The Reduced Volatility of the U.S. Economy: Policy or Progress?

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Abstract

The U.S. economy has experienced a dramatic decline in the volatility of both inflation and output since the early 1980's. In this paper we examine two competing explanations. The first is the popular view that improved Federal Reserve policy since the late 1970's is chiefly responsible. The second asserts that improvements in information technology have stabilized aggregate output variability, primarily through their effects on inventory behavior. We model the joint determination of output, inflation, and policy in an optimizing framework, and argue that the technology story plays the primary role in explaining the relative stability of the last two decades.

1 Introduction

The standard deviation of quarterly U.S. real GDP growth over the last fifteen years is less than half that of the rest of the post-war period. By comparison, the instability of the 1970's and early 1980's represents a relatively modest and brief episode. At the same time, inflation has also stabilized, though primarily when viewed in comparison to the 1970's. The question naturally arises as to whether the volatility declines have a single unified explanation, such as that put forth by Clarida, Galí and Gertler (2000), who attribute both the real and nominal stability to a change in the reaction function of the Federal Reserve in the late 1970's.

In this paper we argue that changes in inventory behavior stemming from improvements in information technology have played a direct role in reducing output volatility, and indirectly have contributed to stabilizing inflation as well. The idea is that even if the magnitude of the exogenous shocks hitting the economy is unchanged, the role of inventory investment in magnifying or propagating those shocks has moderated significantly. The resulting increased stability of the real economy may have facilitated the policymaker's ability to stabilize inflation.

Our view that technological change is primarily responsible for the reduced volatility of output is formed largely by two important features of the data.[1] First, in a growth accounting sense, the reduction in aggregate variability can be explained by a corresponding reduction in the variability of output in the durable goods sector. The nondurables, services and structures sectors of the economy do not contribute importantly to the increased aggregate stability, nor are these sectors themselves significantly more stable. Second, the dramatic decline in the volatility of durables production is not accompanied by a similar reduction in the variability of durables final sales. In other words, the ratio of output variability to sales variability in that sector drops sharply after the early 1980's. For these features of the data to be compatible with an important stabilizing role for monetary policy, one needs to describe

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[1] See McConnell and Perez-Quiros (MPQ) (2000) for details

a transmission mechanism in which policy only has significant effects on the durable goods sector and has a strong effect on production in that sector, but little impact on final sales.

After documenting some of these changes in more detail, we present a general equilibrium model with inventories that illustrates the interaction between information and inventories' role in the propagation of shocks. We then imbed that in a model of optimal monetary policy, culminating in the argument that the increased stability coming from technological change on the real side of the economy could have led to improved inflation performance as well. In a sense, by not crediting policy so much for the improvement, we are thereby not blaming it so much for the relatively poor earlier performance. As we will make clear below, the policy explanation must presume an implausible degree of incompetence prior to the early 1980's, whereas the progress story is consistent with policymakers making the best of a bad situation.

2 Post-War Inflation and Output Variability

Figure 1 plots U.S. real GDP growth over the period 1953:2 to 2000:2 and Figure 2 plots the Consumer Price Index (CPI), the GDP deflator and the core CPI over the same period. It is easy to see that both inflation and output are less volatile in the most recent two decades than during the turbulent 1970's. When viewed in comparison to the 1950's and 1960's however, the stability of the recent period is considerably more striking for output growth than it is for inflation.

To see more clearly how the volatility of these macroeconomic aggregates has evolved over time, we compute point estimates for the standard deviation of various measures of nominal and real activity over three sub-samples within our larger sample period of 1953:2 to 2000:2. The first is 1953:2 to 1968:4, corresponding to the first 15 years of the post-war sample, the second is the fifteen-year period from 1969:1 to 1983:4, with the end date here corresponding to the date MPQ find for the break in the volatility of output growth[2], and the last is 1984:1 2000:2.

Table 1 reports the standard deviation of the CPI, the GDP deflator and the Core CPI for each sample period. In all cases, the standard deviation of inflation is around twice as large in period (2) as it is in either periods (1) or (3). Thus the current stability of inflation is not unprecedented – in the fifteen or so years following the Korean War, the U.S. economy achieved inflation outcomes similar to those we are currently experiencing.

Turning now to the real side of the economy, we find that the volatility of real activity has behaved a bit differently. The top panel of Table 2 reports the standard deviation of GDP growth and its components for our three sample periods.[3] Focusing first on the behavior aggregate GDP, we see in the first row of the top panel that the point estimates capture what was suggested by Figure 1, namely that the volatility of output since the early 1980's is significantly lower than in either of the earlier subperiods. In fact, as measured by the unconditional standard deviation of real growth, the volatility in the 1970's is not markedly different from that of 1950's and 1960's.[4]

What is the source of the recent decline in output volatility?[5] To answer this question, we report the standard deviation of the components of real GDP growth over our three subperiods in the bottom section of Table 2.

The first aspect to note is that the behavior of durables volatility most closely

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[2] We discuss the determination of this date below.

[3] The numbers reported here are the standard deviations of the growth rates of the individual components, and not of the growth contributions.

[4] McConnell and Perez-Quiros (MPQ) (2000) use tests for structural change of the type described in Andrews (1993) and Andrews and Ploberger (1994) to estimate a break in the residual variance of an AR(1) specification for real GDP growth in 1984:1. They also test for additional breaks within each of the periods 1953:2 to 1983:4 and 1984:1 to 1999:2 and find no evidence of additional breaks. Hence it is the date 1984:1 on which we base our split between the second and third sample periods, and it is only this date that we view as relevent for the behavior of output volatility. The distinction between the first and second sample periods is made purely to illustrate the contrasting behavior of inflation volatility.

[5] MPQ answer this question by applying tests for structural change to both the growth rates and growth contributions of the components of aggregate GDP growth. While we do not present formal statistical tests here, our simple analysis elucidates the main points made rigorously in MPQ.

mimics the behavior of aggregate volatility. In particular, the magnitudes of the standard deviations in each of the early two periods are similar and are more than twice as high as the standard deviation in the later period. This is precisely the pattern observed in the aggregate data, and it is matched in no sector other than durables. In fact, volatility in the nondurables and structures sectors seems to follow more closely the pattern of inflation volatility, being high in period (2), but each presenting similar magnitudes for the earlier and later periods. Finally, while there is sizable reduction in services volatility in the latter two periods relative to the early period, the timing of this reduction does not line up with that of the aggregate volatility decline.

Thus the durables sector experienced a 50 percent decline in the standard deviation of its output roughly contemporaneously with the decline in overall GDP volatility. The share of the durables sector in GDP is only about 20 percent, however, so it does not necessarily follow even in an accounting framework that its impact on aggregate volatility would be large. To illustrate the importance of the durables sector for the behavior of aggregate volatility, we undertake an experiment like one presented in MPQ. Drawing on their finding of a structural break in the residual variance of an AR(1) specification for durables growth in 1985:1, we generate an artificial series for durable goods growth under the counterfactual assumption that the residual variance post-1985 is equal to its average value in the pre-1985 period. We then aggregate to construct an artifical GDP series under this counterfactual assumption and compare the volatility of this series to the actual. Table 3 reports the results of this exercise. It shows that the volatility reduction in the durables sector is large enough to account for over two-thirds of the decline in aggregate volatility.[6]

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[6] Since Table 2 presents only the standard deviation of the growth rates of each of these sectors, it doesn't provide an assessment of the effects of changes in the composition of nominal GDP. There has in fact been some shift in composition over time, with the average shares of the goods, services and structures sectors changing from 0.47, 0.42 and 0.11, respectively, in the pre-1984 period to 0.39, 0.52 and 0.09 in the recent period. A second experiment that holds sectoral shares constant shows that the standard deviation of output would have declined to 2.6, very close to the actual value of 2.2.

Having established that the magnitude of the durables sector's decline in volatility is sufficiently large to account for most of the decline in aggregate volatility, we can then ask what factor within durables—and perhaps within nondurables as well—has contributed to stabilizing output. Again following up on evidence in MPQ, who found that declines in the volatility of durables final sales were considerably smaller than the declines in durables output volatility, we examine the importance of inventory investment. The first row of Table 4 reports the standard deviation of durables output (this is as reported in Table 2), and the second the standard deviation of durables final sales. While there has evidently been some stabilization of final sales in the latter period, the decline has been substantially less dramatic than the decline in production volatility. This point is illustrated in Figure 3, which plots final sales and output in the durable goods sector over the sample 1953:2 to 2000:2. While the variance of production clearly exceeds the variance of sales prior to the early 1980's, one cannot easily pick out the more variable series in the later period.

In fact, as shown in the last line of Table 4, the ratio of the standard deviation of durables output growth to final sales growth falls from 1.7 for the period 1953:2 to 1983:4 (averaging the two early samples) to 0.90 for the period 1984:1 to 2000:2. The value of this ratio in the early period is not surprising, as a large literature exists documenting and seeking to understand the reasons that production is more volatile than sales. The value for the second period, however, suggests that this traditional puzzle of macroeconomic research has been replaced by a new one, namely, what is the source of the dramatic drop in output variability relative to final sales variability?

