Supply Shocks and the Persistence of Inflation

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Abstract

This paper examines the long-run effects of supply shocks (such as oil shocks) on inflation in the United States. The persistence of supply shocks in U.S. inflation fell considerably during the period of Volcker's disinflation (1979-1982). My empirical results suggest that the difference between the pre-Volcker and post-Volcker periods is attributable to the change in the behavior of inflation expectations - agents expected shocks to persist in the pre-Volcker period, but not in the post-Volcker period. I construct a simple model of how different monetary policies lead to different persistence equilibria.

Keywords: inflation, supply shocks, inflation expectations, persistence, Great Inflation

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1 Introduction

There has been much debate about how "supply" shocks effect inflation. Most economists would agree that shocks, such as sudden large changes in the prices of food and oil, influence inflation over the short run: the studies of Ball and Mankiw (1995) and Gordon (1998) show that such shocks explain a large fraction of variability in post-war U.S. inflation. However, there is no consensus about the effects of supply shocks on inflation over the long run. The conventional wisdom about the persistence of supply shocks has been determined in large part by the experience of the Great Inflation of the 1970s. One explanation often given concerning this as well as other periods of inflation instability is that, under an accommodative policy, shocks feed into inflation expectations. Inflation remains high until the FED tightens policy and drives the economy into a recession (Ball, 1991). The other view holds the complete opposite; that supply shocks merely cause short-run fluctuations in inflation (Blinder, 1982).

Knowing whether shocks have permanent or transitory effects and what determines the magnitude of the effects is important in formulating monetary policy. Given the variability in commodity prices, policymakers often face a dilemma as to how to react to shocks. Should they accommodate them over the short run and wait until inflation returns to its initial level? Or do they need to drive economy into a recession to offset the shocks? Another related question is whether favorable shocks can permanently reduce the inflation rate.

Section 2 examines whether supply shocks have permanent or temporary effects on inflation. As an inflation model, I use the Phillips curve augmented with various measures of shocks. I find that the persistence of shocks is very different in two subsamples. In the period before Volcker's disinflation (1960-1979), the shocks had a long-run effect on inflation. The size of the permanent component was roughly 50% of the initial impact. On the other hand, in the period after Volcker's disinflation (1983-2000), the persistence of shocks in the inflation rate was negligible. In this period, supply shocks to inflation die out in less than half a year.

In Section 3, I explore the reasons for the difference. I argue that the persistence of shocks is closely linked to the behavior of expectations. When agents believe that the effects will be permanent, shocks feed into their expectations, and the persistence of shocks is thus large. On the other hand, when agents believe that the effects of shocks are only temporary, inflation quickly returns to its initial level. I estimate a model of expectations where agents take into account information on past inflation and past shocks. Based on the data from the two surveys of inflation expectations, I find that agents expected shocks to persist during the pre-Volcker period but not during the post-Volcker period. Moreover, the degree of persistence in expected inflation is very similar to the degree of persistence in the actual inflation rate for both periods.

In Section 4, I then give a simple theoretical interpretation of the stylized facts. I show how the accommodative policy of the sixties and seventies gave rise to the persistence of shocks in expected inflation, and therefore in actual inflation. In contrast, the activist policy of the eighties and nineties eliminated the persistence of shocks.

In Section 5, I conclude by returning to the continuing debate about the run-up of inflation in the 1970s. I assert that the persistence of shocks during the pre-Volcker period was too short-lived to explain the run-up of inflation in the seventies. Shocks explain only 30% of the increase in inflation during the two relevant episodes. Interpretations of the Great Inflation of the 1970s based on various excess demand stories (e.g., Clarida, Gali, Gertler, 2000, and De Long, 1997) appear quantitatively more important.

2 Persistence of supply shocks

2.1 Inflation model

As a statistical model of inflation, I use a standard version of the Phillips curve:

$$\pi_t = c + \alpha(L)\pi_{t-1} + \beta(L)(u_{t-1} - u^*_{t-1}) + \gamma_0 Shock_t + \gamma(L)Shock_{t-1} + \epsilon_t, \quad (1)$$

where π_t is the inflation rate, u_t the unemployment rate, and u^*_t a measure of unemployment trend. $Shock_t$ is a variable summarizing the inflationary impact of supply shocks (defined below), and ε_t is an unidentified inflation shock with standard statistical properties.

To examine the persistence of supply shocks, I compute the long-run impact of $Shock$ on the inflation rate, holding the level of economic activity constant:

$$\tau = \lim_{k\to\infty} \frac{\partial \pi_{t+k}}{\partial Shock_t} \mid u_t = u^*_t.$$

This is clearly the most practical definition of persistence. The value of τ

tells us to what extent inflation would fall back to its original level after a bad shock if the economy were kept at its potential output. I use two criteria to assess the persistence of shocks. I test whether the long-run effect of shocks on inflation (τ) is statistically significant. To provide a quantitative measure of persistence, I also compute the ratio of long-run and contemporaneous responses of inflation with respect to the shock:[1] $\frac{\tau}{\gamma_0}$.

2.2 Measures of shocks

Researchers have traditionally used the prices of food and energy to measure "supply" or "price" shocks. A large price increase in one sector is inflationary because prices in other sectors do not immediately adjust in the opposite direction to offset the shock. Historically, prices in the food and energy sectors have been extremely volatile and therefore, relative changes of price in the food and energy sectors explain a large fraction of inflation variability. I use this index as one measure of supply shocks.

Ball and Mankiw (1995) developed alternative measures of supply shocks, which take into account the fact that a large price change can occur in any sector. Based on their insights and on the work of Bryan and Cecchetti (1994), I use the "median gap" as my second measure of supply shocks. The median gap is defined as the difference between the inflation rate and the weighted-median (core) inflation rate. The reason for using this measure is that core inflation is not immediately effected by sector-specific price changes. Therefore,

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[1] Taking a ratio of the long-run response over the contemporaneous response is sensible in an environment where the contemporaneous impact of a shock is larger than the impact in all other periods. Since I work with quarter-to-quarter inflation without any time averaging, the estimated impulse responses have this property.

the median gap extracts the inflationary effect of price shocks from all sectors of the economy. This feature is particularly important for the interpretation of recent episodes, where sectors such as technology, health care and tobacco contributed to inflation volatility.[2]

In practice, the median gap is highly correlated with traditional measures of shocks (correlation with food and energy shocks is 72%) and therefore results for both measures are similar. Nevertheless, using the median gap as a more general proxy for supply shocks is desirable, as it is based on explicit theory. Moreover, it explains a larger fraction of inflation changes than food and energy variables alone.

2.3 Estimated Phillips curves

I estimate the Phillips curve (1) using U.S. quarterly data from 1960:1 to 2000:3 (food and energy shocks) and 1968:1-2000:3 (median gap).[3] As a measure of inflation, I use the annualized quarter-to-quarter percentage change in the CPI-U price index.[4] Here, u_t is the seasonally adjusted civilian unemployment rate, and u_t^* is a measure of the unemployment trend, estimated using the HP filter with a smoothness coefficient of λ=1,600. The supply shock "$Shock_t$" is approximated using the median gap, defined as the quarterly CPI inflation

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[2] Ball and Mankiw develop a number of supply shock measures, particularly measures based on the skewness of the distribution of relative price changes. With respect to empirical implementation, I prefer the median gap over the skewness measures as the median gap can easily be computed from data available from the Federal Reserve Bank of Cleveland.

[3] Equations with the median gap are estimated over the shorter sample due to limited availability of median inflation data.

[4] I do not use CPI-U-X1 or CPI-U-RS series as in the next section I will work with measures of survey expectations. The inflation expectation is, of course, formed with respect to inflation as defined at the time of the expectations survey. Moreover, the median inflation series is computed using the historical CPI basket weights.

minus the quarterly change in the weighted median CPI index. Alternatively, the $Shock_t$ is measured using the food and energy index, defined as the difference between the quarterly CPI inflation and the inflation rate ex food and energy. Both measures of shocks are very close to constituting a white noise. I use four lags of all the variables, based on the AIC and BIC criteria.

Historical accounts of post-war inflation in the U.S. (De Long, 1997, and Taylor, 1997) have emphasized that the character of monetary policy changed considerably at the end of the 1970s. It would be natural if changes in the dynamics of inflation corresponded with the regime break as well. Therefore, I test for a structural change in the estimated parameters at an unknown point in time using the Andrews-Ploberger test (Andrews, Ploberger, 1994, and Andrews, Lee, Ploberger, 1996). The null of coefficient stability can be rejected at a one-percent level in all versions of the Phillips curve. For the version of the Phillips curve with the median gap, the lowest p-value of the F-statistics occurs at 1980:3 (0.004). Another local minimum is found at 1981:4. There are also a number of p-values of less than 0.05 around these two dates. The statistical evidence, therefore, is consistent with the idea that the change in the conduct of monetary policy contributed to a change in the dynamics of inflation.

I define the subsamples for the analysis of persistence as the following periods: 1960:1 - 1979:4, and 1983:1-2000:3. I do not include the transitional period 1980:1-1982:4 in the analysis. Certain variants of the tests indicate that there may have been another structural break in equation (1) in 1974. This date coincides with the end of Nixon's price controls, and a temporary tightening of monetary policy by the Federal Reserve. I will nevertheless assume that the pre-Volcker period is, to a first-order approximation, a stable one.

