 recession, the actual level of stocks remained above the desired level. Figure 4 shows that the gap between the actual level of inventories and the target level generally rose before declining considerably over the past recession periods. The results suggest that, in the absence of adjustment costs, firms would have decreased inventories substantially more as the target level is below the actual level during these

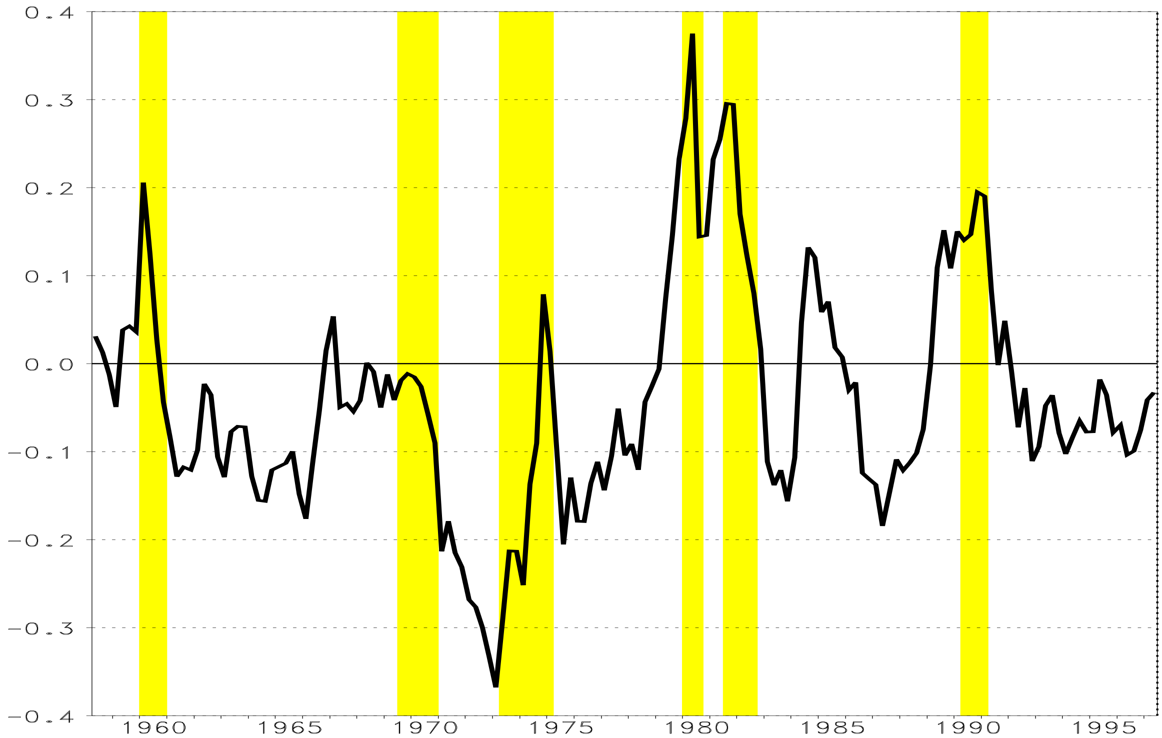
Figure 3:
Actual and desired real business inventories
in billions of chained (1992) dollars
(1958:1 - 1997:2):



Recession periods are shaded.

periods of economic downturns. Interestingly, the actual level of inventories only exceeded the target level towards the end of the 1973–75 recession, possibly because this recession was not the result of domestic imbalances but rather due to a foreign shock. Moreover, as inventories fall back to their desired level and demand resumes following a recession, production appears insufficient to meet demand and maintain the desired level of inventories. As a result, inventories fall below their desired level following each recession, with the exception of the 1980 recession. The comparison of the actual and desired level of inventories also shows that the actual level of inventories was about in line with the target level between the 1960 and the 1969–70 recessions and since the last recession in 1990–91. Interestingly, these two periods are characterized by sustained economic growth and the finding therefore supports the view that inventory imbalances can amplify the business cycle. Anecdotal evidence supports the finding that inventories have recently been “generally normal to somewhat below normal” (see Federal Reserve *Beige Book* prepared for the Federal Open Market Committee in November 1996).

