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Some Intranational Evidence on Output-Inflation Trade-Offs

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SOME INTRANATIONAL EVIDENCE ON OUTPUT-INFLATION TRADE-OFFS

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In a seminal paper, Robert E. Lucas, Jr. provided the theoretical relationship between aggregate demand and real output based on relative price confusion at the individual market level. Subsequently, an alternative New Keynesian aggregate supply relationship was derived and it was demonstrated that the two theories can be distinguished on the basis of how both the rate of inflation and the volatility of relative prices affect its slope. By emphasizing the first implication of New Keynesian theory, strong evidence was obtained supporting this model using international data. We also concentrate on the second difference between the two theories. We derive the individual market-level equilibrium relationship for the Lucas model, i.e., the disaggregate supply curve. We estimate the crucial parameters of the relationship between aggregate nominal demand shocks and real output using U.S. intranational state and industry data. We find that the Lucas model omits important New Keynesian features of the data.

Keywords: New Keynesian Theory, Lucas's Island Model

1. INTRODUCTION

The equilibrium relationship between nominal and real variables has always been a focal point for debate among economists who wished to understand the fundamental role of monetary shocks in economic fluctuations. While early work on the Phillips Curve [Phillips (1958)] suggested that there was an exploitable trade-off between lower unemployment and higher inflation, episodes of stagflation during the late 1960's and early 1970's convinced many economists that the trade-off was illusory. Friedman (1968) and Phelps (1968) argued that lower unemployment could be achieved only through high levels of unexpected inflation, a condition that the monetary authority could not engineer consistently.

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In a series of papers, Robert Lucas, Jr. (1972, 1973) introduced a compelling paradigm for understanding the relationship between nominal and real variables.[1] His paradigm grounded the Phillips curve in a neoclassical framework devoid of money illusion by allowing transactions to occur with incomplete information. Assuming that individuals make rational inferences about the aggregate price level based upon their observed own price, he derived an equilibrium relationship between output movements and unexpected inflation, termed the Lucas supply curve. The intuition for the relationship is that in response to an unexpected increase in all prices due to an unexpected increase in the nominal stock of money, individuals would increase output because they would rationally attribute part of the reason for the observed increase in their own price to an increase in their relative price. One implication of the model is that the effect of aggregate demand will be smaller as aggregate inflation becomes more volatile, because in this case agents will think most of the movements in relative prices are due to movements of the aggregate price level. Lucas (1973) found empirical support for this implication of the model using international data for 18 countries from 1951 to 1967.

For both historical and emperical reasons, New Keynesian economists, however, believe that the link between nominal and real variables should be based upon the stickiness of prices.[2] Both Mankiw (1985) and Akerlof and Yellen (1985) provided theoretical justifications for why agents would choose to create nominal rigidities based primarily on the idea of menu costs. They demonstrated that if a firm must pay a menu cost to change its nominal price, the consequences to the firm's profits from not changing prices would be only second order, but the effect on social welfare would be first order. Ball and Romer (1990) further showed that, to obtain a sufficient amount of nominal rigidity in prices, not only are nominal frictions like menu costs needed, but real rigidities as well.[3]

In light of the theoretical contributions provided by New Keynesian theories, Ball et al. (1988) reanalyzed the empirical results of Lucas (1973). They point out that, in the aggregate, both Lucas's theory and New Keynesian theory predict that real output should respond positively to changes in nominal aggregate demand, albeit for entirely different reasons. Moreover, Lucas's model and New Keynesian theory both predict that the effect of aggregate demand on real output will become smaller as aggregate inflation becomes more volatile. Accordingly, the response of the output-inflation trade-off to the inflation volatility variable used by Lucas (1973) to support his model cannot be used to distinguish between these two theories.

As pointed out by Ball et al. (1988), however, the theories differ in two notable ways based upon what affects the output-inflation trade-off. First, according to New Keynesian theory, the higher the average rate of inflation, the more likely it is that firms will adjust prices rather than output, and hence higher levels of inflation should lead to a smaller response of real output to aggregate demand. Lucas's model does not allow for the average rate of inflation to affect the slope of the aggregate supply curve because the average rate of inflation does not affect the ratio of relative price movements to aggregate ones. Both Ball et al. (1988) and DeFina (1991) in subsequent work find that in cross-country evidence, there is strong support for

New Keynesian theory; namely, higher levels of inflation lower the responsiveness of real output to nominal aggregate demand. However, Akerlof et al. (1988) point out that because the volatility of aggregate inflation and the level of inflation are highly correlated, these tests cannot separate how the responsiveness is affected by the level of aggregate inflation independently from the volatility of inflation. In other words, because the level of inflation and its variability are very positively correlated, the empirical observation that the slope of the aggregate supply curve is negatively related to the variability of inflation—a prediction that both theories share—may cast in doubt the result that the slope is negatively related to the level of inflation, a prediction that distinguishes the two theories.[4]

Second, according to New Keynesian theory, a higher variance of relative prices at a point in time, and hence an increase in uncertainty, will lead to a smaller effect of nominal shocks on real output because prices are set for shorter periods and adjusted more frequently. However, Lucas's model makes the exact opposite prediction, namely, given a higher variance of relative prices, an unexpected nominal shock will have a greater impact on real output because individuals will rationally attribute a greater proportion of the nominal shock as a change in their relative price. Because these two theories make entirely opposite predictions regarding the effect of an increase of the variance of relative prices on the responsiveness of real output to nominal shocks, we believe that testing this implication identifies more clearly which theory is consistent with the observed data. Although Lucas, BMR, and DeFina have examined the effect of aggregate demand on cyclical movements in real output using cross-country data, these researchers could not test the second implication because they have left unexploited the market-level equilibrium relationships.