Data from the goods sector as a whole suggests that a change in inventory behavior has contributed to reduced output volatility, though the effect seems to be strongest—both absolutely and relatively—in durables. Table 5 decomposes the variance of output growth in the goods sector into the variance of the growth contributions of sales and inventory investment along with their covariance (which we interpret as an indicator of a production-smoothing role for inventories). For the overall goods sector, as well as for nondurables and durables separately, the percentage of the decline in output volatility not explained directly by a reduction in sales volatility (reported in the last column) is large—78.3 percent in the overall goods sector and 86.8 percent in the durables sector. Thus, particularly in durables, we find an important role for the variance of the growth contribution of inventory investment, as well as for the covariance between the growth contributions of inventories and sales, in explaining the reduction in output volatility.[7]

Thus we can summarize our look at post-war output and inflation variability as follows. Inflation variability, as measured by either the CPI, the GDP deflator or the Core CPI, was low in the 1950's and 1960's, high in the 1970's and very early 1980's and has been low since then. Output variability, on the other hand, was high throughout the entire post-war period until the early 1980's, at which time it dropped sharply and has remained low. The decline in aggregate output variability was driven by a corresponding decline in the variability of goods production, with changes in other sectors or in the composition of output across broad sectors of the economy, playing little or no role. The increased stability of durables production, however, seems to have occurred largely independently of any change in the variability of durables final sales. In other words, the ratio of the variability of durables production growth to durables final sales growth fell at the same time that durables and aggregate production volatility fell. We now turn to a brief description of the 'policy' and 'progress' hypotheses, and discuss the extent to which each seems consistent with the data as described here.

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[7] In Kahn, McConnell, and Perez-Quiros (2000) we argue that changes in inventory management came later to the nondurables sector, which would account for the smaller role over the 1984-2000 sample.

3 Policy or Progress?

3.1 Policy

Clarida, Galí and Gertler (CGG) (2000) find important differences in the estimated coefficients of the reaction function of the Federal Reserve before and after the appointment of Paul Volker as Fed Chairman in 1979.[8] In particular, they show that an interest rate rule estimated for the pre-1979 period implies that the Fed accommodated increases in inflationary expectations by failing to raise the nominal policy instrument rate by an amount sufficient to raise real rates. In the post-1979 period, however, the estimated reaction function implies that the nominal instrument rises more than one-for-one with an increase in inflationary expectations, and hence real rates rise to offset the initial increase in expectations. A theoretical model is presented that illustrates how changes in the policy rule of the type estimated in their paper could lead to a more stable macroeconomy.[9]

Estimation of simple rules of the form postulated by Taylor (1993) is now commonplace in the literature, and we estimate such a rule here for the purpose of capturing the flavor of the main CGG result. We follow Rudebusch (1999) and use OLS to estimate a simple rule of the form

$$i_t = \alpha_0 + \alpha_1 \overline{\pi}_t + \alpha_3 y_t + \epsilon_t \tag{1}$$

where $\overline{\pi}_t = \frac{1}{4}\sum_{i=0}^{3} \pi_{t-i}$, $\pi_t = 400(lnP_t - lnP_{t-1})$, Because we estimate a backward looking rule, and CGG use a forward-looking rule, our results are not strictly comparable. However, CGG also report backward looking estimates that accord well with

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[8] Changes in the Fed's reaction function in the spirit of that described in CGG are also documented in Judd and Trehan (1995), Judd and Rudebusch (1999) and Taylor (1998).

[9] Watson (2000) and Taylor (2000) also link the recent stability of U.S. output growth to Federal Reserve policy. Watson points out that the reduced variability of GDP growth has also been accompanied by the reduced variability and increased persistence of short-rates and increased variability of long rate movements. Watson (1999) explains that the increased variability of long-rates is related to the increased persistence of the Federal Funds rate.

those reported here, and they note that the backward looking estimates are similar to those of their forward looking specification.

The results of OLS estimation of Equation 1 are reported in Table 6.[10] We use Andrews (1994) to test for the stability of the coefficients of this rule. The test yields a breakdate of 1979:4, just two quarters from the 1979:2 date imposed by CGG.[11] The change in this rule highlighted in CGG is the coefficient α_1 on the $\overline{\pi}$ term. The value of α_1=0.87 in the early sample is consistent with the Fed conducting accommodative monetary policy. An increase in inflation (or inflationary expectations) is met with a less than one-for-one increase in the federal funds rate, implying a reduction in the real rate, and an associated increase in output and inflation. In the second subsample, however, α_1=1.46, implying that the Fed raises the nominal rate more than one-for-one with inflation (or inflationary expectations), and hence the real rate rises. This response should slow economic activity and inflation. It is this change in the estimated reaction function that CGG link to observed declines in real and nominal variability in the early 1980's.[12]

3.2 Progress

The concentration of the volatility decline in the durable goods sector, as well as the dramatic drop in output variability relative to sales variability in that sector seem hard to reconcile with the monetary policy hypothesis. With regard to concentration of the phenomenon in durables, one might hypothesize that durables purchases are the most interest sensitive and thus that sector should show the effects of policy most

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[10] The values of the equilibrium real interest rate and target inflation that appear in Taylor's original specification are subsumed in the constant term here.

[11] Our sample starts earlier and ends later than does CGG's.

[12] CGG does not, however, split the sample in the late 1960's as we do here. As described above, this sample split reveals that the bulk of the volatility in inflation stems from its behavior in the 1970's, while output instability was a feature of the entire pre-1984 post-war period. Also, implicit in CGG's theoretical model linking the policy rule to output and inflation stability is the assumption that policymakers were not on the efficient output-inflation variability frontier, i.e., the change in the rule afforded them improvement on both the output and inflation variability front. If policymakers were operating efficiently, a rule in which the Fed did not accommodate inflation shocks would tend to destabilize output in the face of supply shocks, at least in the short run.

strongly. But this hypothesis seems only to magnify the puzzle created by the second feature of the data. Since monetary policy presumably works in large part through its effects on interest rates and hence desired consumption and investment spending, it is not easy to see how a change in policy would induce such a sizable response in production but not final sales.

Turning then to the technological progress hypothesis, the break in the variability of production, without a corresponding break in sales, is a straightforward implication of a scenario in which improvements in inventory management technology have allowed firms to economize on inventory holdings in such a way as to reduce the variability of aggregate output. The concentration of the phenomenon in the durable goods sector may simply be an artifact of the way in which this technology has disseminated.

Figures 4 and 5 plot annual real information technology investment for the durable and nondurable goods industries over the sample 1960 to 1995.[13] Spending on information technology increased earlier and more rapidly in a number of durable goods industries (notably, industrial machinery, electrical machinery, transportation equipment and instruments) than for most nondurable industries.

The behavior of inventory-to-sales ratios in the goods producing sectors of the economy are consistent with the progress hypothesis. The bottom panel of Figure 6 plots the ratio of real nonfarm inventories to final sales of goods from 1947 on.[14] There is little drift in this ratio until the early 1980's, when it begins to trend downward.[15] The upper panel of Figure 6 plots the ratios separately for durables and nondurables. From these plots it is clear that the two sectors have followed very different paths.

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[13] There is also anecdotal evidence to suggest that it is the durable manufacturing sector that first took advantage of more advanced inventory tracking technology as well as more flexible production technology.

[14] Since these plots are ratios of two chain-weighted series, the level of the inventory ratio is not meaningful, but movements in the ratio are. Nominal ratios yield the same general picture.

[15] In 1991 Blinder and Maccini wrote ‘Contrary to popular belief, inventories are not leaner now than they were decades ago. Despite the alleged revolution in inventory practices brought about by computerization, the economy-wide ratio of real inventories to real sales has been trendless for 40 years’. Thus, even by 1991 it was not apparent to many that inventory-sales ratios had begun to come down.

The durables ratio has no discernible drift through the early 1980's, and then begins to drop precipitously, down roughly 30 percent by the end of the sample during a timespan of less than 20 years. In nondurables, meanwhile, the ratio has only a slight downward drift over the entire period sample, on the order of a 10 percent total decline over a span of more than 50 years.

Another piece of circumstantial evidence can be found from vector autoregressions. Tables 7 and 8 presents results from the durables and overall goods sectors, for the pre- and post-1984 sample periods (real 1996 chain-weighed dollars, in growth rates). For both sectors, while there are modest declines in the volatility of the dependent variables, what is striking is the increase in the R^2 for the sales equations, apparently due to the increased explanatory role of lagged inventories. At the same time, there is a tendency for lagged sales to play less of a role in explaining inventory investment. Both of these findings are consistent with the story that inventory investment incorporates better information—and is therefore better able to anticipate sales—in the later sample period.

4 Inventories and Output

4.1 Model Setup

We now incorporate inventories into a simple stochastic dynamic general equilibrium model. To simplify the analysis we leave physical capital out of the story. We also depart from the approach of Kydland and Prescott (1982) and Christiano (1988), who put inventories in the production function. To stay closer to the spirit of much of the empirical inventory literature, which focuses more on inventories' role in facilitating sales,[16] we put inventories in the utility function. The idea is that a larger stock of inventories enables consumers either to match their tastes more effectively

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[16] See, for example, Bils and Kahn (2000). Even the standard linear-quadratic inventory model, which puts inventories in the cost function, usually does so in terms of their deviation from expected sales, and motivates it by the desire to avoid lost sales from stockouts.