Figure 4:
Gap between actual and desired real business inventories
in billions of chained (1992) dollars
(1958:1 - 1997:2)



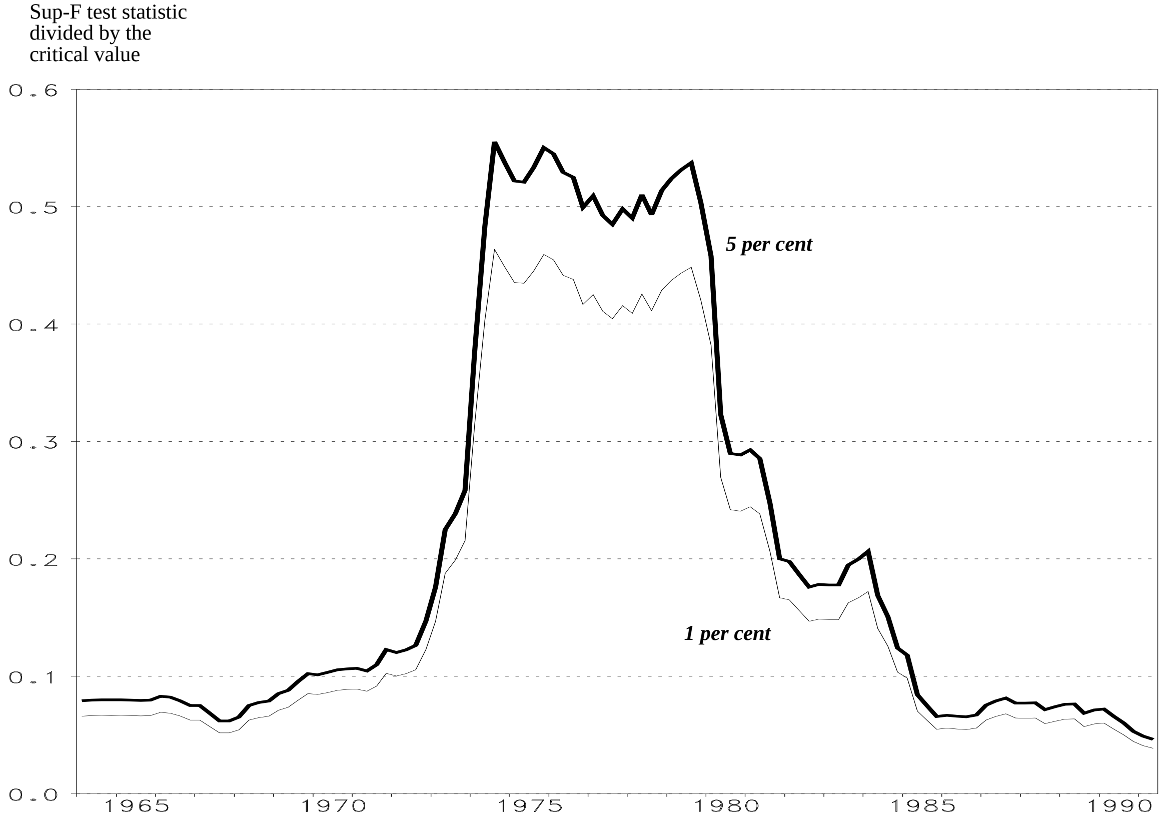
Recession periods are shaded.

The plot of the actual and the desired level of inventories reveals another interesting point. Many forecasters attributed the slowing of the U.S economy over the first half of 1995 to an inventory correction. Although the rate of inventory accumulation indeed moderated over the first six months of the year, the actual level of inventories continued to grow. Figure 3 shows, however, that the slowing in economic activity coincided with a decline in the desired level of stocks. Nevertheless, this decline only served to push actual and desired inventory levels closer together.