Tables 1 and 2 summarize basic regression results. Figure 1 illustrates the quality of fit achieved by equation (1), both in terms of the level of inflation and its changes. The adjusted R^2 of the regressions is between 80 and 90%. Depending on the subsample, supply shocks contribute 20-50% to the in-sample fit of the equations. In line with traditional Phillips curve research, I assume that inflation contains a unit root. I thus restrict the sum of coefficients on past inflation such that it equals one. As a robustness check, I estimate the Phillips curve with unrestricted coefficients. It turns out that the estimated coefficients change very little. The reason is that the sum of the coefficients on lagged inflation is close to one in both subsamples: 0.88 (0.09) or 0.96 (0.05) for the pre-Volcker period and 0.84 (0.09) or 0.92 (0.09) for the post-Volcker period.

2.4 The persistence of supply shocks before and after Volcker's disinflation

Before turning to an analysis of the impulse response functions generated by estimated equation (1), it is interesting to note the sharp change in the sum of the coefficients on supply shocks between the two subsamples. For the pre-Volcker period, the sum is positive (0.466) and significant (with a standard error of 0.214). It is a substantial fraction (approximately 2/3) of the initial impact of shock on inflation. On the other hand, for the post-Volcker period, the sum is very close to zero (-0.036) and insignificant (with a standard error of 0.093).

The persistence of supply shocks apparently changed during the period of

Volcker's disinflation and the impulse responses drawn in Figures 2a and 2b confirm this conjecture.[5] For the pre-Volcker era, the long-run response of inflation to shocks is approximately 50% of the initial impact. The persistence index, defined as the long-run over contemporaneous response ($\frac{\tau}{\gamma_0}$), is 51.3% for median gap (with a standard error of 16%) and 56.5% for food and energy (with a standard error of 7%). Moreover, it takes four to five quarters for the inflation rate to get close to a steady state.

For the post-disinflation sample, the relative price shocks have very little persistence, both in statistical and economic terms. The persistence index is 1.8% for median gap and 4.6% for food and energy. The median gap shock already dies out after 1 quarter. The effect of the food and energy shock disappears at almost the same rate.[6]

Figure 3 demonstrates the robustness of these conclusions using an alternative method. I estimate the persistence index $\frac{\tau}{\gamma_0}$ in rolling samples over a period of 15 years. The figure clearly illustrates how the persistence of supply shocks dropped after the pre-Volcker data fell out of the regressions. The analysis of persistence is also robust with respect to assumptions about the number of lags and HP filter parameter λ.

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[5] The impulse responses are calculated from equation (1) assuming unemployment is at its natural level and inflation contains a unit root.

[6] Hooker (2002) reaches a similar conclusion about the persistence of supply shocks using a different methodology. He finds that oil shocks do not pass through into core inflation after 1981, but do so prior. Hooker also demonstrates that a model with a structural break in the effects of shocks provides a better fit for the data than models based on asymmetries or nonlinearities.

3 Supply shocks and inflation expectations

3.1 Expectation hypothesis

When prices are sticky, inflation expectations are the main force driving inflation dynamics. The central feature of inflation dynamics - inflation inertia - is often attributed to the strong backward-looking component in expected inflation (Ball, 2000), or to the slow propagation of information (Mankiw and Reis, 2002). In this section, I examine whether another important feature of inflation dynamics - the persistence or non-persistence of supply shocks - can also be clearly linked to the behavior of expectations.

The textbook version of a Phillips curve incorporating expectations and supply shocks is:

$$\pi_t =_{t-1} \pi_t^e + \beta(L)(u_{t-1} - u_{t-1}^*) + \gamma_0^I Shock_t + \epsilon_t, \tag{2}$$

where ${}_{t-1}\pi_t^e$ is the time $t-1$ aggregate expectation of time t inflation. In this equation, actual inflation depends on expected inflation, the unemployment gap, and on shocks not known at time $t-1$.

The simplest theory of expectation formation capturing inflation stickiness is the one assuming adaptive expectations:

$${}_{t-1}\pi_t^e = c^I + \alpha^I(L)\pi_{t-1}.$$

However, this theory fails to explain, among other things, why supply shocks have permanent effects on inflation in one regime, and only temporary effects in another. Based on the empirical results in Section 2, a better reduced-form description of expectation formation seems to be:

$$_{t-1}\pi_t^e = c^I + \alpha^I(L)\pi_{t-1} + \gamma^I(L)Shock_{t-1} + \mu_{t-1}. \tag{3}$$

Equation (3) assumes that agents distinguish between different sources of inflation changes, and that different shocks can have different effects on expected inflation. In particular, supply shocks can have either permanent or temporary effects depending on the magnitude of coefficients γ. If γ's are zero (or moderately negative) and the sum of α's is one, then supply shocks can be expected to have permanent effects. On the other hand, if γ's are large and negative, shocks are more or less expected to die out. Therefore, specification (3) makes allowance for supply shocks to have different degrees of persistence under different monetary regimes. The term μ_t captures information other than past inflation and shocks, which agents conceivably might take into account when formulating their inflation forecast. The implicit assumption in the regression analysis below is that μ_{t-1} is orthogonal with respect to other right-hand variables in (3).

The above equation for inflation expectations should not be interpreted as an attempt to formulate the true mechanism of expectation formation. This reduced form will only be used to illustrate the changing beliefs of agents concerning the effects of supply shocks, and to show how, following supply shocks, expectations behavior influences actual inflation dynamics.

After substituting equation (3) into equation (2), we obtain a Phillips curve with the same functional form as the Phillips curve estimated in Section 2:

$$\pi_t = c^I + \alpha^I(L)\pi_{t-1} + \beta(L)(u_{t-1} - u^*_{t-1}) + \gamma^I_0 Shock_t + \gamma^I(L)Shock_{t-1} + \widetilde{\epsilon}_t. \quad (4)$$

The idea that the persistence of shocks is related to the expectations of agents is testable using data from inflation expectations surveys. In this respect, equation (3) has two specific implications. First, one can test whether agents at all take into account information about supply shocks when they form their expectations. At the same time, one can examine whether agents put "correct" weights on past inflation and shocks; i.e. one can test whether $\alpha(L) = \alpha^I(L)$, $\gamma(L) = \gamma^I(L)$, and $c = c^I$.

Secondly, equation (3) asserts that the persistence of supply shocks in actual inflation is determined by the beliefs of agents. If this is correct, then lags of shocks should only enter the Phillips curve through the expected inflation term. To test this prediction, I estimate Phillips curves adding a measure of expected inflation to the right hand side. After controlling for expectations, the coefficients on past shocks (γ^{II}'s) should be zero:

$$\pi_t =_{t-1} \pi^e_t + \beta(L)(u_{t-1} - u^*_{t-1}) + \gamma^I_0 Shock_t + \gamma^{II}(L)Shock_{t-1} + \epsilon_t. \quad (5)$$

In addition, the coefficients on contemporaneous $Shock_t$ should be the same as the coefficients on $Shock_t$ in Phillips curve (1); $\gamma_0 = \gamma^I_0$.

As a measure of expected inflation, I use inflation forecasts from the Survey of Professional Forecasters and the University of Michigan Survey of Consumers.[7]

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[7] Other sources of inflation forecasts, most notably the Livingston survey and the OECD forecasts, are reported only semi-annually, and are not suitable for my analysis, which is based on quarterly data.

Since the SPF and Michigan surveys collect data about qualitatively different inflation rates, I carry out the analysis of expectations in two separate sections, 3.2 and 3.3. It will be interesting to verify whether supply shocks influence the average inflation forecasts of professional economists and households similarly.

3.2 The Survey of Professional Forecasters

The Survey of Professional Forecasters collects forecasts from private-sector economists who predict future developments in the economy as their normal course of business. The Survey is currently run by the Philadelphia Federal Reserve Bank, and the typical number of respondents per survey varies between 20 and 40. I use data on one-quarter-ahead CPI inflation forecasts, the database for which dates back to 1981. In the optimal case, we would like to recover ${}_{t-1}\pi_t^e$ from the expectations data. The survey participants, however, have only partial information about the $t-1$ state of the economy when submitting their forecasts for time t inflation. For example, forecasts for the third quarter are reported to the Philadelphia FED already at the end of May. If a shock should occur in July, the respondents would not have that information available. Therefore, the coefficients on the regressors dated $t-1$ in equation (3) should be interpreted with caution: respondent cannot react to information they do not have. Fortunately, tests of expectation formation can still be carried out on the regressors dated $t-2$ and earlier.

(i) Test 1

In this subsection, I explore whether the predictions of professional economists concerning inflation are consistent with equation (3). I regress expected inflation on four lags of past inflation and shocks (the baseline number of lags from the previous section). As a measure of shocks, I use the median gap.[8] The sample period is 1983:1-2000:3.

Since supply shocks quickly die out from the actual inflation for this period, one would expect shocks to enter equation (3) with large negative coefficients. Table 4 confirms that this conjecture indeed holds true in the data. All coefficients are negative, most of them significantly.[9]

Moreover, the magnitude of the coefficients on inflation lags and supply shocks is comparable to those obtained from the Phillips curve (1). A quick informal comparison of the relevant coefficients is provided in Table 4. The similarity between the two sets of coefficients is striking. For example, the coefficients on shocks $t-2$, $t-3$ and $t-4$ in equation (3) are -0.26, -0.14 and -0.12, while those in the Phillips curve are -0.28, -0.15 and -0.17 respectively.