The purpose of this paper is to reexplore the output-inflation trade-off by considering states and industries as markets within a country. We derive the individual market-level equilibrium relationship as well as the aggregate-level one. We estimate the market-level equation using cross-sectional data for the United States, and allow the crucial parameters of the relationship between aggregate nominal demand shocks and real output to be time varying. We then analyze what affects the trade-off between output and inflation in each year, including a measure of the volatility of relative prices.

To estimate the market-level model, we first need to define what a market is with the available disaggregate data. We adopt two interpretations of a market which both provide important cross-sectional information on the intranational output-inflation trade-off. First, if we interpret a market in Lucas's model as a geographical description, then a regional definition of a market is the right choice. Accordingly, we estimate the market-level equation using nominal and real Gross State Product (GSP) data for 50 states plus the District of Columbia at the annual frequency over the time period 1977–1991. However, recent studies show that U.S. business cycles are driven to a greater extent by industry-specific shocks rather than region-specific shocks.[5] Therefore, a second interpretation of a market is at the industry level. To this end, we estimate the market-level equation using

Gross Product Originating by Industry (GPO) data for 27 industries at the annual frequency over the same time period.

The regression results suggest that the market-level model provides a good fit of the data at both the state and industry levels. However, we find strong support for New Keynesian theory in that both an increase in inflation as well as an increase in the standard deviation of relative prices leads to a smaller effect of demand shocks on real output. This finding holds even when we control for the volatility of aggregate inflation. We conclude that the Lucas model omits New Keynesian aspects of intranational data.

The remainder of the paper is organized as follows. In Section 2, we derive the market-level relationship obtained from the Lucas model, and we discuss in Section 3 why the New Keynesian theory provides an observationally equivalent interpretation. In Section 4, we discuss the data used in our analysis, and in Section 5, we present estimates of the market-level equation using both cross-sectional state and industry data. On the basis of these estimates, we test the competing hypotheses put forth by the Lucas and New Keynesian models. We conclude in Section 6.

2. MODEL

The structure of the model is identical to that of Lucas (1973) with the addition that we focus on solving for the disaggregate market-level equilibrium. Suppliers are located in a large number of scattered competitive markets. The quantity supplied in each market can be decomposed into a trend component and a cyclical component which are denoted by y_{nt} and y_{ct}, respectively, where lowercase letters denote that the variables are in natural logs. Letting z index markets, supply in market z is $y_t(z) = y_{nt} + y_{ct}(z)$. The trend component is assumed to be the same for each market: $y_{nt}(z) = y_{nt} = \alpha + \beta t$. The cyclical part is determined in each market by the expected relative price level and its own lagged value,

$$y_{ct}(z) = \gamma\{p_t(z) - E[p_t \mid I_t(z)]\} + \lambda y_{ct-1}(z), \qquad -1 < \lambda < 1, \tag{1}$$

where $p_t(z)$ is the observed price in market z and $E[p_t \mid I_t(z)]$ is the expected aggregate price level conditional on information available in market z at time t. According to (1), individual producers will respond positively to anticipated increases of their relative price.

The overall price level, p_t, is assumed to be distributed $N[\bar{p_t}, \sigma^2]$. The market price is assumed to be determined by a multiplicative shock to the aggregate price level,

$$p_t(z) = p_t + z. \tag{2}$$

The idiosyncratic shock to the observed own price is denoted by z and is assumed to be distributed $N(0, \tau^2)$.

The aggregate demand curve for the economy is represented by the following equation:

$$y_t + p_t = x_t, \tag{3}$$

where x_t represents nominal aggregate output. We further assume that Δx_t is a sequence of independent shocks that are distributed $N(\delta, \sigma_x^2)$. Using a linear conjecture for the aggregate price level, the solutions for output in each market and in the aggregate are, respectively,

$$y_{ct}(z) = -\pi\delta + \pi\,\Delta x_t + \theta\gamma z + \lambda y_{ct-1}(z), \qquad \textbf{(4)}$$

$$y_{ct} = -\pi\delta + \pi\,\Delta x_t + \lambda y_{ct-1}, \qquad \textbf{(5)}$$

where $\pi = \theta\gamma/(1+\theta\gamma)$ and $\theta = \tau^2/(\sigma^2+\tau^2)$. The responsiveness parameter to aggregate demand (π) falls as the volatility of the aggregate price level (σ) increases, or as the standard deviation of relative prices across markets (τ) decreases. On the basis of estimates of the aggregate equation (5) using data for 18 countries, Lucas (1973) found supporting evidence that π becomes lower for a country as its σ^2 rises. Because he relied on the aggregate equation with aggregate data, he could not verify the other implications, namely that π becomes higher as τ^2 increases. Ball et al. (1988) and DeFina (1991) also estimated equation (5) to test other implications of New Keynesian theory.