4.3.4 Sup-F test for parameter constancy

The structural stability of the long-run parameter estimates is tested over the sample period using Andrews’ 1993 Sup-F test for parameter constancy as proposed by Hansen (1992) for I(1) processes.[10] Figure 5 plots the Sup-F test statistics divided by the 1 and 5 per cent critical values respectively. Both ratios are below one indicating that the null hypothesis of parameter stability cannot be rejected at conventional levels of significance.

Figure 5: Sup-F test for parameter constancy[11]



The finding that there is no evidence of instability over the sample period suggests that the recent introduction of innovative inventory control methods, such as "just-in-time" (JIT) management techniques and the use of bar codes, does not appear to have had an impact on inventory holdings at the *aggregate level*. Allen (1995) notes that retailers must have a visible inventory on hand to stimulate sales and are much less flexible with inventory holdings. An increased retail inventory-to-sales ratio and a greater share of retail inventories in total inventories may have offset the impact of these innovative inventory control methods.

10. The test was performed using Tkacz (1997) RATS procedures for testing structural breaks in linear regression models.
11. Critical values are obtained from Andrews (1993).

4.4 Estimation of the Euler equation

After having found a cointegrating vector between the forcing variables in X_t and the level of inventories, inv_t, we are able to estimate the Euler equation. As a first step, we re-write equation (10) as follows

$$\Delta inv_t = \beta \Delta inv_{t+1} - \Upsilon \hat{u}_t + \eta_{t+1} , \tag{12}$$

where the estimated forward-looking error-correction term, using the Stock and Watson (1993) procedure, is given by $\hat{u}_t = inv_t - X_t' \hat{\alpha}$. As all the variables in equation (12) are I(0), we are able to estimate the discount rate, β, and the ratio of the disequilibrium to adjustment costs, Υ, using Hansen's 1982 generalized method of moment (GMM).[12] This technique is frequently applied to the estimation of non-linear dynamic rational expectations models using the generalized instrumental variable (IV) procedure introduced by Hansen and Singleton (1982).[13] The GMM estimate is obtained by minimizing a quadratic form in the sample moments. Hall (1992) notes two advantages of GMM estimation over maximum likelihood (ML). GMM estimation is computationally more convenient than maximum likelihood as GMM estimation only requires the specification of the Euler equation in order to obtain sufficient moment conditions. Moreover, inference about the parameter estimates is not biased even if the model is misspecified. One should note, however, that maximum likelihood based on a correctly specified model yields the asymptotically most efficient results. The parameters in the Euler equation could also be estimated jointly using a full-information approach. However, a disadvantage of the full-information approach is that it requires an explicit solution for the model's control variables in terms of the forcing processes. In contrast, the limited-information approach applied in this paper yields consistent estimates of the parameters while exploiting the time-series properties of the data.

Lags of Δinv_t, $\Delta orders_t$, $caput_t$, Δraw_t, and $spread_t$ at time $t-1$ are valid instruments for GMM estimation given that υ_t is serially uncorrelated. A constant is also included in the set of instruments. Moreover, we allow for the possibility that the disturbance term has an MA(1) structure. In models in which the data are subject to a time aggregation problem, the disturbance has an MA(1) structure and the instrumental variables need to be lagged at least an additional period. The model is therefore estimated using lags of Δinv_t, $\Delta orders_t$, $caput_t$, Δraw_t, and $spread_t$ at time $t-i$, for $i > 1$.