Statistically, the p-value of the F-test checking whether the coefficients on lagged shocks are the same in equations (1) and (3) is 0.75 or 0.35, depending on the assumption about the stationarity of inflation. The F-test of whether the inflation lags are the same, $\alpha(L) = \alpha^I(L)$, has a p-value of 0.24 or 0.16. The joint F-test of $\alpha(L) = \alpha^I(L)$, $\gamma(L) = \gamma^I(L)$ and $c = c^I$ (where applicable) has a p-value of 0.11 or 0.05 (again, depending on the assumption about the

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[8] Regressions using the food and energy variable produce results qualitatively consistent with expectation equation (3), although the tight quantitative restrictions imposed by equations (2) and (3) are rejected more often than is the case with regressions using the median gap.

[9] Moreover, $Shock_t$ should not enter equation (3) significantly. This holds true as well. I do not report the relevant regression results for the sake of brevity.

stationarity of inflation). All tests exclude $t-1$ variables. The slight rejection in one of the specifications should not be overstated as the coefficients are very close to one other in economic terms. Also, I treat the Phillips curve coefficients in $\alpha(L)$ and $\gamma(L)$ as constants, making the tests conservative.

As expected, the coefficient on the $t-1$ shock in equation (3) is far away from its Phillips curve counterpart in equation (1), and is biased towards zero. This is natural as respondents do not have full $t-1$ information when they form their SPF inflation forecast for period t.

(ii) Test 2

Now I test another implication of expectation equation (3): that lags of supply shocks only enter the Phillips curve (1) through the expected inflation term. If this is the case, the coefficients on past shocks should be zero when the Phillips curve is augmented with a measure of expectations, as in equation (5). The first column of Table 6 reports the relevant coefficients. The results are broadly consistent with the hypothesis.

The coefficients on lags of shocks fall towards zero (γ_2, γ_3, and γ_4 are -0.11, -0.01, and -0.06 respectively) and are insignificant as expected (the p-value of the F-test that they are jointly equal to zero is 0.28). The t-statistic on the first lag of *Shock* is relatively high (1.7 in absolute value), but again, this is attributable to the fact that respondents do not always have information about the $t-1$ supply shock when they form their SPF inflation forecast. Note also that the coefficient on contemporaneous shock (0.86) correctly remains close to its counterpart from the Phillips curve (1): 0.83 (p-value of 0.72).

In sum, the results from the Survey of Professional Forecasters strongly support the hypothesis that during the post-Volcker period, agents have viewed supply shocks as only a temporary phenomenon. Moreover, on average, their belief apparently materializes.

3.3 The University of Michigan Survey of Consumers

Now I carry out both tests of the expectations hypothesis (equation (3)), using inflation forecasts from the University of Michigan Survey.[10] The Michigan data is available for the period before Volcker's disinflation. I am, therefore, able to compare behaviors of expectations for the pre-Volcker and post-Volcker periods. The tests are not a mere repetition of the exercises done in sub-section 3.2, as the two surveys ask about different inflation rates. The SPF reports quarter-to-quarter inflation forecasts one period ahead - ${}_{t-1}(\frac{P_t}{P_{t-1}} - 1)^e$ - while the Michigan survey reports expectations of annual average inflation four quarters ahead; that is, ${}_{t-4}(\frac{P_t}{P_{t-4}} - 1)^e$. This fact requires a substantial modification of the tests.

First of all, I need a baseline equation for the dynamics of average inflation. To avoid complications arising from the MA structure in residuals generated by time averaging, I do not estimate the Phillips curve for average inflation, but rather make use of the regressions results from Section 2. I define four-quarter average inflation as $\pi_t^{avg} = \frac{1}{4} \sum\limits_{j=\{0,1,2,3\}} \pi_{t-j}$, and assume that $\pi_t^{avg} \approx (\frac{P_t}{P_{t-4}} - 1)$.

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[10] The (quarterly) University of Michigan study surveys a sample of 1500-2000 U.S. households. The households are selected based on demographic criteria such that the structure of the sample matches the composition of the U.S. population. Among other questions, the respondents are asked: "by what percent do you expect prices to go up, on average, during the next twelve months."

I can now average the Phillips curve (1) across time to obtain:

$$\pi_t^{avg} = c + \delta(L)\pi_{t-1} + \omega(L)(u_{t-1} - u_{t-1}^{*}) + \lambda_0 Shock_t + \lambda(L) Shock_{t-1} + \nu_t. \quad (6)$$

Coefficients δ, ω and λ are averages of the original Phillips curve parameters α, β, and γ from equation (1). The relevant formulas are provided in Appendix A.

Once I compute the coefficients of the Phillips curve for average inflation (equation (6)), I will be able to test whether the weights on past inflation and shocks in the Michigan expectations are consistent with weights in actual inflation. Technically, the Michigan survey is carried out through the whole quarter, and as with the SPF, respondents do not have all the necessary information about $t-4$ variables to make forecasts of time t average inflation. The tests therefore exclude regressors timed at $t-4$. In the next two subsections, I will show how the restrictions imposed by the expectation hypothesis (3) apply when working with average inflation and one-year ahead forecasts.

(i) Test 1

Here I examine whether households take into account information about supply shocks when forming their forecasts, and whether they put appropriate weights on past inflation and shocks. I estimate the following equation for inflation expectations:

$$_{t-4}(\pi_t^{avg})^e = \delta^I(L)\pi_{t-4} + \lambda^I(L) Shock_{t-4} + \epsilon_t. \quad (7)$$

I subsequently test whether the coefficients in $\delta^I(L)$ and $\lambda^I(L)$ are close to the coefficients implied by the Phillips curve (6). I denote these theoretical coefficients as $\delta^{II}(L)$ and $\lambda^{II}(L)$. Formulas for them are provided in Appendix A.[11]

Tables 5a and 5b summarize the regression results from equation (7). For the post-Volcker period, the lags of shocks enter negatively. By contrast, for the pre-Volcker period, the coefficients on lags of shocks are close to zero and are insignificant. As explained above, this qualitative difference is consistent with what one would expect given the empirical pattern of persistence in actual inflation.

The quantitative implications of the expectation hypothesis hold approximately as well. The coefficients λ^{I} on lags of shocks in the equation for expectations (7) are not far from the coefficients λ^{II} derived from the Phillips curve (see Tables 5a and 5b). Specifically, for the I(1) model of inflation, the λ^{I} coefficients for t-5, t-6, and t-7 shocks for the pre-Volcker period are -0.07, 0.02, and -0.03 respectively. The equivalent λ^{II}'s are 0.03, 0.10, and 0.19. For the post-Volcker period, the tested λ^{I}'s are -0.29, -0.24, and -0.09. The equivalent λ^{II} coefficients are -0.27, -0.15, and -0.09.

For the pre-Volcker period, the null that coefficients on shocks in $\lambda^{I}(L)$ are equal to those in $\lambda^{II}(L)$ has a p-value of 0.35. The test on inflation coefficients, $\delta^{I}(L) = \delta^{II}(L)$, has a p-value of 0.68 and the joint test of $\lambda^{I}(L) = \lambda^{II}(L)$ and $\delta^{I}(L) = \delta^{II}(L)$ has a p-value of 0.40 (all statistics apply to the I(1) model). For the post-Volcker period, the same tests have p-values of 0.62, 0.11, and 0.27

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[11] Polynomials $\delta^{II}(L)$ and $\lambda^{II}(L)$ in equation (7) are different from $\delta(L)$ and $\lambda(L)$ in equation (6) as at time $t-4$, agents do not know π_{t-1}, π_{t-2}, π_{t-3}, and must therefore forecast these variables.

respectively. Looking at the battery of tests for both I(1) and I(0) models of inflation, the expectation hypothesis is not, with one exception, rejected. Further, the coefficient estimates of $\delta^{I}(L)$ and $\lambda^{I}(L)$ are, in economic terms, remarkably close to their theoretical values $\delta^{II}(L)$ and $\lambda^{II}(L)$. Again, the tests are conservative as the coefficients in λ^{II} and δ^{II} are treated as constants. Similarly, as was the case with the Survey of Professional Forecasters, the coefficient on the supply shock $Shock_{t-4}$, which occurs in the quarter during which expectations are formed, is excluded from testing. It is biased towards zero as not all the respondents know the value of the shock when they form their forecasts.

(ii) Test 2

The second test examines whether inflation expectations fully account for the dynamic response of inflation to supply shocks. The intuition behind this test is similar to that in the case of the Survey of Professional Forecasters. I first estimate the following equation:

$$\pi_t^{avg} =_{t-4} (\pi_t^{avg})^e + \omega(L)(u_{t-1} - u_{t-1}^*) + \lambda_0 Shock_t + \lambda(L) Shock_{t-1} + \nu_t. \quad (8)$$

Then, I test whether the coefficients on shocks, which occurred after the expectations were taken, stay significant and unchanged in size. The coefficients on the shocks which occurred before the expectations were taken should become insignificant.

