An Equilibrium Analysis of Relative Price Changes and Aggregate Inflation

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Abstract

The existence of a relationship between the degree of skewness of the cross-section distribution of price changes and aggregate inflation has been known for some time. The conventional interpretation of this relationship is that it reflects sluggishness in the adjustment of individual prices in response to shocks. In this paper we question the traditional interpretation of this observation, and show that a simple equilibrium model with complete price flexibility is capable of reproducing the relationship observed in the data.

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1. Introduction.

There is a substantial literature that documents the relationship between the first and second moments of the distribution of price changes, or more precisely, the relationship between the aggregate rate of inflation and the variability of relative price changes for individual products (appropriately defined). This literature originated in the high-inflation experience of the 1970's, and was motivated in part by the idea that one of the costs of high inflation was greater price uncertainty which undermined the efficiency of the price system as a transmitter of information about relative scarcities. Most studies find a positive correlation between the variability of individual price changes and the aggregate inflation rate. Representative studies include Vining and Elwertowski (1976) for the United States using annual data and Domberger (1987) for the United Kingdom using quarterly data. This literature has been reviewed by Marquez and Vining (1984) and more recently by Golob (1993). Most recently, Ball and Mankiw (1995) have further documented the existence of a positive relationship between inflation and the standard deviation of the cross section distribution of price change for components of the PPI, essentially updating the earlier findings of Vining and Elwertowski.

A number of these earlier studies also noted the existence of a statistical relationship between the shape of the cross-section distribution of prices (as measured by a statistic such as the skewness of this distribution) and the aggregate inflation rate. Yet this relationship has received much less attention than that between the variance (or standard deviation) of the cross section distribution and aggregate inflation. This is surprising, as the former relationship is arguably stronger than the latter. For example, using data from Vining and

Elwertowski's Tables 1 and 2, the simple correlation coefficient between the mean rate of price change and the standard deviation is 0.23 for the WPI and 0.22 for the CPI. But the simple correlation between the mean rate of price change and the skewness of the distribution is 0.41 for the CPI and 0.61 for the WPI. (Note that the aggregate inflation measure in Vining and Elwertowski is the mean of the distribution of individual price changes, which is not the same as the inflation rate as measured by the CPI or WPI. The latter is more accurately thought of as a weighted mean of individual price changes). Similar correlations can be calculated from the data in Table II of Ball and Mankiw (1995). The most striking finding from that table is that the correlation between the "Asym10" measure of the degree of asymmetry in the cross section distribution of price changes and the aggregate inflation rate is 0.85 (as opposed to correlations of 0.38 and 0.57 for the unweighted and weighted standard deviations respectively).[2] Figure 1 plots inflation and *Asym10*.

The motivation for studying this relationship, and its interpretation, is somewhat different to that for studying the relationship between the first and second moments of the distribution of price changes. Marquez and Vining (1984) note that "The ...reason for studying the shape of the distribution of relative prices has to do with the degree of price flexibility in the economy...*an asymmetrical or skewed distribution of relative price changes indicates the existence of price inflexibility in the economy*. A normal distribution of relative price changes, on the other hand, is evidence of price flexibility in the economy."(Marquez

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[2]The statistic *Asym10* is defined as $Asym10 = \int_{-\infty}^{-10} rh(r)dr + \int_{10}^{\infty} rh(r)dr$ where r denotes an industry inflation rate minus the mean of industry inflation rates and $h(r)$ is the density of r including weighting for industry size.

and Vining, 1984, p. 10, emphasis added). They further argue that the presence of skewness in the distribution of relative price changes is indicative of asymmetric price responses in the economy, noting for example that right skewness in the distribution would be consistent with downward rigidity of prices.

Most recently Ball and Mankiw (1995) argue that the existence of a statistically significant relationship between the skewness of the cross section distribution of price changes an aggregate inflation is a novel empirical prediction of menu cost models and as such lends credibility to models of this type.

There are at least two reasons why we might want to be skeptical about the traditional interpretations of the skewness-inflation relationship as reflecting nominal rigidities. The first is that, despite frequent claims to the contrary, there is remarkably little serious documentation of just how frequently prices do in fact change. The claims of Ball and Mankiw (1994) notwithstanding, there are not in fact "...many microeconomic studies of the behavior of prices..."(Ball and Mankiw, 1994, p. 131) that find substantial price stickiness. Four would be more like it, and even these studies are not immune to elementary criticisms about how prices ought to be measured.[3] But perhaps a more important criticism of the traditional interpretation of the skewness-inflation relationship is the failure of previous authors to demonstrate formally how a model incorporating menu costs associated with changing prices can in fact generate this correlation when calibrated to match certain features of the real world data, and further, to show that a model with complete price flexibility cannot.

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[3]These studies are critically surveyed in Wynne (1995).

In this paper we set ourselves the task of discovering to what extent can an equilibrium model with complete price flexibility generate the correlations that we see in the data, and further, to document those dimensions along which the model fails. We show that a simple equilibrium model with no interaction between sectors and with all sectors subject to iid shocks is in fact incapable of generating the relationship between skewness and inflation that we see in the actual data. This would seem to confirm the prior beliefs of many advocates of the sticky-price interpretation of this relationship. But we will also show that when this most elementary of equilibrium models is calibrated to match certain features of the postwar U.S. economy (specifically the input-output relationships between sectors and the volatility of productivity shocks that can be measured using postwar data), it is remarkably successful in capturing the skewness-inflation relationship. We further document that skewness seems to have a stronger leading than contemporaneous relationship with aggregate inflation, and that the simple model we sketch out in this paper is less successful in capturing this aspect of the data. It remains to be seen whether models with sticky prices (of whatever sort) are more or less successful in this regard.

2. Data

The most recent study of the relationship between skewness and inflation is Ball and Mankiw (1995). They look at the relationship between the distribution of prices in the Producer Price Index (PPI) on an annual basis over the period 1949-1989. One advantage of looking at the PPI is that it is available at a high degree of disaggregation. At the four digit level of disaggregation, the number of component series rises from 213 in 1949 to 343 in

1989.[4] Ball and Mankiw document the relationship between the distribution of the changes in these several hundred price series and the overall inflation rate (as measured by the PPI).