Table 4 in Appendix 4 presents the results from the estimation of the Euler equation using a constant, inventories, new orders, and raw material prices all in first-differences and the level of capacity utilization and the yield spread as instruments. Following West and Wilcox (1994), the model is estimated including a relatively large number of lags.[14] Instrument sets that are lagged at least two periods yield consistent estimates of the structural parameters even if the disturbance follows an MA(1) process. Table 4 indicates that the point estimates of both the discount rate, β,

12. For a review of GMM estimation, see Ogaki (1993).
13. In fact, Hansen (1982) and Hansen and Singleton (1982) show that IV estimation is a special case of GMM.
14. The choice of one to five, two to six, one to six, and two to seven follows Amano (1995).

and the ratio of the disequilibrium to adjustment costs, Υ, are significantly different from zero at conventional levels of significance, except for the point estimate of Υ in the model that includes two to six lags. Estimates of the discount rate, β, lie within the range of 0.996 to 0.972, and the estimated ratio of the disequilibrium to adjustment costs, Υ, lies within the range of 0.134 and 0.092. Note that Υ is indeed small and, therefore, partly explains the difficulty in detecting cointegration. This result supports the view that adjustment costs are substantially more important than the disequilibrium costs in determining inventory behaviour.

The estimated model includes more instruments than parameters to be estimated and the validity of the over-identifying restrictions is tested for each instrument set using Hansen's 1982 J-test for over-identifying restrictions. The J-test statistic, which is the number of observations times the minimized value of the objective function, i.e., equation (12), is asymptotically χ^2 distributed with the degree of freedom equal to the number of over-identifying restrictions. The number of over-identifying restrictions results from the included instruments and parameters to be estimated. The results of the J-tests, also presented in Table 4 (Appendix 4), are unable to reject the validity of the over-identifying restrictions imposed by the estimation for any information set and are consistent with a model that is correctly specified.

4.5 Estimation of the speed of adjustment

In a last step, we estimate the speed of adjustment term, λ.[15] Under the assumption that the law of motion for X_t is integrated of order one, the Wiener-Kolmogorow prediction formula can be used to replace the expectation in equation (5), i.e.,

$$\Delta inv_t = (\lambda - 1)(inv_{t-1} - X_{t-1}'\alpha) + (1 - \lambda)\Delta X_t'\alpha + (1 - \beta\lambda)(1 - \lambda)\mu_t . \tag{13}$$

The Wiener-Kolmogorow prediction formula implies that forecast target inventories are a function of lagged target inventories (see Hamilton 1994). Phillips and Loretan (1991) show that applying non-linear least squares to equation (13) results in a consistent estimate of the speed of adjustment parameter, λ. The point estimate of the speed of adjustment is 0.404, with a standard error of 0.054. This implies that it takes about a year for 95 per cent of the adjustment of the actual level to the target level to be completed. The finding implies a slow adjustment of inventories to their target level. Compared with the findings of many earlier studies, this estimate is not implausibly low.

5. Concluding remarks

In this paper we used the time-series properties of U.S. real inventories, new orders, capacity utilization, raw material prices, and the yield spread to model the behaviour of U.S. inventories. More specifically, a linear-quadratic model with integrated variables was estimated to evaluate the relative importance of disequilibrium to adjustment costs using a limited-information approach. We exploited a long-run, cointegrating restriction for estimating and testing the model.

15. Estimating the speed of adjustment parameter in a separate step follows Amano (1995).

We found that the actual level of U.S. inventories was generally above the target level during recession periods. Following a recession, production appeared insufficient to meet demand and maintain the desired level of inventories. As a result, inventories fell below their desired level. Furthermore, the actual level of inventories appears to have been more or less in line with the target level between the 1960 and the 1969–70 recessions and since the last recession in 1990–91. These two periods coincided with sustained economic growth and the finding supports the view that inventory imbalances can amplify the business cycle. This paper also provided evidence that adjustment costs are substantially more important than disequilibrium costs. Our estimate of the speed of adjustment implies that firms adjust their holdings of inventories slowly as it takes about a year for 95 per cent of the adjustment of the actual level to the target level to be completed. This estimate is not implausibly low as with many earlier studies.