We demonstrate in the Appendix that the individual market-level equilibrium equation is

$$y_{ct}(z) = -\pi\delta + \pi\,\Delta x_t + \pi[x_t(z) - x_t] + \lambda[\pi y_{ct-1} + (1-\pi)y_{ct-1}(z)]. \qquad \textbf{(6)}$$

Equation (6) holds for every market in each period. Because in the aggregate both $[x_t(z) - x_t]$ and $[y_{ct-1} - y_{ct-1}(z)]$ are zero, aggregating equation (6) over all markets yields the aggregate equation (5) that has been the focus of the empirical literature. We estimate the market-level equation (6), our so-called disaggregate Lucas supply curve, in Section 5.

3. A NEW KEYNESIAN INTERPRETATION

According to the Lucas model, nominal income has two effects on output at the disaggregate level. First, unexpected increases in nominal aggregate demand will cause output to rise in the entire economy. This aspect is captured by the term $\pi(\Delta x_t - \delta)$ in both the aggregate and disaggregate equations, (5) and (6). Second, markets with higher-than-average nominal income also will have higher output as the effects of their beneficial real demand shock filters through the signal extraction process. This feature is captured by the term $\pi[x(z)_t - x_t]$ in the disaggregate equation (6). In Hess and Shin (1997) we demonstrate that a standard New Keynesian model such as Mankiw's (1985) makes similar predictions to the Lucas model about the market-level relationships between real and nominal variables, not just at the aggregate level as pointed out by Ball et al. (1988). In this sense, both theories are observationally equivalent.

Nevertheless, although both Lucas's and the New Keynesian models predict similar responses between nominal and real variables, the two approaches can be distinguished as to what *influences* the responsiveness of real output to nominal aggregate demand. For example, as pointed out by Ball et al. (1988), the responsiveness of real output to nominal shocks (π) is constant in the Lucas model, but it is a decreasing function of the average level of inflation in the New Keynesian model. This is because, in the New Keynesian framework, higher average levels of inflation suggest more price changes and, therefore, fewer adjustments to output. This approach has been explored at the aggregate level for international data by Ball et al. (1988) and DeFina (1991), although it has been criticized by Akerlof et al. (1988). Our approach is to focus on another distinction between the two theories. According to New Keynesian theory, a higher variance of relative prices will lead to a smaller effect of nominal shocks on real output because prices will be adjusted more frequently. However, Lucas's model makes the opposite prediction, namely, as the variance of relative prices increases, an unanticipated nominal shock will have a greater impact on real output because individuals will rationally attribute a larger proportion of the nominal shock as a change in their relative price, i.e., $\partial\pi/\partial\tau^2 > 0$. In the following section, we describe the data we use to distinguish these two theories, and in Section 5 we estimate the market-level responsiveness of real output to nominal shocks and we explore whether New Keynesian theory or Lucas's theory better explains this responsiveness.

4. THE DATA

The data that we use to investigate intranational output-inflation trade-offs for the United States are GSP and GPO data published by the U.S. Department of Commerce, Bureau of Economic Analysis (BEA). Both nominal and real GSP data are reported for all 50 states plus the District of Columbia for 1977–1991 on an annual basis.[6] The data were made per capita by dividing by the state's population. Nominal and real GPO data are also available back to 1977 for all two-digit industries. To make these data per capita we use average employment in the industry, which unfortunately restricts our sample to 27 industries.[7] We constructed the implicit price for each state (industry) by dividing nominal GSP (GPO) by real GSP (GPO).

The real GSP series, however, are constructed by the BEA using highly disaggregate industry deflators [see Beemiller and Dunbar (1994)]. Nevertheless, examining intranational output-inflation trade-offs at the state level, in addition to the industry level, is still important for the following reasons: First, the heterogeneity of output-per-worker is quite high across industries, but much less across states.[8] This is important because the models assume that each market is identical ex ante. Second, industry-level data also suppress regional variation in output prices within an industry. Third, because industries are geographically concentrated, the state deflators will pick up differences in state prices, even though based on industry-level data. Fourth, the metaphor that Lucas uses to justify his assumption of limited information is a spatial one, and we believe that states are the best proxies to capture this. Fifth, because we adjust the industry data by employment, we only have 27 industries that have data for the entire sample, which lowers the precision of our cross-sectional estimates as compared to those for state-level data.[9] Finally, the state-level data have the benefit that they aggregate up to total U.S. GDP, which the industry data do not as they exclude, among other things, the agricultural and government sectors. In summary, our approach is consistent with Lucas's framework: The ratio of a state's (industry's) price deflator to the overall price level is the state's (industry's) relative price of its representative unit of output, and the difference across states (industries) in their price levels reflects the fundamental heterogeneity of their output. To the extent that we obtain similar results using both state and industry data, this would be an indication of the robustness of our findings.