(what might be called the Baskin-Robbins effect), or to economize on shopping costs. Although non-finished goods (i.e. works-in-process and materials) comprise a significant share of inventories, the same argument applies: A manufacturer with a large inventory of paint colors ultimately facilitates the consumer ending up with a product that provides the most satisfaction.

Consider a representative consumer and producer with an inherited stock of inventories $\tilde{I}_{t-1}$, choosing how much to produce and consume at date t. (Variables with a "˜" are those that will grow in a steady state, and therefore will be normalized below.) We will assume for now that production for period t gets chosen at date $t-1$, i.e. before news about demand arrives. (This will be relaxed later as part of our notion of "progress.") We will solve for the equilibrium by examining a planner's problem. The planner solves

$$\max_{\{c,n\}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(\tilde{c}_t, n_{t-1}; \tilde{I}_{t-1}, \zeta_t) \right\}$$

subject to

$$\tilde{I}_t = \tilde{I}_{t-1} + A_t f(n_{t-1}) - \tilde{c}_t \tag{2}$$

where n_{t-1} is work effort (again, dated $t-1$ only because we will assume it is chosen before news arrives about period t shocks), $\tilde{c}_t$ consumption, $\tilde{I}_t$ the stock of inventories at the end of period t, A_t a technology shock, and ζ_t a taste shock (in the form of a shock to the marginal rate of substitution between leisure and goods).[17]

We assume that U and f take the following forms:

$$\begin{aligned} U(\tilde{c}_t, n_t; \tilde{I}_{t-1}, \zeta_t) &= \log \left[\theta \tilde{c}_t^{1-\rho} + (1-\theta) \tilde{I}_{t-1}^{1-\rho} \right]^{\frac{1}{1-\rho}} \zeta_t - n_{t-1}^{1+\delta} \\ f(n_t) &= n_t^{1-\alpha}. \end{aligned}$$

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[17] While such shocks are rather ad hoc, Hall (1997) argues persuasively that it is difficult to account for a large part of high-frequency movements in aggregate data without resort to this type of shock to the marginal rate of substitution between consumption and leisure.

and that

$$\begin{aligned} A_t &= (1+g)A_{t-1}\xi_t\tau_t/\tau_{t-1} \\ \zeta_t &= \zeta_{t-1}^{\phi}v_{t-1}w_t \end{aligned}$$

where $E_{t-1}\{\xi_t\} = E_{t-1}\{v_t\} = E_{t-1}\{w_t\} = 1$. The first term in U captures the idea that a larger inventory stock increases the marginal utility of any given purchase c_t, either by reducing transactions costs (e.g. shopping time) or by better matching the consumer's tastes. The parameter ρ is the inverse of an elasticity of substitution, which will dictate the degree to which consumption and inventories are linked. The second term is a standard disutility of labor, with $\delta > 0$. Finally, ξ_t represents a permanent technology shock, and τ_t a transitory "supply shock." The combined error term $v_{t-1}w_t$ is an i.i.d. shock, part of which (the v_{t-1}) is observable when n_{t-1} is chosen.

If we define $c_t \equiv \tilde{c}_t/A_{t-1}$, and $I_{t-1} \equiv \tilde{I}_{t-1}/A_{t-1}$, then we have

$$U(\tilde{c}_t, n_{t-1}; \tilde{I}_{t-1}, \zeta_t) = A_{t-1} + U(c_t, n_{t-1}; I_{t-1}, \zeta_t).$$

The resource constraint becomes

$$A_t I_t = A_{t-1}I_{t-1} + A_t n_{t-1}^{1-\alpha} - A_{t-1}c_t$$

$$(I_t - n_{t-1}^{1-\alpha})(1+g)z_t - I_{t-1} + c_t = 0$$

where $z_t \equiv \xi_t\tau_t/\tau_{t-1}$. With this normalization, I, c, and n will be constant in steady state.

We can express the first-order conditions as

$$\begin{aligned} \left[\theta c_t^{1-\rho} + (1-\theta)I_{t-1}^{1-\rho}\right]^{-1}\theta c_t^{-\rho}\zeta_t - q_t &= 0 \qquad (3) \\ (1+\delta)n_t^{\delta} - n_t^{-\alpha}(1+g)^{-1}E_t\left\{q_{t+1}z_{t+1}\right\} &= 0 \qquad (4) \end{aligned}$$

$$E_t\left\{\beta\left[\theta c_{t+1}^{1-\rho}+(1-\theta)I_t^{1-\rho}\right]^{-1}(1-\theta)I_t^{-\rho}\zeta_{t+1}-q_t(1+g)+\beta q_{t+1}\right\} \quad = \quad 0 \qquad (5)$$

where q_t is the shadow price of consumption goods at date t. These conditions can be solved for their steady-state implications. Ignoring uncertainty, we have, for example:

$$\frac{I}{c} \quad = \quad \left[\frac{\beta(1-\theta)}{\theta(1+g-\beta)}\right]^{1/\rho} \qquad (6)$$

$$\frac{n^{1-\alpha}}{I} \quad = \quad \frac{g}{1+g}+\frac{1}{1+g}\left[\frac{\theta(1+g-\beta)}{\beta(1-\theta)}\right]^{1/\rho}. \qquad (7)$$

This means that for c/I to be near one, θ should be near β.

It will be useful to consider a market equilibrium corresponding to the solution to the above system. In this case we would want to consider a real interest rate. According to standard asset pricing theory (e.g. Lucas, 1978), we can compute the equilibrium risk-free rate of return from the price of a risk-free asset, which will be

$$\beta E_t\{U_{\tilde{c}_{t+1}}\}/U_{\tilde{c}_t}.$$

Thus the equilibrium risk-free rate of return is equal to the inverse of this, i.e.

$$1+r_t=\frac{U_{\tilde{c}_t}}{\beta E_t\{U_{\tilde{c}_{t+1}}\}}=\frac{(1+g)q_t}{\beta E_t\{q_{t+1}\}}.$$

Thus in a deterministic steady state this return would equal $(1+g)/\beta$.

Next we can log-linearize the system in the standard way, by writing the system in terms of first-order approximations of log deviations from the steady state. First, define

$$\mu\equiv\frac{\theta c^{1-\rho}}{\theta c^{1-\rho}+(1-\theta)I^{1-\rho}},$$

a function of steady-state I/c (and usually close in value to θ). Using "$\hat{\ }$" to denote the deviations, we have

$$\begin{aligned}(1-\rho)[\mu\hat{c}_t+(1-\mu)\hat{I}_{t-1}]-\rho\hat{c}_t+\hat{\zeta}_t-\hat{q}_t &= 0 \quad (8)\\ E_t\left\{(\alpha+\delta)\hat{n}_t-\hat{q}_{t+1}-\hat{z}_{t+1}\right\} &= 0 \quad (9)\\ E_t\left\{(1-\rho)[\mu\hat{c}_{t+1}+(1-\mu)\hat{I}_t]-\rho\hat{I}_t+\hat{\zeta}_{t+1}-\frac{\hat{q}_t-\beta(1+g)^{-1}\hat{q}_{t+1}}{1-\beta(1+g)^{-1}}\right\} &= 0 \quad (10)\\ \hat{I}_t-(1+g)^{-1}\hat{I}_{t-1}+\frac{c}{I(1+g)}\hat{c}_t-\frac{n^{1-\alpha}}{I}\left[(1-\alpha)\hat{n}_{t-1}+\hat{z}_t\right]+\hat{z}_t &= 0, \quad (11)\end{aligned}$$

and

$$\hat{r}_t=\hat{q}_t-E_t\left\{\hat{q}_{t+1}\right\}$$

for the real interest rate.

Note that (8) and (10) can be combined to yield

$$E_t\left\{-\rho(\hat{I}_t-\hat{c}_{t+1})-\frac{\hat{q}_t-\hat{q}_{t+1}}{1-\beta(1+g)^{-1}}\right\}=0$$

or

$$E_t\left\{\hat{I}_t-\hat{c}_{t+1}\right\}=-\left(\frac{1}{\rho}\right)\frac{\hat{r}_t}{1-\beta(1+g)^{-1}},$$

which says that the inventory-sales ratio responds negatively to the real interest rate in proportion to $1/\rho$, the elasticity of substitution between I and c in utility.