Their data analysis reveals a number of interesting findings. First, there is considerable variation in the distribution of price changes over time. For example, in 1987 the distribution is fairly symmetric, while in 1973 it is skewed sharply to the right and in 1986 it is skewed sharply to the left.[5] Not surprisingly, both 1973 and 1986 were also years in which there were significant oil price shocks, with oil prices rising dramatically in 1973 and falling dramatically in 1986. Second, they document a statistically significant relationship between their various measures of skewness and the overall inflation rate. They show that the skewness of the distribution of price changes tends to dominate the standard deviation of the distribution as an explanatory variable for inflation. This result is robust to their use of any of three measures of skewness.

The relationship between skewness and inflation was also noted in the earlier paper by Vining and Elwertowski (1976). They noted that "...the shape of the distribution of individual price changes...is generally a highly skewed and asymmetrical distribution: and there are at least suggestions in the data that the direction of skew is the same as the direction of change in the rate of inflation (a high positive skew has been a particularly prominent feature of the current inflation)." (Vining and Elwertowski, 1976, p.703). Vining and Elwertowski provide summary statistics on the distribution of price changes in the CPI

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[4]Vining and Elwertowski (1976) analyze PPI data at the eight digit level of disaggregation, which gives them a sample size of between 1159 and 2033 commodities.

[5]The skewness of a distribution is defined as $E[(X-\mu)^3]/\sigma^3$ where μ is the mean of the distribution of X and σ is the standard deviation.

and WPI, but do not examine the strength of the relationship between them.

The first step in our investigation was to try to replicate the relationship between skewness and inflation using a different data set. We look at prices as measured by the (implicit) GDP deflators for 49 industries or commodities. In Table 1 we present statistics on the behavior of various measures of skewness as leading or lagging indicators of different measures of inflation. This is an aspect of the relationship between these two variables that seems to have been neglected by previous authors. We start by examining the CPI and PPI data sets studied by Vining and Elwertowski (1976) and Ball and Mankiw (1995). Note that in the Vining and Elwertowski data set the strongest correlation between skewness and aggregate inflation (which they measure simply as the unweighted mean of the cross section distribution of prices) is contemporaneous, although we do see some modest leading behavior. In the Ball and Mankiw data set, unweighted skewness seems to lead inflation, while for the weighted skewness measure and the *Asym10* measure, the peak correlation is again contemporaneous. Finally in the last four rows of the table we document the correlations between unweighted and weighted measures of skewness and aggregate inflation using the GDP price series. In the first two rows we measure aggregate inflation as simply the unweighted or weighted mean of the cross section distribution of price changes, while in the last two rows we measure inflation as the rate of change in the fixed-weight GDP deflator.[6] In this data set we see a much stronger tendency for skewness to lead the inflation

[6]The difference between the three measures of aggregate inflation is as follows. The unweighted mean of the GDP deflators for each sector is simply $\sum_{i=1}^{I} \Delta\log(P_{i,t})/I$ where I is the number of sectors; the weighted mean is given by $\sum_{i=1}^{I} w_i \Delta\log(P_{i,t})$; and the rate of inflation (continued...)

rate (that is, the correlations with aggregate inflation are higher for lags of either measure of skewness than for leads, and the peak correlation is at a one-year lag). Finally, note that there is a somewhat stronger correlation between the weighted skewness measure and aggregate inflation than between the unweighted measure and aggregate inflation.

It might reasonably be argued that the simple correlations in Table 1 fail to control for the fact that inflation is quite persistent, and the possibility that if this persistence were taken into account the correlation between inflation and skewness would disappear. Table 2 presents some simple regression results for the relationship between the rate of inflation as measured by the rate of change of the fixed-weight GDP deflator and measures of the distribution of prices across forty-nine sectors of the U.S. economy. These regressions are similar to regressions reported by Ball and Mankiw to illustrate the explanatory power of a skewness measure. Table 2 shows that skewness does seem to have a statistically significant relationship with aggregate inflation, albeit with a lag, even when the past behavior of inflation is taken into account. Note that this is true for both the weighted and unweighted measures. We also report the results of including the standard deviation of the cross section distribution in the regression, and find that it does contribute to explaining the variation in inflation. This contrasts with Ball and Mankiw's finding that the standard deviation has marginal incremental explanatory power at best. We also report the F-statistics for standard exclusion restrictions on the skewness and standard deviation variables and find that we are able to reject the hypothesis that either variable should be excluded from the regression.

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[6](...continued)

as measured by the aggregate GDP deflator is $\log(\sum_{i=1}^{I} P_{i,t}Y_{i,b}/\sum_{i=1}^{I} P_{i,t-1}Y_{i,b})$.

Overall the results in Table 2 support the evidence from Table 1 that there is a statistically significant relationship between inflation and the skewness of the distribution of individual price changes. It is also clear that we can obtain the same strong statistical relationship between the skewness of the distribution of price changes and aggregate inflation looking at only 49 prices as Ball and Mankiw or Vining and Elwertowski do looking at several hundred prices. The relationship between these two variables seems to be fairly robust. Our objective in what follows is to see to what extent we can replicate the facts about the relationship between skewness and inflation as documented in here in the context of a simple equilibrium model.

3. An equilibrium model with multiple sectors.

The next step in our analysis is to lay out a simple equilibrium model that is capable of addressing questions about the relationship between the distribution of price changes and aggregate inflation. The model presented here is the simplest one we could think of that could begin to provide insights into this relationship and is essentially a variant of the model of Long and Plosser (1983) with a larger number of sectors, extended to include a role for money.