During estimation, I include MA terms to control for serial correlation in ν_t generated by time averaging. The second and third columns of Table 6 report the regression results. Qualitatively, predictions about the significance of coefficients are met. The coefficients on shocks t, $t-1$, $t-2$ and $t-3$ are jointly significant (with p-values of 0.04 or less), and often individually significant. Quantitative predictions about the values of coefficients on this group of supply shocks are not rejected. The p-values of the F-tests are 0.56 for the pre-Volcker period and 0.13 for the post-Volcker period. Shocks which occured before expectations were taken ($t-5$, $t-6$, $t-7$) are, individually and jointly, statistically insignificant as expected: the p-values of F-tests are 0.54 and 0.19. Finally, the joint predictions of the expectations hypothesis about the values of coefficients (t, ..., $t-3$, $t-5$, $t-6$, $t-7$) are not rejected at the 0.73 level for the pre-Volcker period and are only weakly rejected at the 0.05 level for the post-Volcker period.

4 Equilibrium persistence of shocks

4.1 A simple model of the economy

In the previous section, I demonstrated that the persistence of shocks is closely related to, and possibly determined by, the behavior of inflation expectation. But how are these expectations formed in the first place? The natural answer is that expectations are consistent with the anticipated actions of policymakers. When agents expect policymakers to accommodate shocks, the expected inflation is likely to rise after unfavorable shocks. On the other hand, when policymakers move aggressively against supply shocks, agents expect the shocks to die out. In this section, I describe how different policy regimes lead to different persistence equilibria.

Consider a simple model where all firms set prices every period. The relationship between the output gap and inflation is summarized by an expectations-augmented Phillips curve:

$$\pi_t =_{t-1} \pi_t^e + \beta y_t + \varepsilon_t^\pi, \tag{9}$$

where ε_t^π is a "supply" shock; that is, a shock that increases inflation for any given level of output.

I express the monetary policy objective using inflation target π^* (this target can be explicit or implicit). Policymakers are able to perfectly implement their target, with the qualification that they cannot offset the current-period inflation shock ε_t^π:

$$\pi_t = \pi_t^* + \varepsilon_t^\pi.$$

Further, I assume that firms can forecast the systematic component of the policymakers' target. I make this assumption because, as discussed below, my analysis focuses on two types of stable policy regimes: accommodative and anti-inflationary. I ignore the problem of transitions between regimes as well as the important fact that expectations adjust slowly to changes in regime (Ball, 1991). Using this simple model, I study how the two different policies affect the persistence of inflation shocks.

4.2 An accommodative policy

Policymakers that are mainly concerned about the output effects of their policy actions and are insensitive to the level of inflation select their inflation target such that expected output is zero: $Ey = 0$. Following from the Phillips curve (9), the policy objective can be written in terms of the inflation target as:

$$\pi_t^* =_{t-1} \pi_t^e. \tag{10}$$

We may think of the target as an approximate description of the actual behavior of policymakers during the 1960s and 1970s. De Long (1997) and Romer and Romer (1989) demonstrate that the primary objective of policymakers during these decades was to keep output at or above its potential.[12]

The solution of the model for inflation is:

$$\pi_t =_{t-1} \pi_t^e + \beta y_t + \varepsilon_t^\pi. \tag{11}$$

Ball (1991) and Christiano and Gust (2000) have argued that accommodative policies like those in equation (10) generate an infinite number of inflation equilibria. The reason is that policymakers are willing to set their target equal to any inflation expectation; as such, the beliefs of agents become self-fulfilling. Using the terminology of Christiano and Gust, accommodation creates an "expectations trap." The same feature is also present in this model. Since the expected values of the output gap and inflation shock are zero, inflation equals, on average, its expectation. At the same time, any path for expectation ${}_{t-1}\pi_t^e$ can be made consistent with the model.

The expectations trap theory makes no provision for predicting the persistence of supply shocks. As an illustration, we may think of agents as forming expectations based on the inflation trend, as well as their belief as to how much

---

[12] Of course, policymakers stopped accommodating when inflation became too high, specifically in 1968 and in 1974 (Romer and Romer). In both cases, the turnaround in policy was only temporary. For simplicity, I ignore these two policy shocks and assume that agents thought of the accommodative policy as the typical regime.

of the recent inflation shock policymakers will accommodate:

$$_{t-1}\pi_t^e = \alpha\pi_{t-1}^{core} + \gamma\varepsilon_{t-1}^{\pi}.$$

The inflation trend, or core inflation, is here defined as the level of inflation without inflation shock: $\pi_{t-1}^{core} = \pi_{t-1} - \varepsilon_{t-1}^{\pi}$. It is apparent that any expectation process (any set of parameters α and γ) can constitute an equilibrium:

$$\begin{aligned}\pi_t &= \alpha\pi_{t-1}^{core} + \gamma\varepsilon_{t-1}^{\pi} + \beta y_t + \varepsilon_t^{\pi} \\ &= \alpha\pi_{t-1} + \beta y_t + \varepsilon_t^{\pi} + (\gamma - \alpha)\varepsilon_{t-1}^{\pi}. \qquad (12)\end{aligned}$$

Equation (12) suggests that an accommodative policy supports the equilibrium observed over the pre-Volcker period: inflation has unit root, while supply shocks partly die out. The degree of pass-through into inflation of supply shocks is regulated by the difference between parameters γ and α.

4.3 An aggressive policy

The indeterminacy of the inflation process disappears in the model as soon as policymakers stop pursuing a fully accommodative policy. To build an analogy with the previous example, we might postulate that policymakers set their inflation target taking the core inflation rate as a benchmark, while accommodating some fraction of the past inflation shock:

$$\pi_t^* = \alpha\pi_{t-1}^{core} + \gamma\varepsilon_{t-1}^{\pi}. \qquad (13)$$

Firms understand this objective, therefore:

$$_{t-1}\pi_t^e = \pi_t^* = \alpha\pi_{t-1} + (\gamma - \alpha)\varepsilon_{t-1}^{\pi}. \qquad (15)$$

The solution for inflation is the same as previously:

$$\pi_t = \alpha\pi_{t-1} + \beta y_t + \varepsilon_t^{\pi} + (\gamma - \alpha)\varepsilon_{t-1}^{\pi}.$$

However, the equilibirium for degree of persistence is now determined by policymakers. Consider the special case where $\alpha = 1$ and $\beta = 0$. Here, core inflation represents that part of the underlying movement of inflation, which policymakers do not counteract. At the same time, policymakers move aggressively against inflation shocks. In equilibrium, supply shocks die out from the inflation rate autonomously. The reason is that both the core and expected inflation rates are independent of ε^{π}. This special case qualitatively fits the stylized facts about the conduct of policy and the behavior of inflation persistence during the 1980s and 1990s. Since Volcker's disinflation, policymakers have acted aggressively against deviations in inflation from its implicit target (Clarida, Gali and Gertler, 2000, and Taylor, 1998). Phillips curves (1) estimated over the post-Volcker period exhibits stickiness of core inflation and only short-lived effects of supply shocks on headline inflation.

5 The relative importance of supply shocks during the Great Inflation

The traditional textbook treatment of the Great Inflation blames supply shocks for the run-up of inflation during the seventies (Mankiw, 1997). A number of recent papers, however, advocate a revisionist view of this stagflationary period (Barsky and Kilian, 2001, Clarida, Gali and Gertler, 2000, De Long, 1997, and Orphanides, 2000). While these papers approach the issue from different perspectives, they share one common feature. In their accounts, supply shocks played only a minor role in the run-up of inflation during this decade. The main causes were fiscal and monetary policies which not only accommodated supply shocks, but were, on average, expansionary. In this paper, I find evidence supporting the revisionist view. Although supply shocks had permanent effects on inflation, they were not sufficiently strong to explain most of the observed increases in inflation.

I use the Phillips curve (1) to simulate the path of inflation assuming that the economy was not subject to any supply shocks. Figure 4 demonstrates that inflation was steadily rising even after controlling for the effects of shocks. (See the line "ex supply shocks.") Supply shocks accounted for less than 30% of inflation increases during the two major episodes of inflation, 1971:4-1974:3 and 1976:1-1979:2. I also compute the hypothetical inflation rate based on the assumption that unemployment was at its natural rate throughout the 1970s, and conclude that the unemployment variable seems to constitute a more important cause of rises in inflation. Unemployment was often below its natural rate and the resulting negative output gap had strong inflationary effects.[13] To be specific, inflation rose by 10.5 percentage points during both episodes. In the first episode, shocks contributed only 3.2% to this rise, while the unemployment gap contributed 5.2%. 2.1% of inflation increase is unexplained by the model. In the second episode, supply shocks contributed 3.3%, unemployment gap 3.6%,

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[13] Policymakers may not have been aware of the negative output gap in real time (Orphanides, 2000), however historical accounts of the period document that the policy stance was expansionary, even after controlling for uncertainty about the natural rate (De Long, 1997, Romer and Romer, 1989).

and the remainder (3.6%) is unexplained by the model.

6 Conclusion

The paper revisits traditional wisdom about the persistence of inflation shocks. Their effects are either temporary or permanent, depending on the behavior of inflation expectations. The fall in the persistence of shocks observed in the U.S. data can be modeled as arising from the higher aggressivity of policymakers for the period following Volcker's disinflation.

Besides contributing to a re-interpretation of the events of the 1970s, this paper has another, more current, policy implication. Policymakers often argue that the most convenient way to further reduce a relatively low rate of inflation is through favorable supply shocks. This idea has been known as the "opportunistic approach to disinflation," and has been discussed in the academic literature by Orphanides and Wilcox (1996). However, the assumption that the inflation rate permanently falls after a favorable (e.g. commodity) shock is not necessarily satisfied. As this paper suggests, supply shocks have only had very short-lived effects on U.S. inflation during the current policy regime.