We will assume that the permanent and transitory components of the supply shock $\hat{z}_t$ are not separately observable. In that case $\hat{z}_t$ can be represented as an $MA(1)$ process $\eta_t-\nu\eta_{t-1}$, with

$$\nu=\begin{cases}1+\frac{1}{2}\frac{\sigma_\xi^2}{\sigma_\tau^2}-\frac{1}{2}\sqrt{4\frac{\sigma_\xi^2}{\sigma_\tau^2}+\left(\frac{\sigma_\xi^2}{\sigma_\tau^2}\right)^2} & \sigma_\tau^2>0\\ 0 & \sigma_\tau^2=0\end{cases}$$

and

$$E_t\{\hat{z}_{t+1}\}=-\nu(\hat{z}_t-E_{t-1}\{\hat{z}_t\}).$$

4.2 Equilibrium

We can solve the system (8)-(11) using the method of undertermined coefficients, i.e. obtain a solution of the form

$$\begin{bmatrix} \hat{I}_t \\ \hat{n}_t \end{bmatrix} = P \begin{bmatrix} \hat{I}_{t-1} \\ \hat{n}_{t-1} \end{bmatrix} + Q \begin{bmatrix} \hat{\zeta}_t \\ \hat{v}_t \\ \hat{\eta}_t \\ \hat{\eta}_{t-1} \\ \hat{\tau}_t \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} \hat{c}_t \\ \hat{q}_t \end{bmatrix} = R \begin{bmatrix} \hat{I}_{t-1} \\ \hat{n}_{t-1} \end{bmatrix} + S \begin{bmatrix} \hat{\zeta}_t \\ \hat{v}_t \\ \hat{\eta}_t \\ \hat{\eta}_{t-1} \\ \hat{\tau}_t \end{bmatrix} \tag{13}$$

where P, Q, R, and S are matrices of coefficients to be determined from (8)-(11). The process for the exogenous shocks can be described as

$$\begin{bmatrix} \hat{\zeta}_{t+1} \\ \hat{v}_{t+1} \\ \hat{\eta}_{t+1} \\ \hat{\eta}_t \\ \hat{\tau}_{t+1} \end{bmatrix} = N \begin{bmatrix} \hat{\zeta}_t \\ \hat{v}_t \\ \hat{\eta}_t \\ \hat{\eta}_{t-1} \\ \hat{\tau}_t \end{bmatrix} + \begin{bmatrix} \hat{w}_{t+1} \\ \hat{v}_{t+1} \\ \hat{\xi}_{t+1} + \hat{\tau}_{t+1} \\ 0 \\ \hat{\tau}_{t+1} \end{bmatrix} \tag{14}$$

where

$$N = \begin{bmatrix} \phi & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \nu & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{15}$$

We also have

$$a_{t+1} = a_t + \hat{z}_{t+1} \tag{16}$$

where $a_t \equiv \log(A_t)$. For details of the solution method, see the Appendix.

Given the solution, we can easily compute, for example, equilibrium output $\hat{y}_t^* \equiv (1-\alpha)\hat{n}_{t-1} + a_t$, or the equilibrium real interest rate $\hat{r}_t^* = \hat{q}_t - E_t\left\{\hat{q}_{t+1}\right\}$. Specifically, if we partition the matrices by row, e.g. $P' = [P_1'|P_2']$, etc., we have

$$\hat{r}_t^* = R_2(I_{[2]} - P)\begin{bmatrix} \hat{I}_{t-1} \\ \hat{n}_{t-1} \end{bmatrix} + [S_2(I_{[2]} - N) - R_2 Q]\begin{bmatrix} \hat{\zeta}_t \\ \hat{v}_t \\ \hat{\eta}_t \\ \hat{\eta}_{t-1} \\ \hat{\tau}_t \end{bmatrix} \tag{17}$$

where $I_{[2]}$ is a 2×2 identity matrix.

4.3 Progress

Because of the nature of the inventory problem, in which forecast errors carry over into current production decisions, improvements in information technology or inventory management can reduce output volatility. There has been a wealth of anecdotal and case study evidence to suggest that information about final sales travels upstream much more quickly than it used to, because of advances in information technology.

We will consider the following structural shift: Recall that we have $\hat{\zeta}_t = \phi\hat{\zeta}_{t-1} + \hat{v}_{t-1} + \hat{w}_t$, so that $E_{t-1}\{\hat{\zeta}_t\} = \phi\hat{\zeta}_{t-1} + \hat{v}_{t-1}$. We will consider the impact of this by varying the signal-to-noise ratio σ_v^2/σ_w^2. Figure 7 provides some structural impulse responses to illustrate this. The shocks are to $\hat{v}_{t-1}$ and $\hat{w}_t$ and $t = 4$, such that $\hat{v}_{t-1} + \hat{w}_t = 0.1$. The three panels show the effect of increasing $\hat{v}_{t-1}/(\hat{v}_{t-1} + \hat{w}_t)$ from 0 to 1/3 to 2/3. They show clearly that the impulse to $\hat{n}$ (and hence to production) is moderated relative to that of $\hat{c}$ as the shock becomes more anticipated. The reason is that to the extent the demand shock is foreseen, output responds in anticipation, to moderate the impact on inventories and to reduce marginal cost (which is proportional to $\hat{n}$).

Note that this reduced volatility of production occurs without any change in the actual shocks (ζ_t, ξ_t, τ_t) hitting the economy. It is only the information about the shocks that is reaching decision-makers in a more timely fashion.[18] But to an observer who only sees the output data, for example, it might appear that the magnitude of the shocks has diminished.

Another aspect of better information could be a decline in inventory-sales ratios, as determined by the parameter θ. In stockout-avoidance models (e.g. Kahn, 1987), the average inventory-sales ratio would typically be related to one-period-ahead uncertainty about sales. While we have not modeled this relationship explicitly, we can allow for the impact of declining ratios on inflation and output volatility as well by recalibrating the model according to observed ratios.

5 Inflation and Output

We will now introduce inflation into the picture, along with a role for discretionary policy. To do this we adopt a variation of the simple log-linear accelerationist framework employed by a number of contributors to the literature on policy research.[19] According to this view, output rises and inflation accelerates to the extent that "demand" exceeds "supply," which in this context means the extent to which the real interest rate is below its equilibrium value. To implement this notion requires the assumption that the policymaker can manipulate real interest rates in the short run. We will also assume that rates are set based on information one period earlier, and that the impact of policy is a function of the *ex ante* deviation of the real rate from its *expected* equilibrium value.

The last assumption is designed to distinguish between two potential sources of

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[18] An alternative interpretation is that production is more "flexible," so that firms can wait longer (i.e. obtain more information) before making production decisions.

[19] See, for example, Rudebusch (1999), Orphanides (1998).

improvements in policy-making. If policy performance depended on the difference between the real rate set by the policymaker and the *ex post* equilibrium rate, then a change in the propagation of shocks to the economy would have a direct impact on policy performance simply because it would affect the size of the forecast errors for the equilibrium rate. Without dismissing that as a contributing factor, our specification focuses instead on how such a change affects inference about the *current* state of the economy rather than on the ability to forecast one period ahead. Thus we will introduce incomplete information as playing a key role in policy performance. First, however, we will lay out the policy model with complete information.

Let $\tilde{r}_t \equiv E_{t-1}\{\hat{r}^*_t\}$. This is the forecast of the equilibrium rate given all potential information as of $t-1$. Our model of the Phillips curve is:

$$\begin{aligned} \hat{y}_t - \hat{y}^*_t &= -\psi(\hat{r}_t - \tilde{r}_t) && (18) \\ \pi_t - \pi_{t-1} &= -\gamma(\hat{r}_t - \tilde{r}_t) + \epsilon_t. && (19) \end{aligned}$$

We will assume that policy is neutral with respect to inventory investment, i.e.

$$\hat{c}_t - \hat{c}^*_t = -\psi(\hat{r}_t - \tilde{r}_t) \tag{20}$$

The error term ϵ_t in (19) could reflect the effects of supply shocks (and could be negatively correlated with $\Delta\xi_t$, for example). It could also reflect other noise in the system, or classical measurement error. It is there simply to prevent the policymaker from uncovering the underlying state of the economy later when we introduce incomplete information. Note that one could get a more conventional-looking specification simply by substituting (18) into (19).

The policymaker's objective is as follows:

$$\min_{\{\hat{r}_t\}} E_t \left\{ \sum_{s=0}^{\infty} \beta^{\tau} [\omega \pi^2_{s+t} + (1-\omega)(\hat{y}_{s+t} - \hat{y}^*_{s+t})^2] \right\} \tag{21}$$

subject to the system (18)-(19), and given π_{t-1}. It is worth noting that the objective is not to stabilize output, but rather to avoid distorting output away from $\hat{y}^*$, its equilibrium value. The quantity $\hat{y}_t - \hat{y}_t^*$ can be thought of as the usual output gap, but where "potential output" $\hat{y}_t^*$ includes transitory demand shocks.

We can solve this problem by substituting for $\hat{y}_t - \hat{y}_t^*$, since $\hat{y}_t - \hat{y}_t^* = -\psi(\hat{r}_t - \hat{r}_t^*) = \frac{\psi}{\gamma}(\pi_t - \pi_{t-1} - \epsilon_t)$, to get an equivalent problem:

$$\min_{\{i_t\}} E_t \left\{ \sum_{\tau=0}^{\infty} \beta^\tau [\omega \pi_{\tau+t}^2 + (1-\omega) \left(\frac{\psi}{\gamma}\right)^2 (\pi_{\tau+t} - \pi_{\tau+t-1})^2] \right\} \tag{22}$$

where $\pi_{\tau+t+1}$ is a function of $\hat{r}_{\tau+t}$. Differentiation with respect to π_t yields:

$$E_{t-1}\{\omega\pi_t + (1-\omega)\left(\frac{\psi}{\gamma}\right)^2 (\pi_t - \pi_{t-1}) - \beta(1-\omega)\left(\frac{\psi}{\gamma}\right)^2 (\pi_{t+1} - \pi_t)\} = 0. \tag{23}$$

If $\omega = 1$, (23) implies $E_{t-1}\{\pi_t\} = 0$ as in the previous section, though the solution will still differ because of the availability of $\hat{y}_t$ as an indicator for $\tilde{r}_t$.