Before presenting our regression results, two obstacles must be overcome in constructing relative measures of prices and nominal and real income. First, all states and industries are not equal in terms of their income per capita, and these differences can persist over time. To capture these systematic, deterministic differences that are not incorporated into the theory, we detrend the log of the relative nominal and real income series for each state and industry separately.[10] Second, by design, the implicit price level for each state and industry is equal to one in 1987, the benchmark year, and hence the relative price for all states is equal to one in 1987. Accordingly, we measure relative prices by relative inflation rates.

Finally, consistent with Lucas's model, we treat each state and industry as identical ex ante, although each will differ ex post depending on the realization of the idiosyncratic shocks. For example, if we observe that relative inflation rates across states and industries are more dispersed, we can interpret this as an increase in the volatility of a state or industry's ex ante relative price. Accordingly, a measure of the recent volatility of realized relative inflation rates is an appropriate measure for the ex-ante volatility of each state's or industry's relative price (τ^2).[11] Even though in the New Keynesian framework, the more relevant measure is the volatility of a given relative price rather than the dispersion across different relative prices, we use the estimate of the latter as an appropriate proxy for the former under the assumption that states and industries are identical ex ante.

In the next section, based on the equation derived in Section 2, we estimate the disaggregate market-level relationship between real output and nominal shocks and further explore the nature of the aggregate supply curve.

5. ESTIMATION RESULTS

In this section, we estimate the disaggregate-level equation which captures elements of the aggregate supply curve for both Lucas's theory and New Keynesian theory. Because the disaggregate supply curve holds across states and industries at a point in time, we utilize these annual cross-sectional observations to estimate equation (6). One benefit we obtain is that, unlike other approaches, we can allow the crucial parameter that represents the effect of aggregate demand on real output, π, to vary with time. We then can analyze the relationship between π_t and other related variables without relying on international data.[12]

Ball et al. (1988) estimated a single value of π for each country and then related the π for each country to characteristics such as the average or volatility of its inflation rate so as to test New Keynesian theories. This approach is unsatisfactory because all of the crucial parameters are assumed to be constant over time despite structural changes. Moreover, it also assumes that these countries are identical except for the specific characteristics considered. However, different institutions and factors in each country raise the possibility that a country's real output may respond differently to nominal aggregate demand for other reasons which make it difficult to pinpoint what affects the responsiveness of real output to nominal aggregate demand. By utilizing cross-sectional data within a country, this problem is mitigated. DeFina (1991) incorporates interaction terms which allow π to change over time for each country because of changes in the moving average or moving volatility of inflation. Although this partly corrects for the problem of Ball et al. (1988), it introduces endogenous variables into his econometric specification. Moreover, because DeFina only considers the aggregate equation, he cannot analyze the relation between π and the variance of relative prices, which is a major objective in this paper.

Using our cross-sectional approach, introducing a time-varying π requires that other parameters such as τ or σ (and hence θ) in Section 2 also be time varying.[13] Because the ratio of the variance of relative nominal shocks to the variance of the relative price shocks is changing, the degree of confusion also is changing and therefore the effect of aggregate demand on real activity also is changing across time. This makes the estimated value of π in equation (6) different in each year. Of course, nothing inherent to our empirical methodology necessitates that the estimated value of π fluctuate over time. Indeed, it is critical to our analysis that we relate movements in the slope of the aggregate supply curve to variables proposed by the competing theories.

Tables 1 and 2 present the estimated values of equation (6) for the period 1978–1991 using state and industry data, respectively. At a point in time Δx_t and y_{ct-1} are common for all states, and so, the following equation was used to estimate π and λ for each year of our sample:

$$y_{ct}(z) = c + \pi[x_t(z) - x_t] + \lambda(1-\pi)y_{ct-1}(z). \tag{7}$$

The constant term, c, captures the remainder of the terms, $-\pi\delta + \pi\Delta x_t + \lambda\pi y_{ct-1}$, which includes aggregate variables that are common to all states at a point in time.[14] The parameters c, π, and λ were estimated using nonlinear least squares.

The results reported in Table 1 suggest that the specification for the market-level model, equation (7), provides a good fit for the state-level data. The adjusted R^2 vary between 0.678 and 0.963, which is quite high considering that the data have been detrended and the regressions are cross sectional. The estimates of the key parameter π, which reflects the average responsiveness of real output in each state to relative movements in a state's aggregate demand, vary between a low of

Table 1. Estimation results for disaggregate Lucas supply equation using state-level data[a] $\{y_{ct}(z) = \hat{c} + \hat{\pi}[x_t(z) - x_t] + \hat{\lambda}(1 - \hat{\pi})y_{ct-1}(z)\}$