There are several possible extension to this paper. Applying the methodology to Canadian data would allow the comparison of inventory behaviour in Canada and the United States. Over the past business cycle, the economic performances of these two closely linked economies appear to have diverged. One factor that could have contributed to this divergence is that inventory imbalances have been more important in recent years in Canada than in the United States. Moreover, the speed of adjustment could differ in the two countries.

The framework of the representative firm was used in this paper to characterize inventory adjustment at the macroeconomic level and no inference can be made about the adjustment behaviour at the firm's level. Using aggregate data raises an important issue—the degree of aggregation. For instance, Bivin (1988) notes the differences between the durables and non-durables manufacturing sectors. Firms in the non-durables sector tend to hold larger inventories of finished goods than firms in the durables sector. This is partly due to the generally shorter production process in the non-durables sector. Furthermore, output is often standardized in the non-durables sector and not customized as it is often the case in the durables sector. Disaggregating the data by sectors or by stage of fabrication is a possible extension to this paper.

Finally, some evidence was provided that the recent introduction of innovative inventory control methods, such as "just-in-time" management techniques and the use of bar codes, did not have an impact on inventory holdings at the aggregate level. One explanation is that a rising share of retail inventories in total inventories may have offset the impact of these innovative inventory control methods on the aggregate data as retailers are generally much less flexible with inventories than, for instance, are wholesalers. Figure 6 in Appendix 5 illustrates the rising share of retail inventories in total inventories. A disaggregation of the data by stage of distribution could yield different results.

Appendix 1

The data

Business inventories - manufacturing. Billions of chained (1992) dollars. Quarterly. Seasonally adjusted at annual rates. Source: U.S. Department of Commerce. Bureau of Economic Analysis. “Survey of Current Business” and other materials. U.S. National Income & Product Accounts. Table 5.11.

Capacity utilization - manufacturing. Monthly. Seasonally adjusted. Source: Board of Governors of the Federal Reserve. Statistical release G.17.

New orders. Millions of current dollars. Monthly. Seasonally adjusted. Source: U.S. Department of Commerce. Bureau of the Census. “Manufacturers Shipments, Inventories, and Orders.”

Producer price index - intermediate materials less foods and feeds. Monthly. Seasonally adjusted. Index base 1982 = 1.0. Source: U.S. Department of Labor. Bureau of Labor Statistics.

Producer price index - finished consumer goods excluding foods. Monthly. Seasonally adjusted. Index base 1982 = 1.0. Source: U.S. Department of Labor. Bureau of Labor Statistics.

Rate on U.S. Government three-month T-bills. Secondary market. Per cent per annum. Not seasonally adjusted. Average of daily closing bid prices. Board of Governors of the Federal Reserve System. Statistical Release G.13. “Selected Interest Rates & Bond Prices.”

Yield on Treasury securities at constant maturity of ten years. Per cent per annum. Not seasonally adjusted. Average of daily figures. Board of Governors of the Federal Reserve System. Statistical Release G.13. “Selected Interest Rates & Bond Prices.”

Appendix 2

Table 2: Tests of the time-series properties of the data[a]