Substituting for π in the above first order condition using (19) yields, after some rearranging,

$$\hat{r}_t = \tilde{r}_t + \frac{\omega}{\gamma} \frac{\pi_{t-1}}{1 - \kappa F}, \tag{24}$$

where F is the forward operator conditional on $t-1$ information, i.e. $Fx_t = E_{t-1}\{x_{t+1}\}$, and $\kappa = \frac{\beta(1-\omega)\psi^2}{\gamma^2\omega + (1-\omega)\psi^2}$. This difference equation can be simplified further to get

$$\hat{r}_t = \tilde{r}_t + \frac{1-\lambda}{\gamma}\pi_{t-1}, \tag{25}$$

where λ is the smaller root of the associated characteristic equation. As ω ranges from 0 to 1, λ varies from 1 to 0. Thus λ primarily represents (except for its dependence on ψ/γ) policy preference with regard to inflation versus output gap variability.

Plugging (25) into (19), we have

$$\pi_t = \lambda\pi_{t-1} + \epsilon_t,$$

which shows that the policy preference parameter λ can be identified from a simple inflation autoregression. The idea is that the ability to forecast inflation is inversely related to the policymaker's anti-inflation focus. A complete inflation hawk would correspond to $\lambda = 0$, because any anticipated inflation would always be countered by higher interest rates. On the other hand, a policymaker completely unconcerned with inflation would just set $\hat{r}_t = \tilde{r}_t$ and let inflation follow a random walk.

On the assumption that ψ/γ has not changed we can do a quick test to see whether by this measure, the Fed's policy stance toward inflation has become tougher since the early 1980's. Using quarterly data with inflation measured as GDP deflator growth, we get the results depicted in Table 9. These offer only modest support for the notion that the Fed became more hawkish on inflation in the late 70's or early 80's.

As for the policy problem, since $\tilde{r}_t$ is observable, it is relatively straightforward. In fact, it can be shown that the presence of inventories makes the policymaker's problem easier, since inventories (or, equivalently, the difference between output and consumption) provide information about the underlying shocks. Thus the only inference problem the policymaker has is to distinguish permanent from transitory supply shocks; there is no confusion between supply and demand shocks.

There is clearly no interaction between progress and policy under complete information, and hence no impact on inflation. As long as policy preferences (as represented by λ) remain the same, the unconditional variance of inflation will be $\sigma_\epsilon^2/\left(1-\lambda^2\right)$ independently of any progress in the form of better information. Thus the model could explain the decline in output variability, but would be silent on the moderation of inflation.

5.1 Policy with Incomplete Information

Now we assume that the policymaker has less information than private decisionmakers have collectively. The idea here is that the policymaker may not be able to measure many of the relevant variables in an accurate or timely way, whereas each individual decisionmaker may only need to know his own personal data, which he can measure accurately.

Specifically, we assume that the policymaker does not observe anything but the history of $\hat{y}_t$, π_t and $\hat{r}_t$. From this he makes a period-by-period estimate of the underlying shocks in order to form the best possible estimate of $\tilde{r}_t$. Under these assumptions the policy rule will be modified from (25) above to

$$\tilde{r}_t = E(\hat{r}_t^* | \hat{y}_{t-1}, \pi_{t-1}, ...) + \frac{1-\lambda}{\gamma} \hat{\pi}_{t-1} \tag{26}$$

where the expectation is formed from Kalman filter updating (see the Appendix), and the "..." refers to earlier values of y and π. Substituting (26) into (19) yields

$$\pi_t = \lambda \pi_{t-1} + \gamma [\hat{r}_t - E(\hat{r}_t^* | \hat{y}_{t-1}, \pi_{t-1}, ...)] + \epsilon_t. \tag{27}$$

So the error term remains orthogonal to π_{t-1}, and the regression estimates of λ are still valid. But note that the variance of the error term is increasing in the variance of $\hat{r}_t - E(\hat{r}_t^* | \hat{y}_{t-1}, \pi_{t-1}, ...)$. Thus to the extent the environment changes to enable the policymaker to get a better read on $\tilde{r}_t$, the result can be a reduction in the volatility of both inflation and output.

5.2 Simulation Results

Table 10 shows the results of simulations of the model for a representative set of parameter values. The only calibration was to λ, set at 0.87 and 0.73 according to the earlier regression results, and θ, which was set so that the inventory-sales ratio is 1.5, roughly corresponding to the average for the goods sector over the whole time period (this value is computed from nominal ratios). Beyond that the parameters were chosen so that the volatilities and dynamics of the model roughly matched those in the data for the early sample period. The results were not particularly sensitive to the parameter choices.

For comparison, the Table 10 provides the average volatilities of output growth and sales growth in the goods sector (i.e. excluding services), and of inflation for the periods before and after 1984. In the base simulation the output and sales volatilities are somewhat lower than in the data, while the inflation volatility is similar. We then do combinations of two exercises: A change in policy, reducing λ from 0.87 to 0.73, and an increase in the signal-to-noise ratio from 0.1 to 0.7. The policy change alone has essentially no effect on the volatility of output growth (recall that it is the output gap, not growth, that enters the objective), but reduces the volatility of inflation from approximately 3 percent to 2.2 percent. Progress, on the other hand, reduces both volatilities by modest amounts. Putting the two together in simulation IV results in a fairly substantial reduction in inflation volatility coupled with a modest reduction in the standard deviation of output growth.

We also consider two additional variations. Since the 1970's are typically associated with increased supply shocks, we triple the standard deviation of supply shocks and rerun the base simulation. The effects are a 0.5 percent increase in output volatility but only a very small increase for inflation. In the last simulation we reduce the inventory-sales ratio from 1.5 to 1.25 by increasing θ. The results in only a 0.1% decline in output volatility and essentially no effect on inflation.

Overall the results confirm the potential of the story to deliver the qualitative finding of a reduction in the volatility of both output growth and inflation, although quantitatively the effects are on the small side, particularly since the experiment involved a large increase in the signal-to-noise ratio. On the other hand, by requiring policy to obey the restrictions imposed by an optimizing framework we have shown that there is limited scope for an explanation of both the real and nominal volatility declines that relies on a change in policy regime.

6 Conclusions

In this paper we have documented substantial changes in inventory behavior, and have argued that these changes have contributed to the improved economic performance of the U.S. economy since the early 1980's. Some of the improvement is direct: Reduced output volatility stemming from better inventory management. But we have also argued that there is a spillover effect, in which reduced volatility of demand facilitates a reduction in the variability of inflation.

The view that an exogenous improvement in monetary policy alone is responsible for the increased stability of output and inflation implicitly blames policy for the poor earlier performance—indeed we would argue that it implies an implausible degree of incompetence, since the higher inflation and output volatility pre-1984 means policy must have been highly inefficient if there were no other accompanying structural changes in the economy.[20] While we would not rule out incompetence a priori as an explanation, we can at least tell a consistent story in which both pre- and post-1984, policymakers were doing the best they could.

7 Appendix

To solve the linearized system we use the method described in Uhlig (1997). We express the system as follows:

$$\begin{aligned} 0 &= A\begin{bmatrix}\hat{I}_t\\ \hat{n}_t\end{bmatrix} + B\begin{bmatrix}\hat{I}_{t-1}\\ \hat{n}_{t-1}\end{bmatrix} + C\begin{bmatrix}\hat{c}_t\\ \hat{q}_t\end{bmatrix} + D\begin{bmatrix}\hat{\zeta}_t\\ \hat{v}_t\\ \hat{\eta}_t\\ \hat{\eta}_{t-1}\\ \hat{\tau}_t\end{bmatrix} \\ 0 &= E_t\left\{G\begin{bmatrix}\hat{I}_t\\ \hat{n}_t\end{bmatrix} + J\begin{bmatrix}\hat{c}_{t+1}\\ \hat{q}_{t+1}\end{bmatrix} + K\begin{bmatrix}\hat{c}_t\\ \hat{q}_t\end{bmatrix} + L\begin{bmatrix}\hat{\zeta}_t\\ \hat{v}_t\\ \hat{\eta}_t\\ \hat{\eta}_{t-1}\\ \hat{\tau}_t\end{bmatrix}\right\} \end{aligned}$$

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[20] In this sense our story has some similarities to the work of Orphanides (1998).

$$\begin{bmatrix} \hat{\zeta}_{t+1} \\ \hat{v}_{t+1} \\ \hat{\eta}_{t+1} \\ \hat{\eta}_{t} \\ \hat{\tau}_{t+1} \end{bmatrix} = N \begin{bmatrix} \hat{\zeta}_{t} \\ \hat{v}_{t} \\ \hat{\eta}_{t} \\ \hat{\eta}_{t-1} \\ \hat{\tau}_{t} \end{bmatrix} + \begin{bmatrix} \hat{w}_{t+1} \\ \hat{v}_{t+1} \\ \hat{\xi}_{t+1} + \hat{\tau}_{t+1} \\ 0 \\ \hat{\tau}_{t+1} \end{bmatrix}$$

where $A = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$, $B = \begin{bmatrix} -(1+g)^{-1} & -(1-\alpha)\frac{n^{1-\alpha}}{I} \\ (1-\rho)(1-\mu) & 0 \end{bmatrix}$,

$$C = \begin{bmatrix} \frac{c}{I(1+g)} & 0 \\ -(\rho - \mu(1-\rho)) & -1 \end{bmatrix}, D = \begin{bmatrix} 0 & 0 & 1 - \frac{n^{1-\alpha}}{I} & -\nu\left(1 - \frac{n^{1-\alpha}}{I}\right) & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$G = \begin{bmatrix} -(\rho - (1-\mu)(1-\rho)) & 0 \\ 0 & \alpha + \delta \end{bmatrix}, J = \begin{bmatrix} \mu(1-\rho) & \frac{\beta(1+g)^{-1}}{1-\beta(1+g)^{-1}} \\ 0 & -1 \end{bmatrix},$$

$$K = \begin{bmatrix} 0 & -\frac{1}{1-\beta(1+g)^{-1}} \\ 0 & 0 \end{bmatrix}, L = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\nu & 0 \end{bmatrix},$$

and

$$N = \begin{bmatrix} \phi & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \nu & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

It then turns out that P is the solution to the quadratic matrix equation

$$\Psi P^2 - \Gamma P - \Theta = 0 \tag{28}$$

with eigenvalues less than modulus one. The solutions for Q, R, and S are also found in Uhlig (1997).