Appendix A

Derivation of the Phillips curve for average inflation (6).

Let π_t^{avg} denote average inflation:

$$\pi_t^{avg} = \frac{1}{4} \sum_{j=\{0,1,2,3\}} \pi_{t-j}. \tag{16}$$

Substituting the Phillips curve (1) into equation (16) gives us equation (6):

$$\begin{aligned}
\pi_t &= c + \alpha(L)\pi_{t-1} + \beta(L)(u_{t-1} - u^*_{t-1}) + \gamma_0 Shock_t + \gamma(L)Shock_{t-1} + \epsilon_t, \quad (1)\\
\pi_t^{avg} &= c + \delta_1\pi_{t-1} + \delta_2\pi_{t-2} + ... + \delta_7\pi_{t-7} + \omega_1(u_{t-1} - u^*_{t-1}) + \omega_2(u_{t-2} - u^*_{t-2})\\
&\quad +... + \omega_7(u_{t-7} - u^*_{t-7}) + \lambda_0 Shock_t + \lambda_1 Shock_{t-1} + ... + \lambda_7 Shock_{t-7}\\
&\quad +0.25\epsilon_t + ... + 0.25\epsilon_{t-3},\\
\pi_t^{avg} &= c + \delta(L)\pi_{t-1} + \omega(L)(u_{t-1} - u^*_{t-1}) + \lambda_0 Shock_t + \lambda(L)Shock_{t-1} + \nu_t. \quad (6)
\end{aligned}$$

The coefficients δ, ω and λ in the Phillips curve (6) are simple functions of the coefficients α, β and γ. Shock ν_t is a moving average of the white noise error, ε_t.

For δ's, the mapping is as follows:

$$\begin{aligned}
\delta_1 &= \frac{\alpha_1}{4}, \quad \delta_2 = \frac{\alpha_1+\alpha_2}{4}, \quad \delta_3 = \frac{\alpha_1+\alpha_2+\alpha_3}{4}, \quad \delta_4 = \frac{\alpha_1+\alpha_2+\alpha_3+\alpha_4}{4},\\
\delta_5 &= \frac{\alpha_2+\alpha_3+\alpha_4}{4}, \quad \delta_6 = \frac{\alpha_3+\alpha_4}{4}, \quad \delta_7 = \frac{\alpha_4}{4}.
\end{aligned}$$

The equations for ω's are analogous. The equations for λ's are as follows:

$$\begin{aligned}\lambda_1 &= \frac{\gamma_0}{4}, \quad \lambda_2 = \frac{\gamma_0+\gamma_1}{4}, \quad \lambda_3 = \frac{\gamma_0+\gamma_1+\gamma_2}{4}, \quad \lambda_4 = \frac{\gamma_0+\gamma_1+\gamma_2+\gamma_3}{4}, \\ \lambda_5 &= \frac{\gamma_1+\gamma_2+\gamma_3+\gamma_4}{4}, \quad \lambda_6 = \frac{\gamma_2+\gamma_3+\gamma_4}{4}, \quad \lambda_7 = \frac{\gamma_3+\gamma_4}{4}, \quad \lambda_8 = \frac{\gamma_4}{4}.\end{aligned}$$

Derivation of the coefficient values in equations (7) and (8).

We would like to derive an expression for inflation expectation ${}_{t-4}(\pi_t^{avg})^e$, which is consistent with the Phillips curve (6). After repeatedly substituting equation (1) for $\pi_{t-1}, \pi_{t-2}, \pi_{t-3}$ in equation (6), we obtain:

$$\pi_t^{avg} = c^{II} + \delta^{II}(L)\pi_{t-4} + \omega^{II}(L)(u_{t-1} - u_{t-1}^*) + \lambda_0^{II} Shock_t + \lambda^{II}(L) Shock_{t-1} + \tilde{\nu}_t.$$

Taking expectations over time $t-4$ information set, here restricted to lags of inflation and supply shocks, we obtain:

$$\begin{aligned}{}_{t-4}(\pi_t^{avg})^e &= c^{II} + \delta_4^{II}\pi_{t-4} + ... + \delta_7^{II}\pi_{t-7} + \lambda_4^{II} Shock_{t-4} + ... + \lambda_7^{II} Shock_{t-7} \\ &= c^{II} + \delta^{II}(L)\pi_{t-4} + \lambda^{II}(L) Shock_{t-4}. \qquad \text{(7a)}\end{aligned}$$

Test 1 based on the Michigan expectations has the following structure. We estimate:

$${}_{t-4}(\pi_t^{avg})^e = c^{II} + \delta^{I}(L)\pi_{t-4} + \lambda^{I}(L) Shock_{t-4} + \epsilon_t, \qquad (7)$$

and test whether the coefficients in $\delta^I(L)$ and $\lambda^I(L)$ in equation (7) equal their theoretical counterparts in equation (7a). To obtain the values of c^{II}, $\delta^{II}(L)$ and $\lambda^{II}(L)$, it is necessary to express the δ^{II}'s and λ^{II}'s in terms of c, α's and γ's from equation (1). The following equations provide the mapping. Subscripts indicate to which lag of inflation or supply shock the coefficient belongs.

$$
\begin{aligned}
c^{II} &= \frac{c}{4}\{4 + 3\alpha_1 + 2\alpha_1^2 + \alpha_1^3 + 2\alpha_2 + 2\alpha_1\alpha_2 + \alpha_3\}, \\
\delta_4^{II} &= \frac{1}{4}\left\{\alpha_1 + \alpha_1^2 + \alpha_1^3 + \alpha_1^4 + \alpha_2 + 2\alpha_1\alpha_2 + 3\alpha_1^2\alpha_2 + \alpha_2^2 + \alpha_3 + 2\alpha_1\alpha_3 + \alpha_4\right\}, \\
\delta_5^{II} &= \frac{1}{4}\left\{\alpha_2 + \alpha_1\alpha_2 + \alpha_1^2\alpha_2 + \alpha_1^3\alpha_2 + \alpha_2^2 + 2\alpha_1\alpha_2^2 + \alpha_3 + \alpha_1\alpha_3 + \alpha_1^2\alpha_3 + 2\alpha_2\alpha_3 + \alpha_4 + \alpha_1\alpha_4\right\}, \\
\delta_6^{II} &= \frac{1}{4}\left\{\alpha_3 + \alpha_1\alpha_3 + \alpha_1^2\alpha_3 + \alpha_1^3\alpha_3 + \alpha_2\alpha_3 + 2\alpha_1\alpha_2\alpha_3 + \alpha_3^2 + \alpha_4 + \alpha_1\alpha_4 + \alpha_1^2\alpha_4 + \alpha_2\alpha_4\right\}, \\
\delta_7^{II} &= \frac{1}{4}\left\{\alpha_4 + \alpha_1\alpha_4 + \alpha_1^2\alpha_4 + \alpha_1^3\alpha_4 + \alpha_2\alpha_4 + 2\alpha_1\alpha_2\alpha_4 + \alpha_3\alpha_4\right\}, \\
\lambda_4^{II} &= \frac{1}{4}\{\gamma_1 + \alpha_1\gamma_1 + \alpha_1^2\gamma_1 + \alpha_1^3\gamma_1 + \alpha_2\gamma_1 + 2\alpha_1\alpha_2\gamma_1 + \alpha_3\gamma_1 + \gamma_2\} \\
&\quad + \frac{1}{4}\{\alpha_1\gamma_2 + \alpha_1^2\gamma_2 + \alpha_2\gamma_2 + \gamma_3 + \alpha_1\gamma_3 + \gamma_4\}, \\
\lambda_5^{II} &= \frac{1}{4}\{\gamma_2 + \alpha_1\gamma_2 + \alpha_1^2\gamma_2 + \alpha_1^3\gamma_2 + \alpha_2\gamma_2 + 2\alpha_1\alpha_2\gamma_2 + \alpha_3\gamma_2 + \gamma_3\} \\
&\quad + \frac{1}{4}\{\alpha_1\gamma_3 + \alpha_1^2\gamma_3 + \alpha_2\gamma_3 + \gamma_4 + \alpha_1\gamma_4\}, \\
\lambda_6^{II} &= \frac{1}{4}\{\gamma_3 + \alpha_1\gamma_3 + \alpha_1^2\gamma_3 + \alpha_1^3\gamma_3 + \alpha_2\gamma_3 + 2\alpha_1\alpha_2\gamma_3 + \alpha_3\gamma_3 + \gamma_4\} \\
&\quad + \frac{1}{4}\{\alpha_1\gamma_4 + \alpha_1^2\gamma_4 + \alpha_2\gamma_4\}, \\
\lambda_7^{II} &= \frac{1}{4}\left\{\gamma_4 + \alpha_1\gamma_4 + \alpha_1^2\gamma_4 + \alpha_1^3\gamma_4 + \alpha_2\gamma_4 + 2\alpha_1\alpha_2\gamma_4 + \alpha_3\gamma_4\right\}.
\end{aligned}
$$

Test 2 involves estimating equation (8)

$$\pi_t^{avg} =_{t-4} (\pi_t^{avg})^e + \omega(L)(u_{t-1} - u_{t-1}^*) + \lambda_0 Shock_t + \lambda(L) Shock_{t-1} + \check{\nu}_t, \quad (8)$$

and checking whether the values of the coefficients on supply shocks which occurred after expectations were taken are equal to their relevant theoretical counterparts:

$$\begin{aligned}
\lambda_0^{II} &= \frac{\gamma_0}{4}, \quad \lambda_1^{II} = \frac{\gamma_0 + \alpha_1\gamma_0 + \gamma_1}{4}, \quad \lambda_2^{II} = \frac{1}{4}\left\{\gamma_0 + \alpha_1\gamma_0 + \alpha_1^2\gamma_0 + \alpha_2\gamma_0 + \gamma_1 + \alpha_1\gamma_1 + \gamma_2\right\}, \\
\lambda_3^{II} &= \frac{1}{4}\{\gamma_0 + \alpha_1\gamma_0 + \alpha_1^2\gamma_0 + \alpha_1^3\gamma_0 + \alpha_2\gamma_0 + 2\alpha_1\alpha_2\gamma_0 + \alpha_3\gamma_0 + \gamma_1\} \\
&\quad + \frac{1}{4}\{\alpha_1\gamma_1 + \alpha_1^2\gamma_1 + \alpha_2\gamma_1 + \gamma_2 + \alpha_1\gamma_2 + \gamma_3\}.
\end{aligned}$$

The coefficients on shocks, which occurred before expectations were taken, should be zero; that is, $\lambda_5^{II} = \lambda_6^{II} = \lambda_7^{II} = 0$.