Households:

The economy is populated by a large number of identical consumers, each of whom has preferences summarized by the following utility function:

$$U = \sum_{t=0}^{\infty} \beta^t u(C_t,\ L_t) \tag{1}$$

where $1 > \beta > 0$ is the discount factor, $C_t = (C_{1,t}, C_{2,t}, \ldots, C_{I,t})'$ is an $I \times 1$ vector of commodities consumed at date t, and L_t denotes leisure at date t. The point-in-time utility function is furthermore assumed to have the following specific functional form:

$$u(C_t,\ L_t) = \theta_0 \log(L_t) + \sum_{i=1}^{I} \theta_i \log(C_{i,t}) \tag{2}$$

where $\theta_i \geq 0\ ,\ \forall\ i$. If $\theta_i = 0$ for some $i \geq 1$ then that commodity has no utility value to the consumer.

The budget constraint of the representative consumer is given by

$$\sum_{i=1}^{I} W_{i,t} H_{i,t} + \sum_{i=1}^{I} R_{i,j,t} K_{i,j,t-1} + \mu_t N_{t-1} \geq \sum_{i=1}^{I} P_{i,t} C_{i,t} + \sum_{i=1}^{I} P_{i,t} \sum_{j=1}^{I} K_{j,i,t} + N_t \tag{3}$$

where $W_{i,t}$ denotes the (nominal) wage in sector i at date t, $H_{i,t}$ denotes hours worked in sector i at date t, $R_{i,j,t}$ denotes the rental rate during period t of capital produced in sector j and employed in sector i during period t, $K_{i,j,t-1}$ and μ_t represents the gross rate of increase in the money stock at date t. In addition to wage and rental income, the sources of funds each period include a transfer from the government which is directly proportional to nominal money holdings held at the end of the previous period, $(\mu_t - 1)N_{t-1}$.[7] The uses of funds each period are for consumption expenditures, $\sum_{i=1}^{I} P_{i,t}C_{i,t}$, purchases of new capital $\sum_{i=1}^{I} P_{i,t}\sum_{j=1}^{I} K_{j,i,t}$ and funds held over to the next period, N_t. Households also receive any profit income earned by firms, but this is always equal to zero in equilibrium.

We introduce money by specifying a simple quantity-theory relationship. Specifically we assume that consumers are obliged to hold some fraction ν of their consumption purchases each period in the form of cash at the *end* of the period. That is, household decisions are subject to the constraint,

$$N_t \geq \nu \sum_{i=1}^{I} P_{i,t} C_{i,t} \tag{4}$$

where N_t denotes the stock of nominal money balances held at the *end* of period t and $\sum_{i=1}^{I} P_{i,t}C_{i,t}$ denotes nominal consumption expenditures *during* period t, with $P_{i,t}$ denoting the price of good i at date t, and $C_{i,t}$ denoting the quantity of good i purchased for consumption purposes at date t. Specifying the timing this way, along with the assumption that transfers are proportional to holdings of nominal balances, minimizes the importance of nominal shocks in this model. The existence of this constraint can be thought of as arising due to the need to, say, maintain some minimum level of cash balances in a bank account to facilitate consumption purchases made with inside money. The addition of this constraint to the model allows us to consider the behavior of prices denominated in terms of money rather than

[7]Note that this assumption is different from the usual assumption that monetary transfers from the government are lump sum. By departing from the standard assumption of lump sum transfers we create an environment in which money is superneutral.

utility as in Long and Plosser (1983).

The remaining constraint that the consumer faces is on the allocation of available time,

$$L_t + \sum_{i=1}^{I} H_{i,t} = 1 \tag{5}$$

which states that the sum of leisure and time worked in each sector cannot exceed the total amount of time available, which we normalize to 1.

The household's problem is to maximize the objective function given in (1) above subject to the budget constraint (3), the cash constraint (4) and the constraint on the allocation of time (5).

Firms:

Production possibilities in the i'th sector are give by the following production function:

$$Y_{i,t} \equiv Z_{i,t} H_{i,t}^{b_i} \prod_{j=1}^{I} K_{i,j,t-1}^{a_{i,j}} \tag{6}$$

where $Z_{i,t} = \eta_i^t \hat{Z}_{i,t}$ is a random variable or productivity shock that denotes the state of technology in the i'th sector at date t (where λ_i^t is the deterministic growth component of labor augmenting technical change), $H_{i,t}$ denotes hours worked in the i'th sector at date t, and $K_{i,j,t-1}$ denotes the quantity of output of the j'th industry employed as capital in the i'th industry at date t (which must be in place at the end of period t-1). The parameters of the production function, b_i and $a_{i,j}$ are assumed to satisfy $b_i > 0$, $a_{i,j} > 0$ and $b_i + \sum_{j=1}^{I} a_{i,j} = 1$ for i = $1, 2, \ldots, I$. That is, we assume that the technology exhibits constant returns to scale.

Market Clearing:

The specification of the model is completed by specifying a market clearing condition for each sector:

$$Y_{i,t} = C_{i,t} + \sum_{i=1}^{I} K_{j,i,t}$$

which simply states that available output is allocated to consumption or is stored for use as capital input next period.

Equilibrium:

The simple structure of the economy sketched out above makes the computation of decision rules a very straightforward matter. The closed-form expressions for the decision variables as follows:

$$C_{i,t} = \left(\frac{\theta_i}{\gamma_i}\right) Y_{i,t} \tag{8}$$

$$L_t = \frac{\theta_0(1 + \nu(1 - \beta))}{\theta_0(1 + \nu(1 - \beta)) + \sum_{i=1}^{I} \gamma_i b_i} \tag{9}$$

$$H_{i,t} = \frac{\gamma_i b_i}{\theta_0(1 + \nu(1 - \beta)) + \sum_{j=1}^{I} \gamma_j b_j} \tag{10}$$

$$K_{i,j,t} = \left(\frac{\beta \gamma_i a_{i,j}}{\gamma_j} \right) Y_{j,t} \tag{11}$$

where $\gamma_j = \theta_j + \beta \sum_{i=1}^{I} \gamma_i a_{i,j}$.