To solve the monetary policy problem under incomplete information, we take the solution above as the starting point for a standard Kalman filter updating problem. Here the observables are assumed to by π_{t-1} and y_{t-1} (and all earlier dates). To obtain the conditional expectation $E\{r_t^* | \pi_{t-1}, y_{t-1}, ...\}$ we simply express the model in the state space formulation in which the stacked variables

$$s_t \equiv \left[\begin{array}{cccccccccc} \hat{r}_t^* & \hat{y}_t^* & \hat{I}_t & \hat{n}_t & a_t & \hat{\zeta}_t & \hat{v}_t & \hat{\eta}_t & \hat{\eta}_{t-1} & \hat{\tau}_t \end{array} \right]'$$

the state vector, and $x_t \equiv \left[\begin{array}{cc} \hat{y}_t + \psi \hat{r}_t & \pi_t + \gamma \hat{r}_t \end{array} \right]'$ the vector of observable variables. We have, then

$$x_t = \left[\begin{array}{cccccccccc} \psi & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \gamma & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array} \right] s_t + \left[\begin{array}{c} 0 \\ \epsilon_t \end{array} \right]$$

and

$$s_t = F s_{t-1} + \Lambda e_t,$$

where $e_t \equiv \left[\begin{array}{ccccc} \hat{w}_t & \hat{v}_t & \hat{\xi}_t + \hat{\tau}_t & 0 & \hat{\tau}_t \end{array} \right]$ is the vector of shocks, while F and Λ are matrices derived from P, Q, R, S, and N.

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Table 1: The Changing Variability of Inflation

	(1) 53:2 - 68:4	(2) 69:1 - 83:4	(3) 84:1 - 00:2
Inflation			
CPI	1.6	3.6	1.5
GDP Deflator	1.4	2.3	1.0
Core	1.4	3.3	1.1

Note: The numbers reported in columns marked (1) through (3) are the standard deviation of the variable listed in the left-hand column. Inflation is measured as the percent change in the price level at an annual rate. The first subsample for 'Core' is 1957:2 to 1968:4 due to data availability.

Table 2: The Changing Variability of Real Activity

	(1) 53:2 - 68:4	(2) 69:1 - 83:4	(3) 84:1 - 00:2
Output Growth			
Aggregate	4.5	4.8	2.2
Durables	18.1	17.9	8.0
Nondurables	5.9	7.9	4.8
Services	3.4	1.5	1.4
Structures	7.0	13.6	8.6

Note: The numbers reported in columns marked (1) through (3) are the standard deviation of the variable listed in the left-hand column. Output growth is measured as the percent change in chainweighted 1996 dollars at an annual rate.

Table 3: Explaining the Changing Variability of Real Activity

	53:2 - 84:4	85:1 - 00:2
Actual	4.7	2.2
‘Durables’ Experiment	4.7	3.9

Note: The numbers reported are the standard deviation of the variable listed in the left-hand column. ‘Durables’ Experiment refers to an artifical GDP series constructed under the counterfactual assumption that the volatility of output in the durable goods sector did not decline after 1985:1. Output growth is measured as the percent change in chainweighted 1996 dollars at an annual rate.

Table 4: The Changing Variability of Durables Output

	(1) 53:2 - 68:4	(2) 69:1 - 83:4	(3) 84:1 - 00:2
Output	18.1	17.9	8.0
Final Sales	10.3	11.2	8.5
Ratio	1.8	1.6	0.9

Note: The numbers reported in the first two rows are the standard deviation of the variable listed in the left-hand column. “Ratio” is the ratio of the standard deviation of durables output growth to durables final sales growth. Output and sales growth are measured as percent changes in chainweighted 1996 dollars at an annual rate.

Table 5: The Role of Inventories in Lower Output Volatility

Component	59:1-83:4	84:1-00:3	% of $\Delta\text{var}(\hat{y})$
Goods			
$\text{var}(\hat{y})$	3.73	1.14	100
$\text{var}(\hat{s})$	1.58	1.02	21.7
$\text{var}(\widehat{\Delta I})$	2.26	1.15	43.4
$2\text{cov}(\widehat{\Delta I}, \hat{s})$	-0.12	-1.02	35.0
Durable Goods			
$\text{var}(\hat{y})$	17.46	3.70	100
$\text{var}(\hat{s})$	5.68	3.91	13.2
$\text{var}(\widehat{\Delta I})$	9.11	3.92	38.2
$2\text{cov}(\widehat{\Delta I}, \hat{s})$	2.68	-4.12	48.5
Nondurable Goods			
$\text{var}(\hat{y})$	2.94	1.39	100
$\text{var}(\hat{s})$	1.12	0.52	38.1
$\text{var}(\widehat{\Delta I})$	2.37	0.99	87.7
$2\text{cov}(\widehat{\Delta I}, \hat{s})$	-0.56	-0.12	-25.8

Note: We work with growth contributions because the data are chain-weighted. $\hat{y}$ refers to the growth rate of output, while $\hat{s}$ is the growth contribution of sales, and $\widehat{\Delta I}$ is the growth contribution of inventory investment. We approximate the growth contribution of sales by its lagged nominal share multiplied by its growth rate. The growth contribution of inventory investment is defined as a residual, so that $\hat{y} = \hat{s} + \widehat{\Delta I}$.

Table 6: Taylor-Type Rule

Specification: $i_t = \alpha_0 + \alpha_1 \overline{\pi}_t + \alpha_2 y_t + \epsilon_t$				
Estimate	1953:1 - 1979:3		1979:4 - 1999:2	
α_0	1.08	(0.00)	2.57	(0.00)
α_1	0.87	(0.00)	1.46	(0.00)
α_2	0.31	(0.00)	0.16	(0.06)
Andrews Test: Break date 1979:4 (0.00)				

Note: OLS estimation of Equation 1. P-values are in parentheses.

Table 7: Durable Goods Sector

VAR Estimates				
	53:1-83:4		84:1-00:2	
	Sales_t	Inventories_t	Sales_t	Inventories_t
Sales_{t-1}	0.152	0.142	-0.212	0.132
	(0.089)	(0.041)	(0.129)	(0.054)
Sales_{t-2}	0.138	0.116	-0.138	0.173
	(0.089)	(0.041)	(0.112)	(0.047)
Inventories_{t-1}	0.445	0.390	1.007	0.446
	(0.206)	(0.094)	(0.286)	(0.121)
Inventories_{t-2}	-0.551	-0.030	0.082	-0.038
	(0.190)	(0.087)	(0.319)	(0.135)
R^2	0.132	0.422	0.275	0.410
s.d. dependent	0.025	0.015	0.020	0.010

Variance Decomposition				
	53:1-83:4		84:1-00:2	
Sales	94.6%	37.8%	84.1%	18.2%
Inventories	5.4	62.2	14.9	81.8%

Note: The numbers reported in the top panel are the results of a VAR on the growth rates (change in the log, not annualized) of final sales and inventories for the durable goods sector. The bottom panel reports the results of a variance decomposition after 10 periods with sales placed first in the ordering.

Table 8: Goods Sector

VAR Estimates				
	53:1-83:4		84:1-00:2	
	Sales_t	Inventories_t	Sales_t	Inventories_t
Sales_{t-1}	0.149	0.127	-0.170	0.216
	(0.087)	(0.040)	(0.130)	(0.070)
Sales_{t-2}	0.091	0.096	0.015	0.178
	(0.089)	(0.038)	(0.116)	(0.062)
Inventories_{t-1}	0.453	0.431	0.752	0.593
	(0.208)	(0.089)	(0.227)	(0.121)
Inventories_{t-2}	-0.412	0.065	0.052	-0.230
	(0.200)	(0.086)	(0.245)	(0.131)
R^2	0.092	0.437	0.253	0.438
s.d. dependent	0.014	0.008	0.010	0.006

Variance Decomposition				
	53:1-83:4		84:1-00:2	
Sales	96.1%	25.1%	84.4%	20.6%
Inventories	3.9	74.9	15.6	79.4

Note: The numbers reported in the top panel are the results of a VAR on the growth rates (change in the log, not annualized) of final sales and inventories for the aggregate goods sector. The bottom panel reports the results of a variance decomposition after 10 periods with sales placed first in the ordering.