Variable	Augmented Dickey-Fuller Test[b]		Modified Phillips-Perron Z_{α}[c]
	t_{ρ}	Process / Lags	t_{ρ}
INV	-2.20441	AR(1)	0.71286
1% critical value	-4.20166		-28.4
5% critical value	-3.58125		-21.3
10% critical value	-3.28129		-18.0
$ORDERS$	-2.63414	AR(1)	0.58226
1% critical value	-4.25759		-28.4
5% critical value	-3.61183		-21.3
10% critical value	-3.27789		-18.0
$CAPUT$	-4.10588*	MA(1)	0.43168
1% critical value	-4.42603		-28.4
5% critical value	-3.68331		-21.3
10% critical value	-3.31858		-18.0
RAW	-1.57861	AR(1)	-2.99515
1% critical value	-4.17392		-28.4
5% critical value	-3.58192		-21.3
10% critical value	-3.25294		-18.0
$SPREAD$	-4.09934 *	ARMA(1,1)	14.88834
1% critical value	-4.28354		-28.4
5% critical value	-3.66407		-21.3
10% critical value	-3.30914		-18.0
ΔINV	-5.09530**	4	-119.15941**
1% critical value	-4.02042		-28.4
5% critical value	-3.43976		-21.3
10% critical value	-3.14403		-18.0
$\Delta ORDERS$	-9.55565**	0	-113.77605**
ΔRAW	-7.62552**	0	-51.90992**
1% critical value	-4.01893		-28.4
5% critical value	-3.43905		-21.3
10% critical value	-3.14361		-18.0

** H_0 of no cointegration is rejected at the 1% level
* H_0 of no cointegration is rejected at the 5% level

a. All test regressions include a constant and a trend term.

b. For details on the ADF test and the simulated critical values see Page (1996a, 1996b). We use the lag-length selection procedure proposed by Paquet (1994) that tests the included lagged terms for significance at the 10 per cent level. The initial number of lags is set equal to the seasonal frequency, i.e., four. Critical values for the ADF test in first-differences are obtained from Table 1 in MacKinnon (1990) for T=157 less data dependent lag.

c. The spectral density is estimated with a AR(4) spectral estimator proposed by Stock (1991). Critical values are obtained from Table B.5 in Hamilton (1994) for T=250.

Appendix 3

Table 3: Cointegration tests

Stock-Watson Estimates of the Long-Run Parameters[a]	Cointegration Tests			
	Stock-Watson Procedure		Engle-Granger Procedure	
$- 5.416 + 2.556orders_t - 3.159caput_t - 1.555raw_t + 0.016spread_t$ (0.329) (0.061) (0.356) (0.271) (0.016)	ADF test[b] (data dependent lag)	MZ_α test[c]	ADF test (data dependent lag)	MZ_α test
	-4.40260* (0)	56.27766***	-3.99735 (1)	-29.72988
1% critical value	-5.10696	-47.5	-5.10123	-47.5
5% critical value	-4.50977	-37.2	-4.50624	-37.2
10% critical value	-4.20339	-32.7	-4.20068	-32.7

*** H_0 of no cointegration is rejected at the 1% level
** H_0 of no cointegration is rejected at the 5% level
* H_0 of no cointegration is rejected at the 10% level

a. Standard errors are in parentheses. The Stock-Watson estimates are based on a three-order leads and lags, Newey and West (1987) consistent variance-covariance estimator with the truncation parameter set equal to the seasonal frequency, i.e., four. The number of leads and lags is chosen based on a stationary VAR model that includes three lags to eliminate serial correlation from the residuals. The lag lengths are chosen based on likelihood ratio tests at the 10 per cent level. The initial number of lags is set equal to the seasonal frequency.

b. Critical values for the ADF tests are obtained from Table 1 in MacKinnon (1990) with T=151 for the Stock-Watson procedure and T=157 for the Engle-Granger procedure.

c. Critical values for the MZ_α tests are obtained from Table B.8 in Hamilton (1994) for T=500.

Appendix 4
Table 4: Estimates of the Euler equation[a]

	Lags one to five	Lags two to six	Lags one to six	Lags two to seven
β	0.994 *** (0.108)	0.996 *** (0.128)	0.972 *** (0.104)	0.984 *** (0.124)
Υ	0.134 ** (0.061)	0.092 (0.070)	0.114 ** (0.056)	0.110 * (0.063)
J-test[b]	21.507 (0.550)	20.974 (0.583)	25.434 (0.328)	24.338 (0.385)

*** significant at the 1% level[c]
** significant at the 5% level
* significant at the 10% level

a. Standard errors are in parentheses. The different versions of the model are estimated using Hansen's 1982 GMM estimator. The weighting matrix is estimated using a lag length of one to allow for the possibility that the disturbance term has an MA(1) structure. The instrument sets include a constant ΔINV_{t-i}, $\Delta ORDERS_{t-i}$, $CAPUT_{t-i}$, ΔRAW_{t-i} and $SPREAD_{t-i}$.