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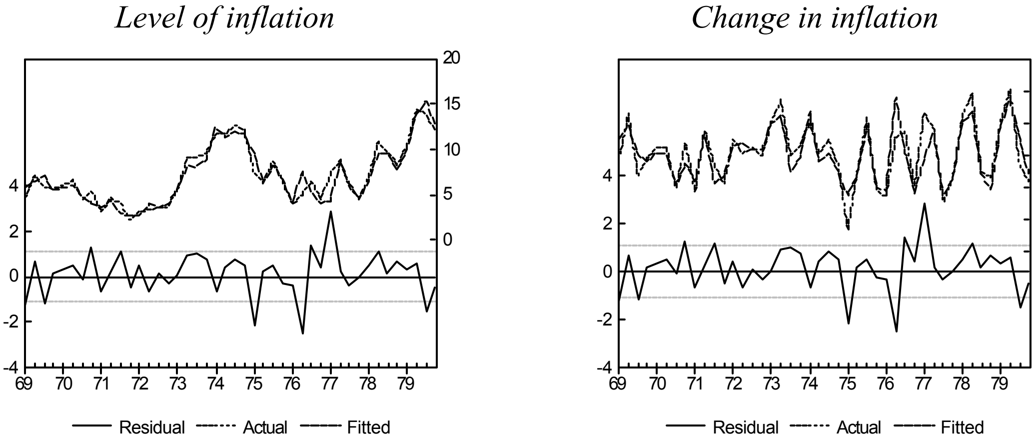
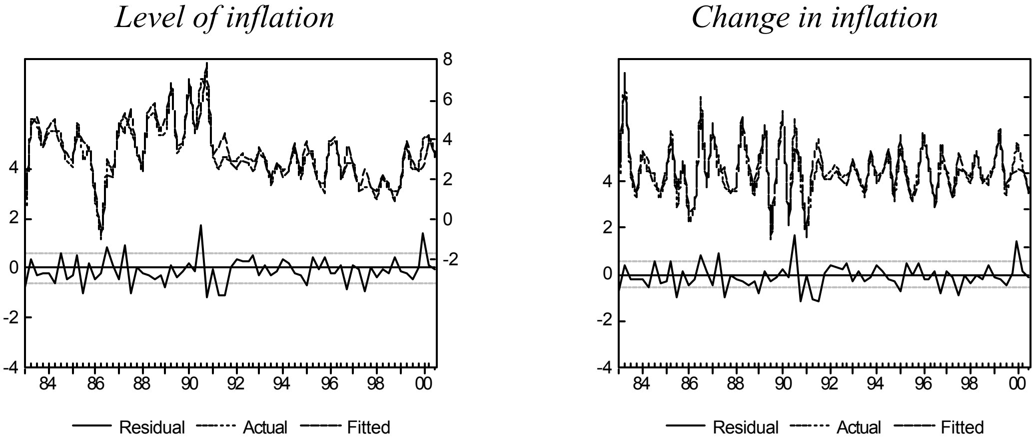
Figure 1a
In-sample fit of the Phillips curve before Volcker's disinflation (1968:1-1979:4)



Level of inflation *Change in inflation*

Note: The measure of supply shocks = median gap; inflation is constrained to contain a unit root.

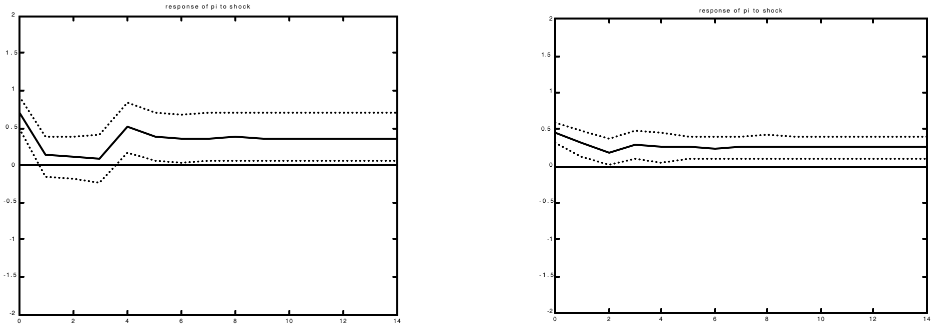
Figure 1b
In-sample fit of the Phillips curve after Volcker's disinflation (1983:1-2000:3)



Level of inflation *Change in inflation*

Note: The measure of supply shocks = median gap; inflation is constrained to contain a unit root.

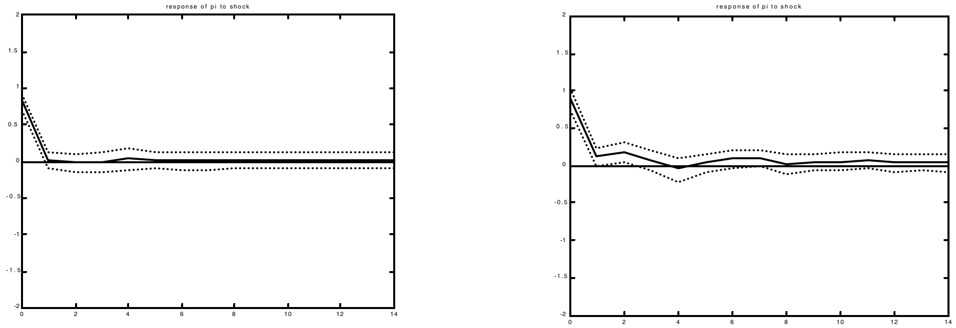
Figure 2a
Response of inflation to a supply shock before Volcker's disinflation



Median gap (1968:1-1979:4)

Food and energy (1960:1-1979:4)

Figure 2b
Response of inflation to a supply shock after Volcker's disinflation

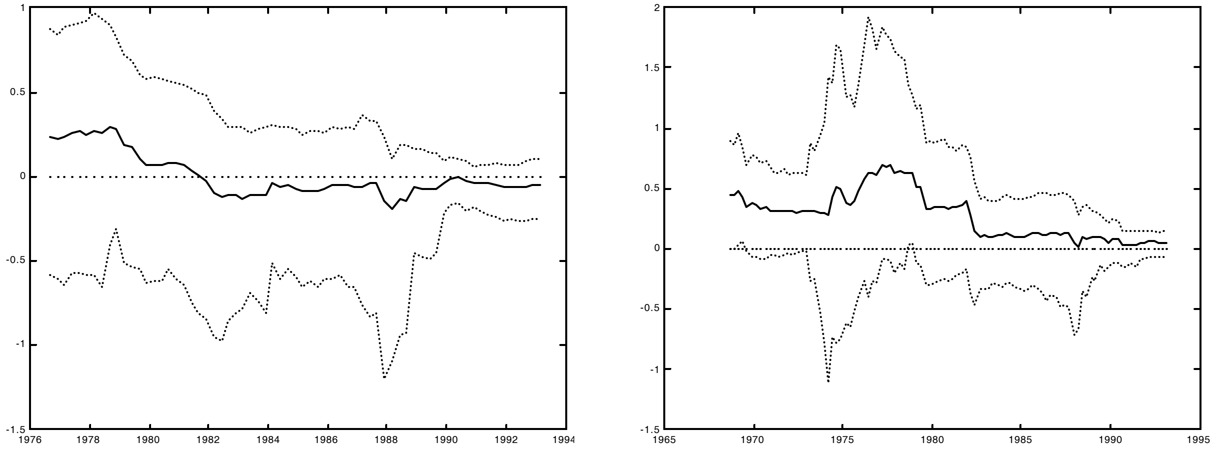


Median gap (1983:1-2000:3)

Food and energy (1983:1-2000:3)

Note: Response to a unit shock, with bootstrapped 95% confidence intervals (5000 repetitions). Table 3a contains numerical values for Figure 2a. Table 3b contains numerical values for Figure 2b.