The simple form of these decision rules is obviously a result of the particular assumptions we have made about preferences, production possibilities and the (100%) rate of depreciation of capital. The decision rules for consumption and capital are in fact identical to those in Long and Plosser (1983). The decision rules for labor and leisure differ from those in Long and Plosser because of the appearance of the ν term. Note that if $\nu = 0$ then the decision rules for labor and leisure are almost identical to those in Long and Plosser. Thus the presence of the cash constraint simply has the effect of lowering the allocation of effort to each of the alternative productive activities, and concomitantly raising leisure. Thus, comparing two economies, one with and one without the cash constraint, the economy with the cash constraint would have a lower level of output and welfare than the one without. One other point to note about these decision rules is the absence of the inflation rate or rate of growth of the money stock, μ. That is, this economy exhibits superneutrality - real allocations are independent of the rate of growth of the money stock, and there are no costs associated with the inflation tax.

It is straightforward to show that in a version of this model without money utility denominated prices for each good are:

$$\tilde{P}_{i,t} = \frac{\gamma_i}{Y_{i,t}}$$

Standard manipulation of the equilibrium conditions of our model allow us to write dollar-denominated prices in our model as

$$P_{i,t} = \frac{N_t}{\nu \sum_{j=1}^{I} \theta_j} \frac{\gamma_i}{Y_{i,t}} = \frac{N_t}{\nu \sum_{j=1}^{I} \theta_j} \tilde{P}_{i,t} \tag{13}$$

That is, the nominal prices are directly proportional to the utility-denominated prices, and also to the nominal money stock. In our model, nominal aggregate output (denominated in terms of dollars) is equal to $\sum_{i=1}^{I} P_{i,t} Y_{i,t} = N_t \left(\sum_{i=1}^{I} \gamma_i / \nu \sum_{i=1}^{I} \theta_i \right)$ and is directly proportional to the money stock. Note that this expression is similar to a strong version of the quantity theory, with "velocity" constant at $\left(\sum_{i=1}^{I} \gamma_i / \nu \sum_{i=1}^{I} \theta_i \right)$.

Dynamics:

The dynamic behavior of this economy is implied by the technology as summarized by the production functions, along with the decision rules for the inputs to the production processes. It is convenient to write the system in logarithmic form as follows:

$$y_t = k + Ay_{t-1} + z_t \tag{14}$$

where we adopt the convention that lower-case letters denote the logarithms of the corresponding upper-case variable. Thus, y_t is the $I \times 1$ vector $(\log(Y_{1,t}), \log(Y_{2,t}), \ldots, \log(Y_{I,t}))'$, k is an $I \times 1$ vector of constants, and z_t is the stochastic vector $(\log(Z_{1,t}), \log(Z_{2,t}), \ldots, \log(Z_{I,t}))'$. Since our primary focus in this paper is on the evolution of the distribution of prices, we also need to specify a stochastic process for the log of the nominal money stock, n_t.

The evolution of prices is given by

$$p_t = k_p + \iota_I n_t - y_t \tag{15}$$

where $p_t = (\log(P_{1,t}), \log(P_{2,t}), \ldots, \log(P_{I,t}))'$, k_p is an $I \times 1$ vector of constants, and ι_I is an $I \times 1$ vector of ones. An important point to note from this expression is that the money stock only affects the mean of the cross-section distribution of prices and not any of the higher moments. On the other hand, the shape of the cross-section distribution of inflation is determined by output growth (including secular trends) in the various sectors.

It is straightforward to calculate a variety of measures of the aggregate price level that correspond to the measures commonly used to gauge inflation in the real world. Three standard price aggregates are the consumer price index (CPI), the fixed-weight GDP deflator (PGDPF), and the implicit GDP deflator, all of which are easily calculated for our model, and which differ primarily in terms of how they weight the individual prices. In what follows we will to focus on the relationship between the skewness of the distribution of prices and the rate of inflation as measured by the GDP deflator. Our results are robust to the use of other measures of the aggregate price level.

4. Calibration

Our objective in this paper is to explore the relationship between the distribution of individual price changes and the aggregate inflation rate in a model with complete price flexibility. Thus it is desirable to have as many prices as possible endogenously determined within our model, and to have fluctuations in these prices driven by shocks that are in some well-defined sense comparable to the shocks hitting different sectors in reality. This creates an important trade off.

In principle there is no limit to the number of sectors we could have in our model. However if we are to allow for interactions between sectors that are in some sense representative of those observed in the real world, we are constrained by the sectoral detail reported in the Input-Output (I-O) Tables. For example, the 1987 benchmark I-O accounts are available at both a two-digit and six-digit level of disaggregation. At the two-digit level, the I-O table covers 95 industries, while at the six-digit level the I-O table provides details for some 480 industries. However, an even more important constraint arises if we wish to calibrate the shocks hitting different sectors to match those hitting sectors in the data. The technology shock in our model is a shock to productivity, so we are constrained by the number of sectors for which we can obtain data on both value added and the labor and capital inputs. Here we are constrained by the level of detail reported in the National

Income and Product Accounts (NIPA) and Fixed Reproducible Tangible Wealth in the United States (U.S. Department of Commerce, 1993b). Section 6 of U.S. Department of Commerce (1992, 1993a) provides estimates of GDP and the number of full-time equivalent employees by industry for some 59 private sector industries (capital stock estimates are available at essentially the same level of sectoral detail), so this provides an upper bound on the amount of sectoral detail that is possible in our model. A final complication arises from the fact that the sectors in the I-O Tables do not always correspond directly to the sectors or industries reported in the National Income and Product Accounts.