Year	$\hat{c}$	$\hat{\pi}$	$\hat{\lambda}$	$\bar{R}^2$
1978	0.028	0.221	0.477	0.843
	(17.248)	(5.093)	(6.852)	
1979	0.020	0.421	0.300	0.905
	(10.898)	(10.241)	(3.840)	
1980	−0.009	0.607	0.431	0.854
	(−3.853)	(15.098)	(1.885)	
1981	−0.013	0.408	0.215	0.901
	(−7.943)	(15.230)	(1.404)	
1982	−0.048	0.396	0.456	0.882
	(−16.173)	(5.907)	(2.399)	
1983	−0.036	0.355	0.256	0.678
	(−6.664)	(3.594)	(1.962)	
1984	−0.002	0.379	0.291	0.686
	(−0.587)	(6.500)	(2.534)	
1985	0.002	0.332	0.755	0.737
	(0.872)	(4.055)	(5.362)	
1986	0.005	0.639	0.797	0.963
	(5.902)	(30.963)	(8.808)	
1987	0.009	0.564	0.590	0.940
	(8.051)	(10.939)	(4.620)	
1988	0.023	0.637	−0.084	0.811
	(11.677)	(9.788)	(−0.351)	
1989	0.020	0.560	0.236	0.880
	(15.799)	(15.275)	(2.875)	
1990	0.015	0.973	−2.803	0.929
	(11.982)	(25.186)	(−0.592)	
1991	−0.018	0.837	1.537	0.897
	(−8.602)	(12.797)	(3.159)	

[a] There are 51 observations per year; t statistics are reported in parentheses.

0.221 in 1978 to a high of 0.973 in 1990. The coefficient estimates for π are all significantly greater than zero at well below the 1% level of statistical significance as the t statistics vary from 3.5 to over 30. This provides strong market-level evidence for the aggregate supply curve which predicts a positive coefficient for π. The estimated values for λ are typically reasonable and statistically significant with the exception of 1990 and 1991 when the estimated values exceed 1 in absolute value.[15]

The results in Table 2 using industry-level data are weaker than those using state-level data, but generally provide the same pattern of results. For 9 of the 14 years, the estimated value of π is statistically different from zero and positive

TABLE 2. Estimation results for disaggregate Lucas supply equation using industry-level data[a] $\{y_{ct}(z) = \hat{c} + \hat{\pi}[x_t(z) - x_t] + \hat{\lambda}(1 - \hat{\pi})y_{ct-1}(z)\}$

Year	$\hat{c}$	$\hat{\pi}$	$\hat{\lambda}$	$\overline{R}^2$
1978	0.038	0.154	0.564	0.459
	(4.136)	(1.770)	(4.06)	
1979	0.016	0.399	0.428	0.632
	(2.027)	(6.701)	(2.330)	
1980	−0.0127	0.145	−0.59241	0.059
	(−0.722)	(0.798)	(−1.590)	
1981	−0.014	0.268	0.45846	0.253
	(−0.989)	(2.531)	(1.891)	
1982	−0.065	0.239	0.66882	0.392
	(−5.405)	(2.491)	(3.133)	
1983	−0.030	0.266	0.53804	0.316
	(−1.674)	(1.760)	(2.509)	
1984	−0.005	0.250	0.10351	0.196
	(−0.506)	(2.887)	(0.746)	
1985	−0.001	0.157	1.062	0.530
	(−0.004)	(1.351)	(4.246)	
1986	0.001	0.555	0.685	0.621
	(0.143)	(3.935)	(1.785)	
1987	0.030	0.287	0.013	0.216
	(3.945)	(2.684)	(0.094)	
1988	0.036	0.283	0.393	0.206
	(3.502)	(1.587)	(1.356)	
1989	0.001	0.357	0.954	0.611
	(0.122)	(3.607)	(4.191)	
1990	0.009	0.461	0.066	0.139
	(1.051)	(2.398)	(0.231)	
1991	−0.037	0.298	1.962	0.730
	(−5.163)	(2.625)	(5.153)	

[a] There are 27 observations per year; t statistics are reported in parentheses.

at below the 5% level of significance, and the estimates vary from 0.15 to 0.55. While the fewer number of observations for industry data may contribute to the equation's poor fit as compared to those using state-level data, what is crucial is that the empirical estimates of π are sufficiently variable to allow us to test the competing theories.

The estimates of the market-level model provide a time series of measures of the responsiveness of output to aggregate demand, namely π_t's. To test the New Keynesian alternatives to the Lucas model, we distinguish the two approaches using the following regression:

$$\pi_t = \pi_0 + \pi_1 \overline{\Delta p} + \pi_2 \overline{\sigma_{\Delta[p(z)-p]}} + \pi_3 \overline{\sigma_{\Delta p}}, \tag{8}$$

where $\overline{\Delta p}$, $\overline{\sigma_{\Delta[p(z)-p]}}$, and $\overline{\sigma_{\Delta p}}$ are the five-year lagged moving-average rate of inflation, the two-year lagged moving average of the standard devation of relative price inflation, and the five-year lagged moving-average standard deviation of aggregate inflation, respectively.[16] First, New Keynesian theory predicts that π should fall as the average inflation rate rises ($\pi_1 < 0$), whereas the Lucas model implies that there should be no effect ($\pi_1 = 0$). Second, New Keynesian theory predicts that π should fall as the variance of relative prices rises ($\pi_2 < 0$), whereas the Lucas model predicts that it should rise ($\pi_2 > 0$).[17] Finally, to control for the criticism by Akerlof et al. (1988) that inflation (and perhaps relative inflation variability) are just proxies for the variation of aggregate inflation, for which both Lucas's and New Keynesian theory predict $\pi_3 < 0$, we include this term as well.