Figure 3
Evolution of persistence over time (rolling regressions; a 15-year window)



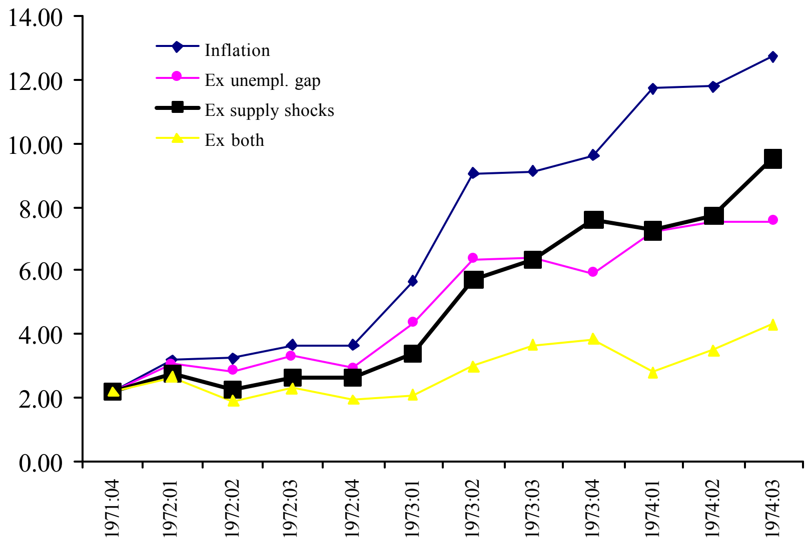
Median gap

Food and energy

Note: The persistence index is defined as the ratio of the long-run over contemporaneous impact of supply shock on inflation, τ/γ_0. The dates on the x-axis correspond to the middle of a 15-year regression sample. Response to a unit shock, with bootstrapped 95% confidence intervals (5000 repetitions).

Figure 4
The decomposition of inflation increases during the 1970s

Episode 1971:4-1974:3



Episode 1976:1-1979:2

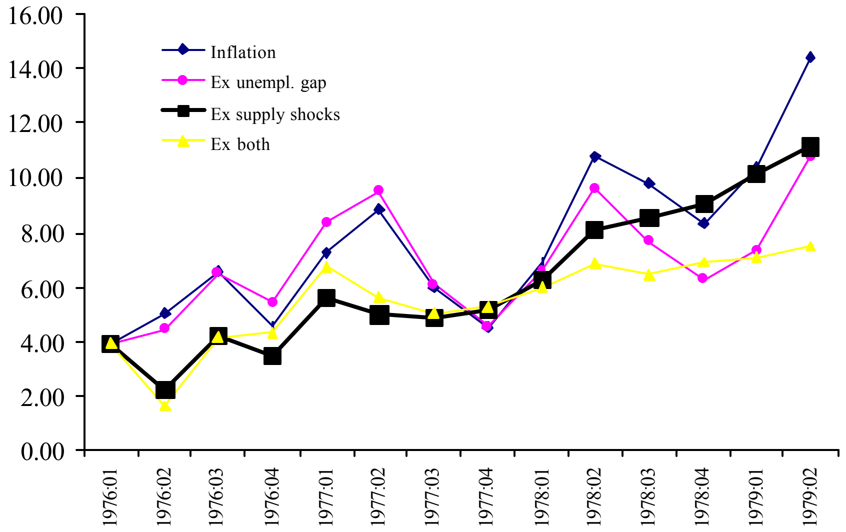


Table 1
Estimated Phillips curves (MG 1968:1-1979:4, FE 1960:1-1979:4)

	p_t	p_t	p_t	p_t
Supply Shock	*Median Gap*		*Food and Energy*	
Model	**I(1)**	**I(0)**	**I(1)**	**I(0)**
p_{t-1}	0.601**	0.537**	0.414**	0.381**
	(0.167)	(0.172)	(0.112)	(0.114)
p_{t-2}	0.113	0.097	0.037	0.025
	(0.204)	(0.203)	(0.126)	(0.125)
p_{t-3}	0.146	0.109	0.138	0.131
	(0.191)	(0.192)	(0.139)	(0.140)
p_{t-4}	0.140	0.137	0.411**	0.425**
	(0.165)	(0.171)	(0.125)	(0.126)
Sum	1.000	0.880**	1.000	0.962**
	(---)	(0.090)	(---)	(0.049)
$u_{t-1}-u^*_{t-1}$	-3.035**	-2.967**	-2.599**	-2.606**
	(0.693)	(0.695)	(0.573)	(0.575)
$u_{t-2}-u^*_{t-2}$	2.670*	2.493*	2.610*	2.517*
	(1.216)	(1.214)	(1.001)	(0.999)
$u_{t-3}-u^*_{t-3}$	-0.575	-0.427	-1.738	-1.633
	(1.261)	(1.260)	(0.963)	(0.961)
$u_{t-4}-u^*_{t-4}$	0.052	-0.232	0.676	0.580
	(0.706)	(0.737)	(0.532)	(0.535)
Sum	-0.887**	-1.134**	-1.050**	-1.142**
	(0.343)	(0.375)	(0.297)	(0.302)
Shock_t	0.677**	0.643**	0.433**	0.419**
	(0.129)	(0.131)	(0.098)	(0.098)
Shock_{t-1}	-0.343	-0.311	0.037	0.037
	(0.189)	(0.189)	(0.106)	(0.107)
Shock_{t-2}	-0.073	-0.075	0.037	0.050
	(0.191)	(0.190)	(0.105)	(0.105)
Shock_{t-3}	-0.088	-0.066	0.083	0.089
	(0.194)	(0.193)	(0.107)	(0.108)
Shock_{t-4}	0.293	0.285	-0.158	-0.155
	(0.171)	(0.173)	(0.097)	(0.099)
Sum	0.466*	0.476*	0.431**	0.442*
	(0.214)	(0.216)	(0.157)	(0.172)
C		0.960		0.355
		(0.633)		(0.251)
Adj. R^2	0.881	0.883	0.899	0.900
s.e.	1.106	1.098	1.154	1.150

Note: OLS estimates from equation (1). The sample is shorter for regressions with median gap due to the limited availability of median inflation data.

Table 2
Estimated Phillips curves (1983:1-2000:3)

	p_t	p_t	p_t	p_t
Supply Shock	*Median Gap*		*Food and Energy*	
Model	**I(1)**	**I(0)**	**I(1)**	**I(0)**
p_{t-1}	0.358**	0.242*	0.319**	0.290**
	(0.104)	(0.112)	(0.085)	(0.090)
p_{t-2}	0.271**	0.232*	0.276**	0.251**
	(0.092)	(0.092)	(0.090)	(0.094)
p_{t-3}	0.153*	0.146	-0.162	-0.158
	(0.079)	(0.077)	(0.095)	(0.096)
p_{t-4}	0.218**	0.215**	0.567**	0.540**
	(0.078)	(0.076)	(0.083)	(0.088)
Sum	1.000	0.835**	1.000	0.923**
	(---)	(0.088)	(---)	(0.088)
$u_{t-1}-u^*_{t-1}$	-2.906**	-2.826**	-2.059**	-2.073**
	(0.451)	(0.438)	(0.517)	(0.519)
$u_{t-2}-u^*_{t-2}$	2.674**	2.321**	2.229**	2.150**
	(0.741)	(0.729)	(0.794)	(0.800)
$u_{t-3}-u^*_{t-3}$	0.700	0.884	-0.416	-0.319
	(0.738)	(0.717)	(0.832)	(0.837)
$u_{t-4}-u^*_{t-4}$	-1.012*	-0.990*	-0.037	-0.072
	(0.430)	(0.415)	(0.502)	(0.504)
Sum	-0.545**	-0.610**	-0.283	-0.314
	(0.150)	(0.147)	(0.170)	(0.172)
$Shock_t$	0.834**	0.830**	0.899**	0.875**
	(0.061)	(0.059)	(0.076)	(0.078)
$Shock_{t-1}$	-0.276**	-0.183	-0.177*	-0.166
	(0.102)	(0.108)	(0.087)	(0.090)
$Shock_{t-2}$	-0.279**	-0.258**	-0.109	-0.110
	(0.089)	(0.091)	(0.088)	(0.090)
$Shock_{t-3}$	-0.150	-0.168*	-0.113	0.100
	(0.082)	(0.081)	(0.084)	(0.086)
$Shock_{t-4}$	-0.167*	-0.188*	-0.630**	-0.624**
	(0.082)	(0.082)	(0.082)	(0.086)
Sum	-0.036	0.033	0.095	0.074
	(0.093)	(0.137)	(0.119)	(0.144)
C		0.471		0.178
		(0.333)		(0.324)
Adj. R^2	0.850	0.860	0.797	0.796
s.e.	0.589	0.569	0.686	0.687

Note: OLS estimates from equation (1).