To overcome this latter complication, we consolidated the industry classifications in the two basic data sources into 49 industries (see Table 3 for the way the industries were matched up). The essential problem with combing information from both sources is that in some cases the NIPA give more industrial detail, while in some cases the I-O table gives more industrial detail. For example, NIPA reports the output and full time equivalent employees on "Farms", while the I-O Table distinguishes between the output of "Livestock and Livestock Products" and "Other Agricultural products". Likewise, whereas the I-O Table reports output for "Insurance" the NIPA distinguishes between "Insurance Carriers" and "Insurance Agents, Brokers and Services". In some cases there is a logical correspondence between the industry categories in each source: for example, "Wholesale Trade" in the I-O Table is probably essentially the same as "Wholesale Trade" in NIPA, and "Air Transportation" in the I-O Table is probably the same as "Transportation by Air" in

NIPA.[8]

Having calibrated the A matrix of our model to the 1987 benchmark I-O table, the vector of coefficients b is recovered from the assumption of constant returns to scale, i.e. $b_i = 1 - \sum_{j=1}^{N} a_{i,j}$. To calibrate the vector θ, we note that the decision rules for consumption of each type of good imply that $\theta_i = \gamma_i \frac{C_{i,t}}{Y_{i,t}}$. We can obtain estimates of the share of each sector's output (γ_i) in aggregate output from the 1987 I-O table. The same table also allows us to estimate the fraction of each sector's output that was allocated to consumption that year, which together with the estimate of γ_i allows us to obtain an estimate of θ_i.

The remaining coefficients that need to be set are the discount factor, β, and the fraction of consumption purchases that must be held as cash at the end of each period, ν. We set $\beta = 0.95$ somewhat arbitrarily, although this figure is comparable to those used in other applied studies. Likewise we set $\nu = 0.1$, again somewhat arbitrarily. Our results are not particularly sensitive to our choices for these two parameters.

Experiment 1: Our first experiment examines the behavior of inflation and the distribution of prices in an economy with forty-nine sectors but with no input-output relations between the sectors and with each sector subject to *i.i.d.* shocks of equal variance. Thus we set the A matrix equal to a diagonal matrix with (arbitrarily chosen) 0.333 on the main diagonal. We assume that productivity follows an *AR (1)* process with persistence parameter equal to 0.95 and with the standard deviation of the innovations set equal to the average value of the

[8] We also adjusted the published I-O table to allocate the non-labor related components of valued added among the other inputs on a proportional basis. See Long and Plosser (1983), fn. 22.

innovations of the Solow residuals estimated for each sector.

Experiment 2: For our second experiment we calibrated the A matrix to the 1987 I-O direct requirements "use" table and the θ vector using data from Table 2.1 of the 1987 I-O accounts, but retained the assumption about the shock process used in experiment 1.

Experiment 3: For our third experiment we returned to the specification of the A matrix and θ vector used in the first experiment, but calibrated the technology shocks to the actual postwar data. One way to do this is simply to estimate standard Solow residuals for each sector, i.e.

$$z_{i,t} \equiv \log(Z_{i,t}) = \log(Y_{i,t}) - \alpha_i \log(H_{i,t}) - (1-\alpha_i) \log(K_{i,t-1})$$

where $\log(Y_{i,t})$ is the log of GDP in sector i, $\log(H_{i,t})$ is the log of the number of full time equivalent employees in the i'th sector, $\log(K_{i,t-1})$ is the log of the net stock of capital in sector i at the end of period t-1, and α_i is the share of labor in sector i production.[9] We linearly detrend sectoral productivity and estimate a first order autoregressive process for the detrended series. The estimated trend and autoregressive model are then used to specify the stochastic process used to generate productivity in the model. In order to capture the comovement present in actual productivity, in our simulation exercises below we employ resampled (with replacement) residuals from the estimated productivity autoregressions. This

[9]Ideally we would also incorporate hours worked in our measure of the labor input in the different sectors, but this data does not seem to be available at the required sectoral detail.

allows technology shocks in our model to reflect the cross-section distribution of actual technology shocks without us having to specify a parametric distribution for sectoral shocks.

Experiment 4: For our penultimate experiment, we calibrate the A matrix, the θ vector to the 1987 I-O tables and the stochastic process for productivity in each sector to the actual postwar data and use resampled residuals for productivity shocks.

Experiment 5: In each of the experiments above we assume that the stock of money is constant to isolate the importance of real shocks in generating the skewness-inflation correlation. For our last experiment, we repeated experiment 4 again, except with a stochastic process for the money stock that is calibrated to the monetary base.

Each of these experiments introduces progressively more interaction between the sectors and allows for greater diversity in the shocks hitting the sectors. The set of experiments is designed to help us isolate the relative importance of the input-output interaction between sectors and idiosyncratic shocks in generating a relationship between skewness and inflation. In the first experiment, there is no interaction and the shocks hitting each sector are completely independent of each other. The second experiment allows for interaction through input-output relationships, but retains the assumption of independent shocks. The third experiment allows for no interaction through input-output relationships but does allow for serially correlated shocks in each sector, with the shocks drawn from the estimated distribution. Drawing from the empirical distribution also allows the shocks to productivity in each sector to be contemporaneously correlated. The fourth experiment allows for input-output type interaction between sectors and also allows for correlation in the state of technology in each sector. Note that for each of the first four experiments we assume a constant money growth rate. The last experiment illustrates the effects of adding monetary "noise" to this simple economy.

5. Results

For each experiment we specified and calibrated the model as described above and simulated it 500 times for 44 periods (with an initial 50-period startup to eliminate any potential effects of initial conditions). For each simulation we calculated the correlations reported in Table 1. Table 4 presents the correlations of various leads and lags of the unweighted and weighted skewness with a variety of aggregate inflation measures in each of the five artificial economies.[10] Moving down through the table, we see that in the economy with no interaction between the sectors and *i.i.d.* shocks (experiment 1) there is no relationship between either measure of skewness and aggregate inflation. Allowing for interaction through the input-output structure alone (experiment 2), we are still unable to obtain much of a relationship between skewness and inflation.