Figures 1–3 present simple cross-plots of the estimated values of π_t with the measures of the moving-average rate of inflation, the moving volatility of relative and aggregate inflation, $\overline{\Delta p}$, $\overline{\sigma_{\Delta[p(z)-p]}}$, and $\overline{\sigma_{\Delta p}}$, respectively, for the state-level data. These pictures demonstrate that the $\hat{\pi}_t$'s are negatively related to inflation, and the volatility of relative and aggregate price inflation, with correlation coefficients equal to -0.73 (-0.48), -0.65 (-0.56) and -0.59 (-0.36), respectively, for state (industry, not shown) data.

Tables 3 and 4 present the estimation results for equation (8) using state and industry data, respectively, and the fitted values for Table 3 are presented in

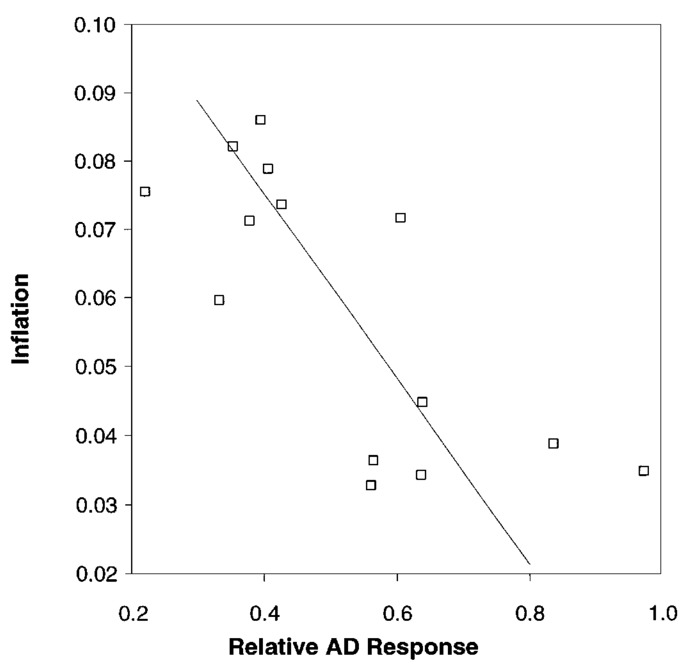

FIGURE 1. Plot of inflation and relative aggregate demand response (π).

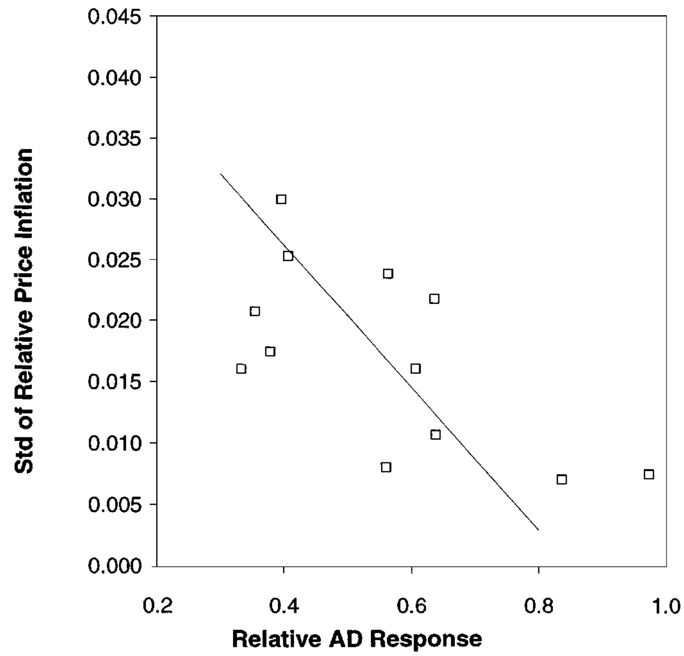

FIGURE 2. Plot of relative price volatility and relative aggregate demand response (π).