Table 9: Inflation Persistence as Measure of Preferences

Sample	λ	R^2	se(x100)
1953:1 to 1979:2	0.85 (0.05)	0.78	3.6
1979:3 to 1999:2	0.91 (0.04)	0.87	2.0
1953:1 to 1983:4	0.87 (0.04)	0.76	3.5
1984:1 to 1999:2	0.73 (0.09)	0.53	2.0

Note: Standard errors reported in parenthesis next to coefficient estimate.

Table 10: Data and Simulation Results

		λ	$\frac{\sigma_{\hat{v}}^2}{\sigma_{\hat{v}}^2+\sigma_w^2}$	I/c	σ_τ	σ_{Δ_y}	σ_{Δ_c}	σ_{Δ_π}
Data								
1953:1-83:4		0.87				8.25	5.78	2.95
1984:1-99:2		0.73				4.55	4.32	1.02
Simulations								
I	Base	0.87	0.1	1.5	0.32	7.52	4.72	3.03
II	Policy	0.73	0.1	1.5	0.32	7.55	4.74	2.19
III	Progress	0.87	0.7	1.5	0.32	6.72	5.15	2.39
IV	Policy and Progress	0.73	0.7	1.5	0.32	6.78	5.18	1.73
V	Base+Supply Shocks	0.87	0.1	1.5	1.28	8.00	4.88	3.17
VI	Both+Lower I/c	0.73	0.7	1.25	0.32	6.69	5.16	1.78

Note: All of the volatilities in the table are in terms of percentages at annual rates. Parameters: $\sigma_{v+w} = 0.16, \sigma_\tau = \sigma_\xi = \sigma_\epsilon = 0.0008, \rho = 7, \phi = 0.95, \gamma = 2, \psi = 0.5$.

Figure 1: U.S. Real GDP Growth: 1953:2 to 2000:2

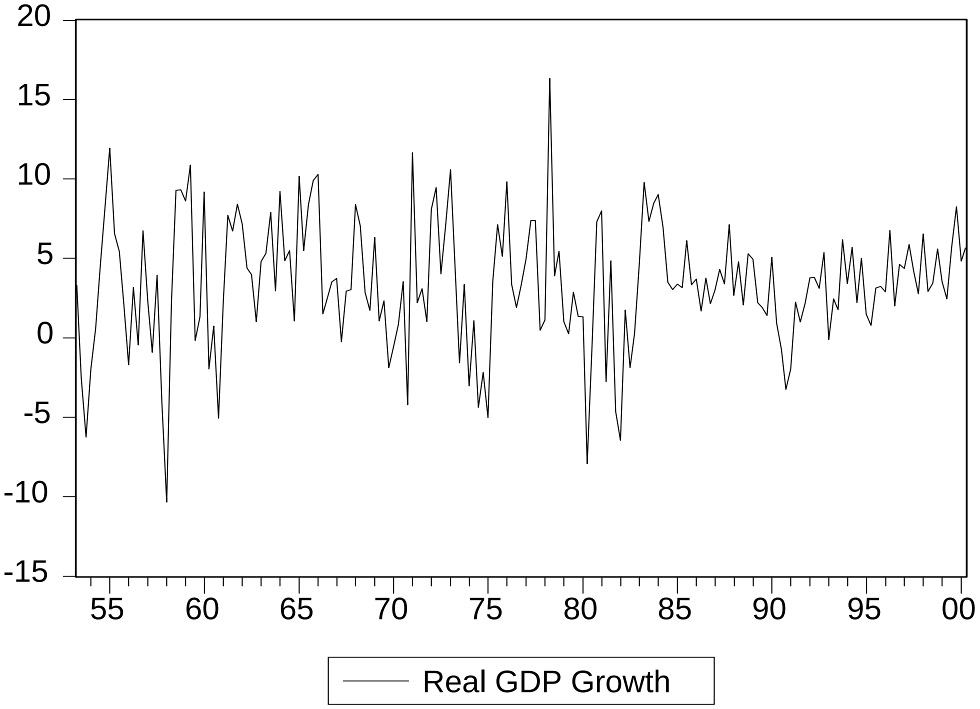

Figure 2: U.S. Inflation: 1953:2 to 2000:2

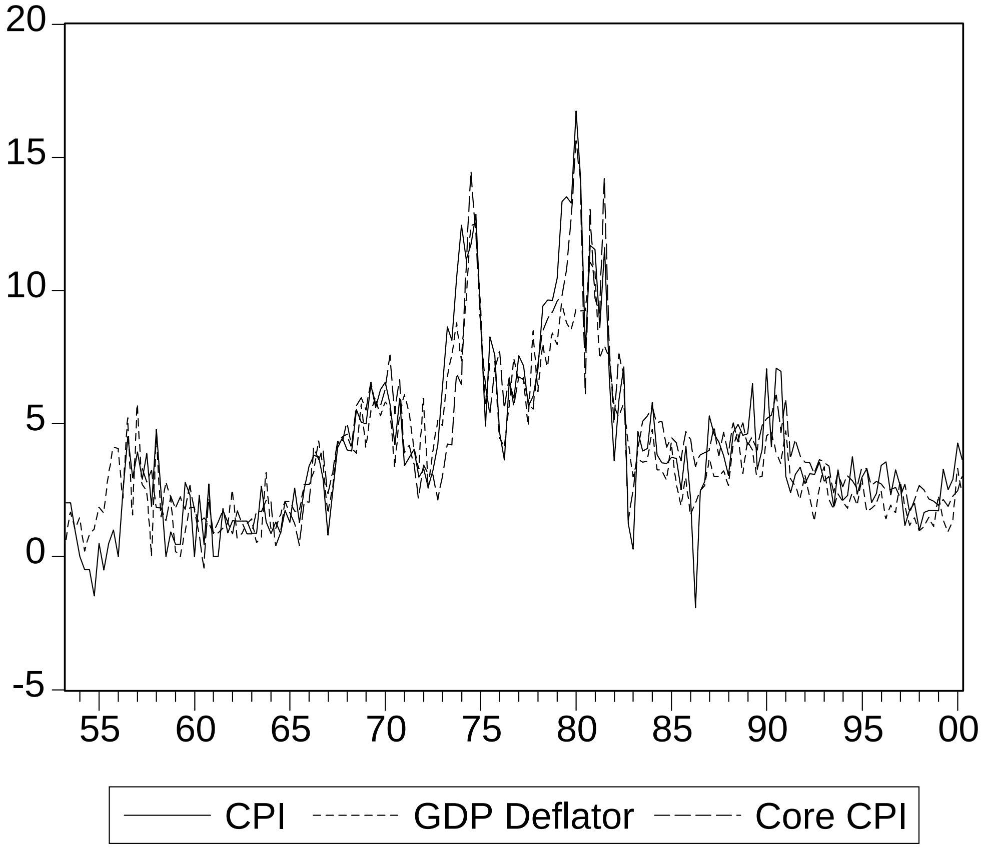

Figure 3: Growth in Durables Sales and Output: 1953:2 to 2000:2

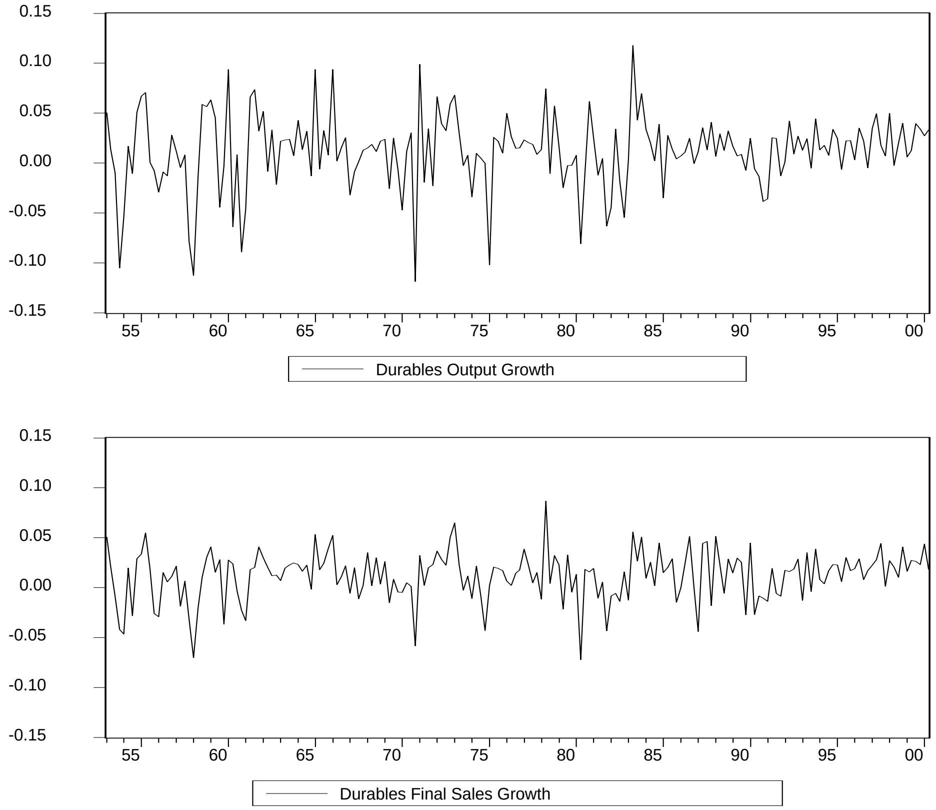

Figure 4: Durable Goods: Real IT Investment By Industry (1992 Chained Dollars)