However, in the third experiment we find a strong contemporaneous relationship between the skewness and aggregate inflation. The correlation with the average of the sectoral price changes is 0.526 while the correlation with the GDP deflator is 0.494. These correlations are both somewhat larger than those observed in the data (0.281 to 0.416). The

[10]Note that for experiments 1 and 3 we only report the correlations between the weighted measures since all sectors are the same size by construction and so there is no difference between weighted and unweighted measures.

intuition for what's going on seems to be as follows. Allowing the sectoral productivity shocks to be correlated with one another (as is the case in the data) causes current sectoral inflation rates to be correlated with each other. This in turn generates a positive correlation between skewness and inflation as a few large shocks have a disproportionate effect on both statistics. However because the A matrix is diagonal, the sectoral interaction is short lived, and as a result the skewness in the cross section distribution does not display substantial leading behavior for aggregate inflation.

In experiment 4, the contemporaneous correlation between both of the skewness measures is slightly less than in experiment 3, but we now find a modest leading relationship between skewness and inflation. At the one-year lag this correlation ranges from 0.173 to 0.253, somewhat less than the correlations found in the data (which range between 0.413 and 0.544). Note that this is the only one of the four economies we study that is capable of generating any sort of a leading role for skewness in explaining inflation.

Adding monetary shocks.

The above experiments demonstrate that it is possible for a flexible price model driven by shocks to total factor productivity to generate the positive correlation between skewness and inflation. The question remains as to how successful a model with both productivity and monetary shocks is in this regard. In this section, we add money growth variability as an additional source of price variability. Because money affects only the mean of the cross section distribution but not any of the higher moments, adding money growth variability essentially adds noise to aggregate inflation-skewness relationship. This will reduce the correlation between inflation and skewness predicted by the model; the degree to which that correlation is reduced depends on the relative variability of money and productivity shocks.

We used monetary base as our measure of the money stock and fitted an *AR(1)* model to the growth rate of the base. The estimated autoregression and the resampled residuals were used as the stochastic process for money in the model. The last four rows of Table 4 (Experiment 5) presents the results of adding money shocks to the model. Adding monetary variability does cause the correlation between inflation and skewness to fall, as we would expect, but not to disappear. The contemporaneous correlations are more in line with what we see in the data, while the correlations at the one-year lag are somewhat lower. The correlations at other leads and lags are all essentially zero.

Thus, even after adding monetary variability, this particular flexible-price model is still capable yielding a positive correlation between skewness and inflation. As expected, adding a variable money stock does reduce the size of this correlation but does not eliminate it. Again it needs to be noted that in a model in which money is not superneutral, such as a model with a standard cash-in-advance constraint, or in which the monetary authority responds to real shocks, a variable money stock will not just add noise to the relationship between skewness and aggregate inflation. Depending on the nature of the nominal and real interactions, the correlation between aggregate inflation and skewness may rise or fall.

Sectoral Solow Residuals and the Inflation-Skewness Correlation

From the preceding analysis is clear that the properties of the actual Solow residuals play a crucial role in generating the correlation between inflation and skewness that we see in the model. Indeed, the correlation between skewness and the mean of the cross-section distribution of sectoral total factor productivity growth rates is *higher* than that of the corresponding sectoral inflation rates (0.656 for the unweighted residuals, 0.632 for the weighted residuals, versus 0.413 for the unweighted prices and 0.397 for the weighted prices in Table 1). This raises the question of what properties of the estimated Solow residuals are important in generating the positive correlation between the skewness of sectoral inflation rates and aggregate inflation when these shocks are used as inputs in our model.

Perhaps, the simplest explanation for the correlation between the skewness of the cross-section distribution of prices and the aggregate inflation rate (as measured by the mean of the cross-section distribution), which we also observe in the sectoral Solow residuals, is that there is substantial comovement in the measured sectoral productivity shocks. To see the importance of this comovement more clearly, in Figures 2 and 3 we examine the (average) effect of a one standard deviation productivity shock in one of the sectors on the cross-section distribution of prices.[11] For experiments 1 and 2 this implies a shock of 0.0456 to just one of the sectors.[12] Because in experiments 3 and 4 the productivity shocks across sectors are correlated, we set the shock equal to the standard deviation of the first principal

[11]These are based on histograms, before and after the shock, averaged over 500 simulations of the model. Because the effect of a shock on the cross-section distribution depends on the shape of the cross-section distribution at the time of the shock, for each impulse response replication the initial cross-section distribution was randomly selected by simulating the model 50 periods before the time period of the shock.

[12]The results are not particularly sensitive to which sector is shocked. In the Figures 2 and 4, we shocked the sector with the largest value of "gamma"--this sector happens to be the retail trade sector with a weight of 0.2378.

component of the covariance matrix of innovations in actual sectoral Solow residuals (0.1995).[13] The first principle component alone explains about 28 percent of the sum of the sectoral productivity shock variances. The factor loading of this shock is determined by the first eigenvector of the covariance matrix. This factor loading is heavily weighted on manufacturing, especially motor vehicles, fabricated metal industries, stone, clay, and glass products, along with truck and water transportation, wholesale and retail trade, nonmetallic minerals mining and oil and gas.

It is clear from Figure 2 that when sectoral shocks are independent these shocks have a negligible effect on the cross-section distribution. Contrast Figure 2 with Figure 3. In Figure 3, we see that a shock to the first principal component of sectoral Solow residuals has a substantial affect on the cross-section distribution. Because actual sectoral Solow residuals are substantially correlated with one another, a shock to the first principal component causes many of the sectoral prices in the model to move in the same way. Furthermore, because a one standard deviation shock to the first principal component is relatively large, this shock has a disproportionately large effect on the cross-section distribution of sectoral inflation rates.