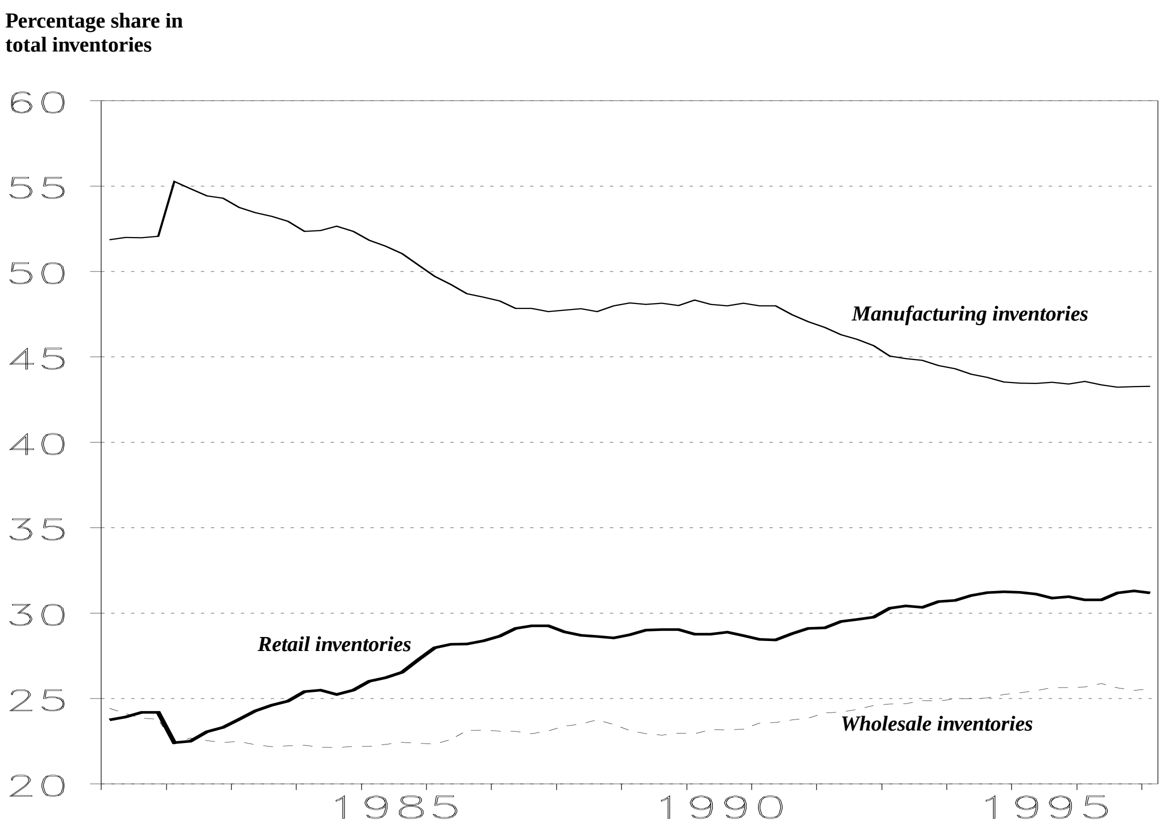
b. Asymptotic probability values are in parentheses. The asymptotic distribution of the J-test is $\chi^2_{(23)}$.

c. Critical values are obtained from Table B.3 in Hamilton (1994).

Appendix 5

Figure 6

Composition of inventories at the distribution level
(1981:1 - 1997:2)



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