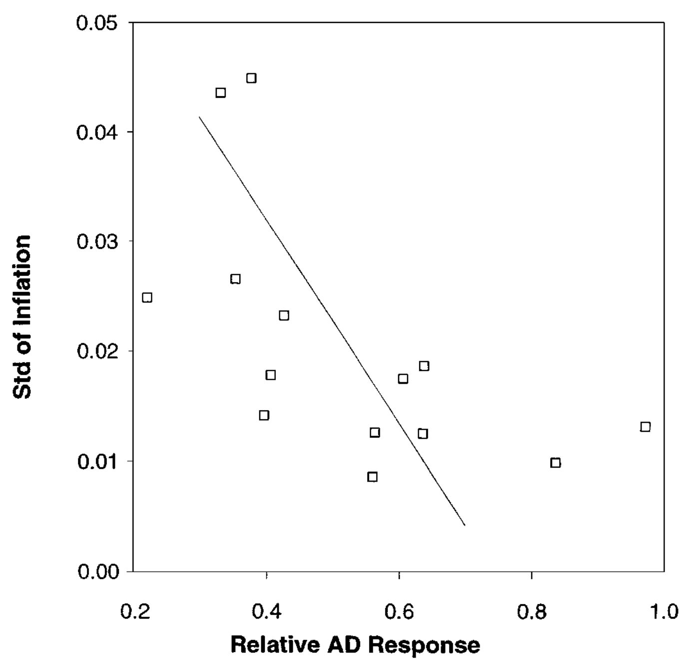

FIGURE 3. Plot of volatility of inflation and relative aggregate demand response (π).

Figures 1–3.[18] For Table 3, as demonstrated in column 5 where we use all of the explanatory variables in our regression, the moving-average inflation rate, and the moving volatilities of relative and aggregate inflation are all negatively related to π_t below the 5% level of statistical significance.[19] Again, the results using industry data in Table 4 are weaker, but they strongly support the view that inflation and the volatility of relative prices is negatively related to the output-inflation trade-off. In fact, the volatility of relative prices independently explains about 42% (32%) of the movement in the estimated value for π with state-level (industry-level) data.

TABLE 3. Estimation results for responsiveness of real output to aggregate demand (π) using state data[a] $\{\pi_t = \pi_0 + \pi_1\overline{\Delta p} + \pi_2\overline{\sigma_{\Delta[p(z)-p]}} + \pi_3\overline{\sigma_{\Delta p}}\}$

Regressors				
Constant	0.958	0.851	0.745	1.033
	(7.535)	(7.513)	(8.469)	(7.558)
$\overline{\Delta p}$	−7.400			−2.016
	(−4.051)			(−2.604)
$\overline{\sigma_{\Delta[p(z)-p]}}$		−17.171		−12.413
		(−3.247)		(−2.836)
$\overline{\sigma_{\Delta p}}$			−10.761	−7.510
			(−3.513)	(−3.860)
R^2	0.540	0.424	0.353	0.737
$\bar{R}^2$	0.501	0.366	0.299	0.639
No. of observations	14	12	14	12

[a]The t statistics, which are robust to heteroskedasticity of unknown form, are reported in parentheses. The dependent variable is the estimated value for π that is reported in Table 1, col. 3. $\overline{\Delta p}$, $\overline{\sigma_{\Delta[p(z)-p]}}$, and $\overline{\sigma_{\Delta p}}$ are the five-year lagged average rate of inflation, the two-year lagged average standard devation of relative price inflation, and the five-year lagged standard deviation of inflation, respectively.

TABLE 4. Estimation results for responsiveness of real output to aggregate demand (π) using industry data[a] $\{\pi_t = \pi_0 + \pi_1\overline{\Delta p} + \pi_2\overline{\sigma_{\Delta[p(z)-p]}} + \pi_3\overline{\sigma_{\Delta p}}\}$

Regressors				
Constant	0.455	0.681	0.370	0.799
	(6.239)	(3.559)	(8.369)	(4.236)
$\overline{\Delta p}$	−2.748			−1.939
	(−2.604)			(−2.072)
$\overline{\sigma_{\Delta[p(z)-p]}}$		−5.416		−4.947
		(−2.107)		(−2.265)
$\overline{\sigma_{\Delta p}}$			−3.687	−2.102
			(−1.358)	(−1.271)
R^2	0.231	0.317	0.129	0.559
$\bar{R}^2$	0.167	0.248	0.056	0.393
No. of observations	14	12	14	12

[a]The dependent variable is the estimated values for π that are reported in Table 2, col. 3. See Table 3 note for explanation of other variables.

Taken together, the evidence from both industry- and state-level data points in the direction of the New Keynesian explanation for the output-inflation trade-off.

6. CONCLUSION

We have estimated the time-varying responsiveness of real output to nominal aggregate demand shocks using intranational data for the United States. This responsiveness measures the slope of the aggregate supply curve. Although Lucas's theory and New Keynesian theory predict a positive slope to the aggregate supply curve, both theories differ significantly as to what affects its steepness. We focus our attention on the following predictions: New Keynesian theory predicts that the response of real output to a nominal shock should decrease as the variance of relative prices rises, because more markets will pay the menu cost and adjust prices more frequently rather than output due to higher uncertainty. In contrast to New Keynesian theory, Lucas's theory predicts that, as the variance of relative prices rises, the response of real output to a nominal shock should increase, because it increases the proportion of the nominal shock that the individual market perceives as real. On the basis of this test, we find strong evidence in favor of the New Keynesian view of the output-inflation trade-off.