To see how the changes in the cross-section distribution displayed in Figures 2 and 3, are related to the aggregate inflation-skewness relationship, we present in Figures 4 and 5 the response of the skewness and the mean of the cross-section distribution (both weighted and

[13]It must be noted that the covariance matrix of innovations to the sectoral Solow residuals is not full rank, as there are only 44 observations but 49 sectors. Thus, the last five eigenvalues are this matrix are identically equal to zero, leaving 44 non-zero eigenvalues.

unweighted) to a sectoral shock. For the case of independent shocks, the effect of a one standard deviation sectoral shock on both the skewness and mean are relatively small and they move in opposite directions. For case of correlated shocks, a shock to the first principal component causes skewness and mean inflation to move in the same direction. In addition, the size of the shock matters as well. A large sectoral shock is more likely to move the mean and skewness of the cross-section distribution in the same direction.[14] Here again, because a just a few volatile shocks dominate the variability of innovations in the Solow residuals--the first three principal components account for over 50% of the sum of the sectoral variances--experiments 3 and 4 are better able to generate a positive aggregate inflation-skewness relationship.

Thus, it is clear that a flexible price model can generate a positive correlation between the skewness of the distribution of price changes at a point in time and the aggregate inflation rate so long as there are few relatively large shocks that drive the movement in sectoral productivities. It seems plausible that shocks in a few important sectors (e.g. energy) have a disproportionately large affect on the cross-section distribution of prices. Thus it comes as no surprise that the first three principal components of innovations to sectoral inflation rates from an *AR(1)* process explain over 50% of the variability of innovations to sectoral inflation rates, mirroring what we find with the sectoral Solow residuals.

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[14]A two standard deviation sectoral shock will move the mean and skewness of the cross-section distribution in the same direction even in experiments 1 and 2. However, shocks this size are relatively rare and their effect is likely to be diminished by the presence of smaller shocks in the other sectors.

While in the model above this would be reflected in correlated productivity shocks, a flexible-price model with a richer contemporaneous input-output structure could generate this sectoral interaction without relying on such strong correlation among sectoral productivity shocks.[15] Of course, it is possible that the comovement in the sectoral productivity shocks reflects other phenomena such as external returns to scale (Caballero and Lyons (1992)) or countercyclical markups (Rotemberg and Woodford (1992)). Indeed, Basu (1995) has argued that to the extent that menu-cost pricing implies countercyclical markups it will result in measured sectoral productivity being correlated with aggregate demand shocks. Whether most of the observed comovement in our estimated sectoral Solow residuals is the result of common productivity shocks or the effects of aggregate demand shocks operating through countercyclical markups or other mechanisms is the topic of future work. Regardless, the existence of a positive correlation between the cross-section distribution of prices and aggregate inflation by itself tells us little about the presence of sticky-prices.

6. Conclusions

In this paper we explored the relationship between shifts in the distribution of prices and the aggregate inflation rate in the context of a simple dynamic general equilibrium model with multiple sectors. The idea that changes in the distribution of relative price changes might have implications for the overall inflation rate dates back at least forty years, and has recently been forcefully argued by Ball and Mankiw (1995). A crucial part of the story that

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[15]In Balke and Wynne (1996), we examine a flexible price model that explicitly include output of other sectors as intermediate inputs.

they tell is that firms face significant menu costs associated with changing nominal prices, and they argue that the existence of a relationship between the skewness of the cross-section distribution of price changes is strong evidence of the existence of menu costs at the firm level.

What we have shown in this paper is that it is possible to observe the same types of correlations between the skewness of the distribution of price changes and the overall inflation rate in a very simple dynamic general equilibrium model with no costs of adjusting prices when such a model is calibrated to match key features of the U.S. economy. We do not claim success along all dimensions. While our model does capture the contemporaneous relationship between skewness and inflation reasonably well, and also some of the tendency for skewness to lead the aggregate inflation rate, we are less successful in capturing other aspects of the lead-lag relationship between the two variables.[16] Whether a model with menu costs is more or less successful in this regard is a question for future research.

Our guess is that where the implications of sticky and flexible prices for the cross-section distribution of prices (and its relationship to the aggregate inflation rate) will probably differ are in the response of the cross-section distribution to purely monetary shocks and not in the overall correlation between the skewness and mean of the distribution. For the flexible-price model described above, monetary shocks shift the entire cross-section distribution but do not change its shape (although as we noted this is an outcome of the way we motivate the holding of money). However, for a menu-cost or sticky-price model

[16]A comparison of the results of experiments 3 and 4 suggests that the elimination of the assumption of a 100% depreciation rate for capital would probably help in this regard.

monetary shocks may affect the shape of the cross-section distribution as some prices change in response to monetary shocks but not others. In future work, we hope to determine whether sticky-price sectoral models imply this "reverse causality" and whether there is evidence for it in the data.

Table 1 Correlation between skewness and inflation									
Measure of aggregate inflation		Number of prices	j=-3	j=-2	j=-1	j=0	j=1	j=2	j=3
CPI - (Vining and Elwertowski)	Unweighted Skewness	110-311	-0.110	-0.118	0.210	0.406	0.096	-0.161	0.006
PPI - (Vining and Elwertowski)	Unweighted Skewness	1159-2033	-0.161	-0.004	0.364	0.610	-0.270	-0.134	0.311
PPI - (Ball and Mankiw)	Unweighted Skewness	213-343	0.046	0.169	0.473	0.270	-0.220	0.015	0.157
PPI - (Ball and Mankiw)	Weighted Skewness	213-343	0.265	0.237	0.507	0.528	-0.073	0.040	0.233
PPI - (Ball and Mankiw)	Asym10	213-343	0.299	0.251	0.528	0.851	0.369	0.162	0.177
GDP deflator - Unweighted mean	Unweighted Skewness	49	0.128	0.280	0.413	0.413	0.135	0.235	0.126
GDP deflator - Weighted Mean	Weighted Skewness	49	0.239	0.363	0.544	0.397	0.245	0.178	0.128
Fixed weight GDP Deflator	Unweighted Skewness	49	0.151	0.261	0.459	0.281	0.238	0.226	0.152
	Weighted Skewness	49	0.210	0.339	0.534	0.416	0.272	0.193	0.120

Notes to Table: Entries show the correlation between inflation and skewness at various leads and lags i.e. $Corr(\pi_t, skew_{t+j})$ for j=-3 to 3. Annual data. Data from Vining and Elwertowski (1976) are from their Tables 1 and 2 and are for the period 1948-1974 at the item (eight digit) level of disaggregation. Note that the inflation series in Vining and Elwertowski is simply the unweighted mean of all of the individual price changes. Data from Ball and Mankiw (1995) are from their Table II and is for the period 1948-1989 at the four-digit level of disaggregation.