Table 3a
Response of inflation to a supply shock (MG 1968:1 – 1979:4, FE 1960:1 – 1979:4)

	Median Gap			**Food and energy**		
Period	*Mean Response*	*Lower bound*	*Upper bound*	*Mean Response*	*Lower bound*	*Upper bound*
0	**0.712**	0.480	0.910	**0.450**	0.315	0.596
1	**0.128**	-0.151	0.371	**0.313**	0.141	0.490
2	**0.106**	-0.185	0.381	**0.189**	0.013	0.372
3	**0.102**	-0.225	0.404	**0.286**	0.101	0.478
4	**0.509**	0.160	0.845	**0.255**	0.048	0.459
5	**0.382**	0.061	0.713	**0.260**	0.110	0.416
6	**0.345**	0.025	0.686	**0.243**	0.101	0.392
7	**0.363**	0.048	0.692	**0.259**	0.109	0.417
8	**0.370**	0.059	0.697	**0.258**	0.099	0.419
9	**0.366**	0.051	0.696	**0.256**	0.104	0.411
10	**0.365**	0.050	0.695	**0.252**	0.106	0.404
11	**0.365**	0.051	0.695	**0.255**	0.108	0.408
12	**0.366**	0.053	0.695	**0.256**	0.104	0.412
13	**0.365**	0.050	0.695	**0.255**	0.105	0.410
14	**0.365**	0.050	0.695	**0.254**	0.106	0.409

Table 3b
Response of inflation to a supply shock (1983:1 – 2000:3)

	Median Gap			**Food and energy**		
Period	*Mean Response*	*Lower bound*	*Upper bound*	*Mean Response*	*Lower bound*	*Upper bound*
0	**0.835**	0.706	0.905	**0.899**	0.742	1.021
1	**0.030**	-0.095	0.140	**0.114**	-0.021	0.240
2	**-0.022**	-0.158	0.095	**0.186**	0.039	0.318
3	**0.003**	-0.137	0.125	**0.072**	-0.065	0.205
4	**0.039**	-0.116	0.176	**-0.051**	-0.229	0.105
5	**0.018**	-0.095	0.116	**0.039**	-0.077	0.143
6	**0.013**	-0.105	0.112	**0.092**	-0.040	0.204
7	**0.016**	-0.103	0.117	**0.089**	-0.025	0.192
8	**0.021**	-0.100	0.127	**0.018**	-0.119	0.141
9	**0.018**	-0.100	0.119	**0.037**	-0.075	0.138
10	**0.017**	-0.101	0.120	**0.055**	-0.072	0.167
11	**0.018**	-0.101	0.120	**0.075**	-0.032	0.170
12	**0.018**	-0.101	0.122	**0.044**	-0.083	0.154
13	**0.018**	-0.100	0.121	**0.047**	-0.064	0.146
14	**0.018**	-0.100	0.121	**0.046**	-0.077	0.156

Note: The above are impulse responses, $(\partial\pi_{t+k}/\partial \text{Shock}_t)|u=u^*$, calculated from equation (1). Responses to a unit shock, with bootstrapped 95% confidence intervals (5000 repetitions). Table 3a contains numerical values for Figure 2a. Table 3b contains numerical values for Figure 2b.

Table 4
Equations for inflation expectations – Test 1
(Survey of Professional Forecasters, 1983:1-2000:3)

Dependent Variable	$_{t-1}p^{e}_{t}$	**Coefficients Implied by the Phillips Curve (1)**	$_{t-1}p^{e}_{t}$	**Coefficients Implied by the Phillips Curve (1)**
Inflation Model	**I(1)**	**I(1)**	**I(0)**	**I(0)**
p_{t-1}	0.309**	0.358	0.238**	0.242
	(0.058)		(0.062)	
p_{t-2}	0.356**	0.271	0.316**	0.232
	(0.063)		(0.063)	
p_{t-3}	0.162**	0.153	0.144*	0.146
	(0.058)		(0.056)	
p_{t-4}	0.173**	0.218	0.146**	0.215
	(0.050)		(0.050)	
Sum	1.000	1.000	0.844**	0.835
	(---)		(0.063)	
Shock $_{t-1}$	-0.109	between 0 and -0.276	-0.051	between 0 and -0.183
	(0.065)		(0.067)	
Shock $_{t-2}$	-0.260**	-0.279	-0.227**	-0.258
	(0.063)		(0.064)	
Shock $_{t-3}$	-0.142*	-0.150	-0.131*	-0.168
	(0.056)		(0.056)	
Shock $_{t-4}$	-0.118*	-0.167	-0.101	-0.188
	(0.054)		(0.054)	
C			0.515*	0.471
			(0.238)	
Adj. R^2	0.727		0.747	
s.e.	0.444		0.428	

Note: OLS estimates from equation (3).

Table 5a
Equations for inflation expectations – Test 1
(Michigan Survey, 1968:1-1979:4)

Dependent Variable	$_{t-4}p^{e\ avg}_{t}$	**Coefs Implied by the Phillips Curve (6)**	$_{t-4}p^{e\ avg}_{t}$	**Coefs Implied by the Phillips Curve (6)**
Inflation Model	**I(1)**	**I(1)**	**I(0)**	**I(0)**
$\mathbf{p}_{t-4}$	0.605**	0.539	0.513**	0.430
	(0.162)		(0.133)	
$\mathbf{p}_{t-5}$	0.172	0.204	0.177	0.161
	(0.225)		(0.185)	
$\mathbf{p}_{t-6}$	0.033	0.167	-0.013	0.128
	(0.220)		(0.181)	
$\mathbf{p}_{t-7}$	0.097	0.090	0.001	0.078
	(0.163)		(0.134)	
Shock $_{t-4}$	0.007	-0.221	-0.044	between 0 and -0.168
	(0.199)		(0.164)	
Shock $_{t-5}$	-0.072	0.025	-0.051	0.035
	(0.216)		(0.177)	
Shock $_{t-6}$	0.018	0.095	-0.031	0.099
	(0.218)		(0.180)	
Shock$_{t-7}$	-0.025	0.189	0.119	0.163
	(0.169)		(0.139)	
C	0.000	0	1.620	1.620
	(---)		(---)	
Adj. R^2	0.531		0.683	
s.e.	1.311		1.078	

Note: OLS estimates from equation (7).

Table 5b
Equations for inflation expectations – Test 1

(Michigan Survey, 1983:1-2000:3)

Dependent Variable	${}_{t-4}\mathbf{p}^{e\ avg}_{t}$	**Coefs Implied by the Phillips Curve (6)**	${}_{t-4}\mathbf{p}^{e\ avg}_{t}$	**Coefs Implied by the Phillips Curve (6)**
Inflation Model	**I(1)**	**I(0)**	**I(0)**	**I(0)**
$\mathbf{p}_{t-4}$	0.428**	0.418	0.360**	0.297
	(0.081)		(0.065)	
$\mathbf{p}_{t-5}$	0.349**	0.287	0.306**	0.227
	(0.082)		(0.066)	
$\mathbf{p}_{t-6}$	0.266**	0.178	0.225**	0.148
	(0.077)		(0.062)	
$\mathbf{p}_{t-7}$	0.069	0.117	0.066	0.097
	(0.073)		(0.059)	
Shock $_{t-4}$	-0.230**	-0.364	-0.166*	between 0 and -0.281
	(0.083)		(0.067)	
Shock $_{t-5}$	-0.287**	-0.273	-0.232**	-0.239
	(0.077)		(0.062)	
Shock $_{t-6}$	-0.244**	-0.154	-0.189**	-0.148
	(0.077)		(0.062)	
Shock $_{t-7}$	-0.089	-0.090	-0.064	-0.085
	(0.083)		(0.067)	
C	0.000		0.657	0.657
	(---)		(---)	
Adj. R^2	0.195		0.477	
s.e.	0.693		0.559	

Note: OLS estimates from equation (7).

Table 6
Phillips curves augmented with inflation expectations – Test 2

(Survey of Professional Forecasters, 1983:1-2000:3,
Michigan Survey, 1968:1-1979:4 and 1983:1-2000:3)

Sample	**1983:1-2000:3**			**1968:1-1979:4**		**1983:1-2000:3**	
Dependent Variable	p_t	**Coefs Implied by the Phillips Curve (1)**		p_t^{avg}	**Coefs Implied by Appendix 1**	p_t^{avg}	**Coefs Implied by Appendix 1**
${}_{t-1}p^{e}_{t}$	1.000		${}_{t-4}p^{e\,(avg)}_{t}$	1.000		1.000	
SPF	(---)		**Michigan**	(---)		(---)	
Shock$_t$	0.857**	0.834	**Shock**$_t$	0.414*	0.161	0.251**	0.208
	(0.066)	(0.061)		(0.182)		(0.055)	
Shock$_{t-1}$	-0.115	≈ 0	**Shock**$_{t-1}$	0.109	0.169	0.325**	0.212
	(0.066)			(0.185)		(0.058)	
Shock$_{t-2}$	-0.106	0	**Shock**$_{t-2}$	0.133	0.170	0.373**	0.197
	(0.062)			(0.194)		(0.064)	
Shock$_{t-3}$	-0.007	0	**Shock**$_{t-3}$	0.280	0.173	0.296**	0.182
	(0.064)			(0.233)		(0.067)	
Shock$_{t-4}$	-0.060	0	**Shock**$_{t-4}$	-0.183	≈ 0	-0.104	≈ 0
	(0.064)			(0.224)		(0.066)	
			Shock$_{t-5}$	0.247	0	0.025	0
				(0.218)		(0.063)	
			Shock$_{t-6}$	0.271	0	0.050	0
				(0.208)		(0.058)	
			Shock$_{t-7}$	0.116	0	0.082	0
				(0.224)		(0.059)	
Adj. R^2	0.773		**Adj. R**^{2}	0.603		0.742	
s.e.	0.675		**s.e.**	1.390		0.530	

Note: For the SPF expectations, OLS estimates are from equation (5). For the Michigan expectations, OLS estimates are from equation (8). The equation with SPF expectations contains four detrended unemployment terms. The equation with Michigan Survey expectations contains seven detrended unemployment terms. There are no constants. The equations with Michigan survey expectations are estimated with moving-average terms to control for the effects of time averaging.