NOTES

1. See Cukierman (1984) for an extensive summary of research that generalizes the Lucas aggregate-relative confusion model.

2. Ball and Mankiw (1994) argue that those who deny the importance of sticky prices depart radically from traditional macroeconomics. For recent microeconomic evidence of price stickiness see Carlton (1986), Cecchetti (1986), Blinder (1991), Kashyap (1995), and Levy et al. (1997).

3. In contrast, Caplin and Spulber (1986) show conditions under which there will be no price stickiness at the aggregate level if firms must pay a fixed cost to change their prices, and hence money will continue to be neutral in the aggregate.

4. Using international data, Koelln et al. (1996) explore the robustness of the finding that the trade-off falls as inflation rises.

5. On the basis of employment and productivity growth rates, Norrbin and Schlagenhauf (1988) and Kollmann (1995) find that industry-specific factors explain a much larger amount of the variation of activity over the business cycle than do region-specific factors.

6. Only nominal GSP is available back to 1963. For example, Barro and Sala-i-Martin (1991) construct real GSP prior to 1977 by using the aggregate GDP deflator to deflate real GSP for each state. This is inappropriate for our purposes because our analysis is based on idiosyncratic shocks to the price level.

7. The industries in our analysis are Mining, Construction, Transportation & Public Utilities, Retail Trade, Wholesale Trade, Finance, Insurance & Real Estate, and Services, as well as the following manufacturing industries listed by their 1987 SIC codes: 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35 & 36, 37, 38, 39, and 48 & 49.

8. See Bernard and Jones (1995) for evidence of the former.

9. We also estimated the model with industry data not corrected for the average number of employees in an industry, which increased our sample to 50 industries. We obtained similar results to those that we report in Tables 2 and 4. See Hess and Shin (1997).

10. This approach is justified econometrically because Lucas, Ball et al., and DeFina include a trend term as an explanatory variable in their regressions which effectively removes a deterministic

trend from both the endogenous and exogenous variables. Recall that the log level of real output in each market and in the aggregate should be detrended according to the theory. The results we present are similar if we also include an oil term. See Hess and Shin (1997).

11. See Neumann and von Hagen (1991) for open-economy evidence on the determinants of conditional relative price variability.

12. Recently, Kandil and Woods (1995) used cross-industry data in an attempt to estimate Lucas supply curves for each industry across time. However, the equation they estimate is inconsistent with the equilibrium market equation we derive from the Lucas model. More specifically, they incorrectly estimate a version of the aggregate equation (5) for each industry, whereas they actually should have estimated the market-level equation (6).

13. Other fundamental parameters could change as well, such as λ and δ. This latter parameter is important because, over this time period, the growth of nominal output has fallen.

14. After estimating the sequence of constant terms, c_t's, we regressed them on a constant, Δx_t and y_{ct-1}. Each coefficient from this regression was statistically significant with the correct sign, and an R^2 near 0.50 for both data sets.

15. Recall that the coefficient on the lagged dependent variable is $\lambda(1-\pi)$, and we estimate $-1 \leq \hat{\lambda}(1-\hat{\pi}) \leq 1$.

16. DeFina uses lagged moving averages for his measure for inflation, and hence to be consistent with his work, we adopt lagged moving statistics for all measures. Also, by using lagged measures, we lessen any simultaneity bias in our estimation procedure. Because we lose observations for the regression when we use lags for the relative inflation measure, we only use two lags. Our results are robust to varying the horizon for the moving-average terms.

17. For proofs of the first and second implications of New Keynesian theory, see Ball et al. (1988). The implications of Lucas's model are explained in Section 2. Recently Ball and Mankiw (1995) constructed a model with sticky prices that shows that inflation is more responsive to the positive skewness of relative input prices that are not available on a regional basis.

18. Because the dependent variable is generated from an earlier regression, the reported t statistics for the estimated parameters in Tables 3 and 4 are robust to heteroskedasticity of unknown form. See Ball et al. (1988, note 43).

19. For the state-level regressions, note that when inflation is low, say 2% per year, the impact parameter is around 0.8, whereas for high-inflation time periods, say 8% per year, the impact parameter is halved to approximately 0.4.

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APPENDIX

To solve for the market-level equilibrium equation, we use the identity, $y_t(z)+p_t(z) = x_t(z)$, which together with (2) and (3) allows us to decompose z as follows:

$$z = [x_t(z) - x_t] + [y_t - y_t(z)]. \tag{A.1}$$

From expressions (4) and (5) we obtain that

$$y_{ct} - y_{ct}(z) = y_t - y_t(z) = -\theta\gamma z + \lambda[y_{ct-1} - y_{ct-1}(z)]. \tag{A.2}$$

Substituting (A.2) into (A.1), we solve for z:

$$z = \left(\frac{1}{1+\theta\gamma}\right)[x_t(z) - x_t] + \left(\frac{\lambda}{1+\theta\gamma}\right)[y_{ct-1} - y_{ct-1}(z)]. \tag{A.3}$$

Finally, by substituting (A.3) into (4), we solve for the cyclical level of output in each market, equation (6).