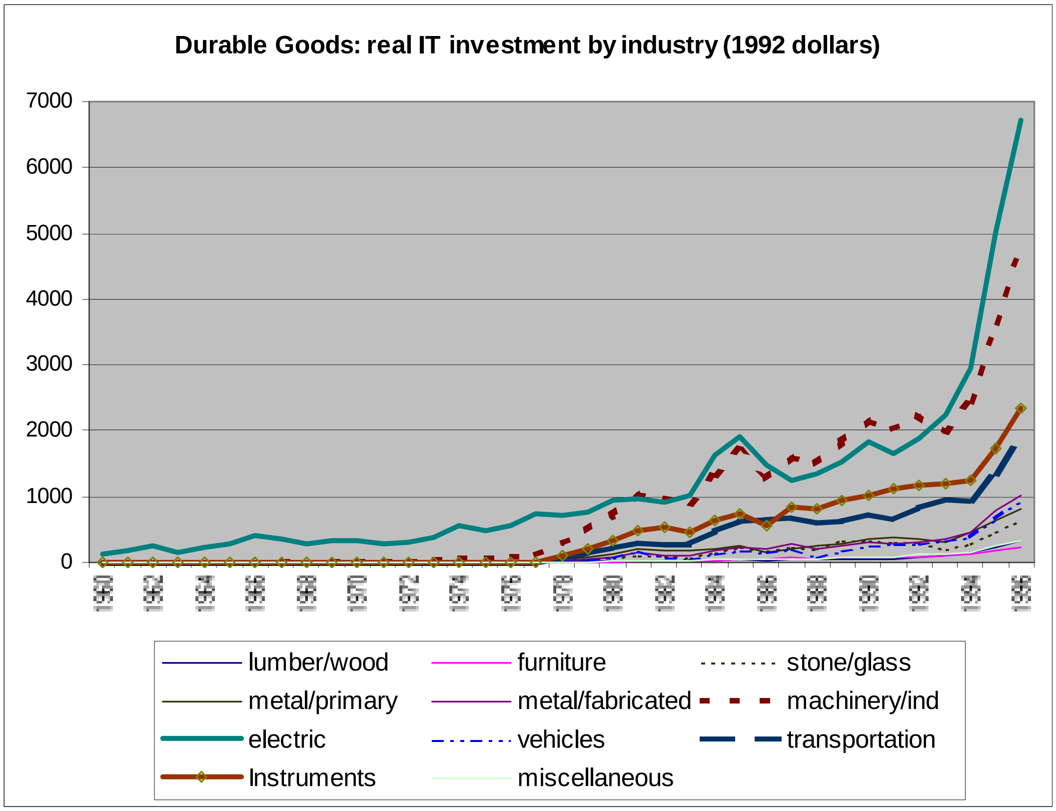

Figure 5: Nondurable Goods: Real IT Investment by Industry (1992 Chained Dollars)

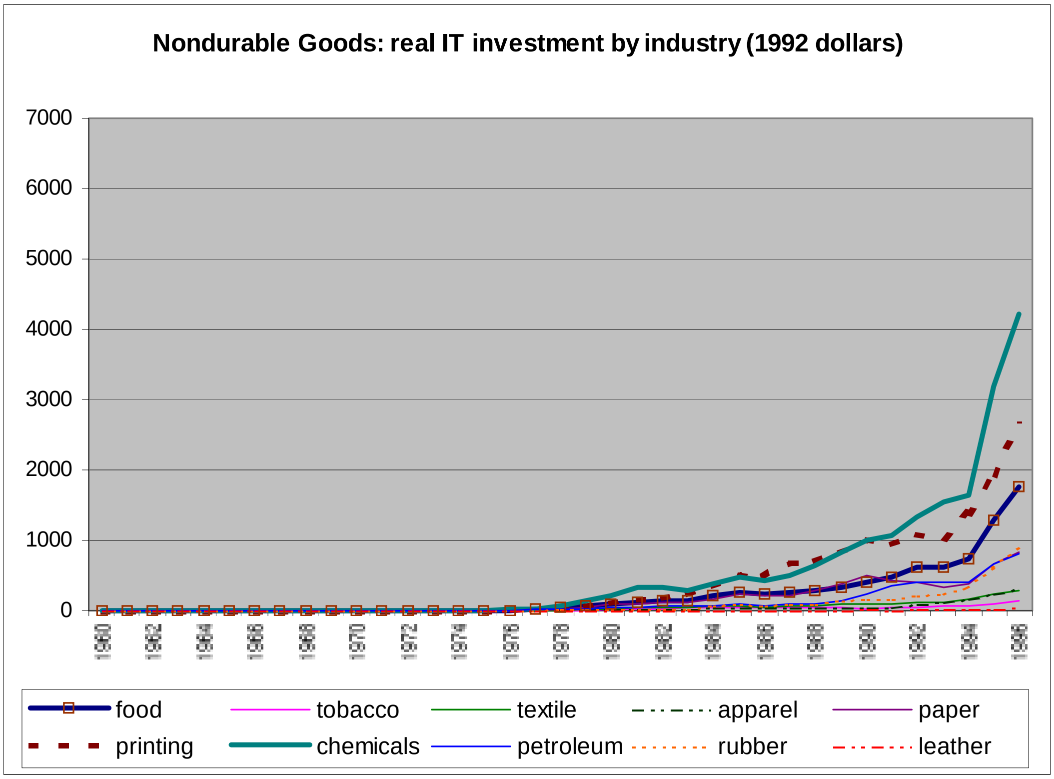

Figure 6: Postwar Inventory-to-Sales Ratios

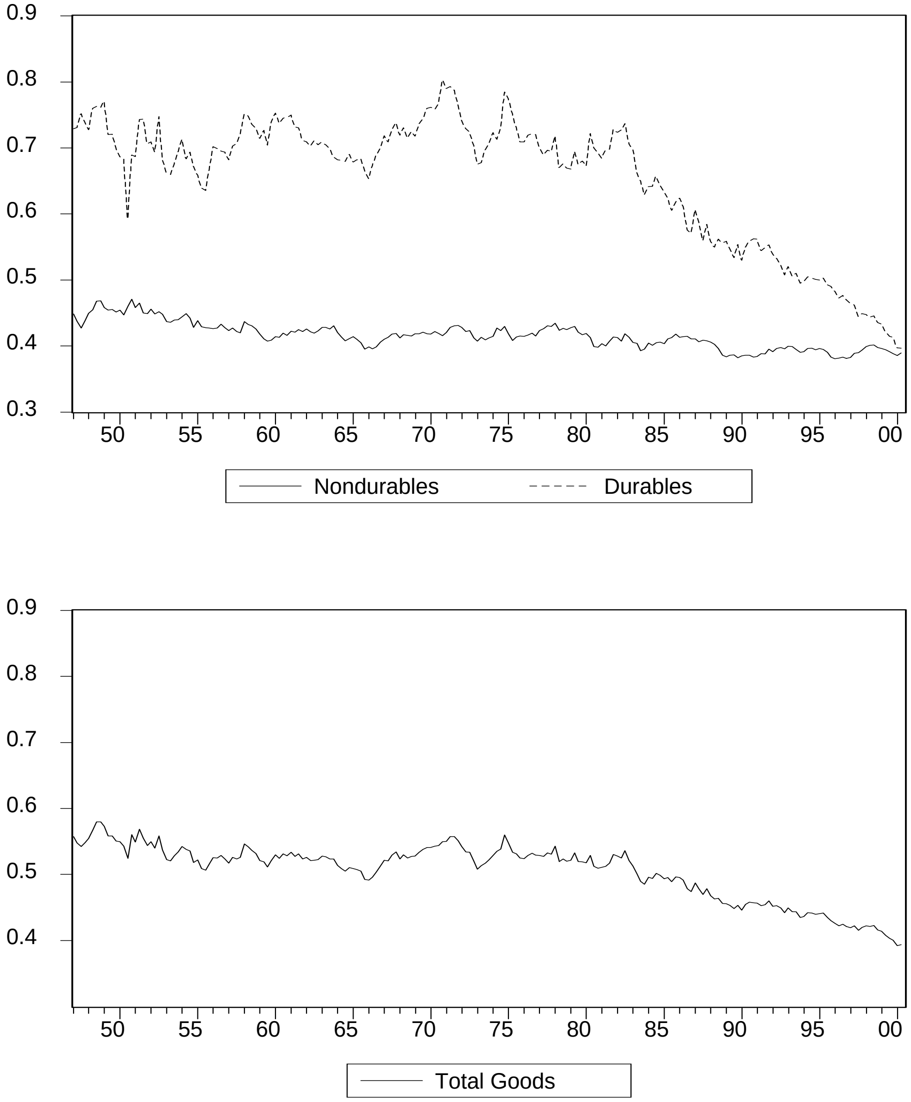

Figure 7: Responses to Demand Shocks