Table 2 Explanatory power of skewness variable for GDP deflator inflation					
		Unweighted measures		Weighted measures	
Constant	0.916E-2** (0.424E-2)	0.125E-1** (0.041E-1)	-0.665E-2 (0.832E-2)	0.126E-1*** (0.041E-1)	-0.780E-2 (0.743E-2)
Lagged Inflation	0.764*** (0.096)	0.655*** (0.096)	0.579*** (0.098)	0.632*** (0.099)	0.497*** (0.100)
Skewness		0.210E-2 (0.167E-2)	0.187E-2 (0.159E-2)	0.254E-2 (0.173E-2)	0.309E-2* (0.170E-2)
Lagged Skewness		0.505E-2*** (0.169E-2)	0.450E-2*** (0.163E-2)	0.385E-2** (0.185E-2)	0.365E-2** (0.169E-2)
Standard Deviation			0.273* (0.136)		0.224 (0.202)
Lagged Standard Deviation			0.112 (0.132)		0.396** (0.207)
F_{Skew}		4.863**	4.164**	4.545**	5.737***
$F_{Std.\ Dev.}$			3.507**		5.186**
$\bar{R}^2$	0.591	0.655	0.693	0.650	0.711
Durbin Watson Statistic	2.02	1.87	1.97	1.92	2.04

Notes to Table: Sample period 1947-1993. Standard errors in parentheses. *** denotes significance at the 1% level; ** denotes significance at the 5% level; * denotes significance at the 10% level. F_{Skew} is the value of the F-statistic for testing the restriction that the coefficients on the skewness variables are jointly equal to zero. $F_{Std.\ Dev.}$ is the value of the F-statistic for testing the restriction that the coefficients on the standard deviation variables are jointly equal to zero.

Table 3 Concordance between NIPA and I-O sector classifications			
Consolidated industry number		Line Number in Table 6 of NIPA	Commodity Number in 1987 Input Output Table
1	Farms	5	1+2
2	Agricultural Services, Forestry and Fisheries	6	3+4
3	Metal Mining	8	5+6
4	Coal Mining	9	7
5	Oil and Gas Extraction	10	8
6	Nonmetallic Minerals (Except Fuel)	11	9+10
7	Construction	12	11+12
8	Lumber and Wood Products	15	20+21
9	Furniture and Fixtures	16	22+23
10	Stone, Clay and Glass Products	17	35+36
11	Primary Metal Products	18	37+38
12	Fabricated Metal Products	19	39+40+41+42
13	Machinery (Except Electrical)	20	43+44+45+46+47+48+ 49+50
14	Electric and Electronic Equipment	21	51+52+53+54+55+56+ 57+58
15	Motor Vehicles and Equipment	22	59A+59B
16	Other Transportation Equipment	23	60+61
17	Instruments and Related Products	24	62+63
18	Miscellaneous Manufacturing Industries	25	64
18	Food and Kindred Products	27	14
20	Tobacco	28	15
21	Textile Products	29	16+17
22	Apparel and Other Textile Products	30	18+19
23	Paper and Allied Products	31	24+25
24	Printing and Publishing	32	26A+26B
25	Chemicals and Allied Products	33	27A+27B+29A+29B
26	Petroleum and Coal Products	34	30+31
27	Rubber and Miscellaneous Plastic Products	35	28+32
28	Leather and Leather Products	36	33+34

Table 3 (Continued)			
29	Railroad Transportation and Local and Interurban Passenger Transit	39+40	65A
30	Trucking and Warehousing	41	65B
31	Water Transportation	42	65C
32	Air Transportation	43	65D
33	Pipelines and Transportation Services	44+45	65E
34	Telephone and Telegraph	47	66
35	Radio and Television	48	67
36	Public Utilities	49	68A+68B+68C
37	Wholesale trade	50	69A
38	Retail Trade	51	69B+74
39	Finance	53+54+55+59	70A
40	Insurance	56+57	70B
41	Real Estate	58	71B
42	Hotels	61	72A
43	Personal Services	62+65	72B
44	Business Services	63+69	73A+73B+73D
45	Auto Services	64	75
46	Movies and Other Recreation Services	66+67	76
47	Health Services	68	77A
48	Educational Services	70	77B
49	Other Services	74	73C

Table 4
Correlation between skewness of distribution of price changes and aggregate inflation
$Corr(\pi_t, skew_{t+j})$

Measure of aggregate inflation	Measure of skewness	j=-3	j=-2	j=-1	j=0	j=1	j=2	j=3
Data								
GDP deflator - Unweighted mean	Unweighted	0.128	0.280	0.413	0.413	0.135	0.235	0.126
GDP deflator -Weighted mean	Weighted	0.239	0.363	0.544	0.397	0.245	0.178	0.128
Fixed weight GDP deflator	Unweighted	0.151	0.261	0.459	0.281	0.238	0.226	0.152
Fixed weight GDP deflator	Weighted	0.210	0.339	0.534	0.416	0.272	0.193	0.1210
Experiment 1								
GDP deflator -Weighted mean	Weighted	-0.003	-0.012	-0.011	-0.009	-0.008	0.012	0.001
Fixed weight GDP deflator	Weighted	-0.011	-0.017	-0.011	0.003	-0.001	0.002	-0.007
Experiment 2								
GDP deflator - Unweighted mean	Unweighted	0.007	0.019	0.030	0.022	0.038	0.022	0.012
GDP deflator -Weighted mean	Weighted	-0.000	-0.000	-0.002	-0.047	0.023	0.028	0.017
Fixed weight GDP deflator	Unweighted	0.000	0.012	0.019	0.035	0.033	0.023	0.013
Fixed weight GDP deflator	Weighted	-0.007	-0.005	0.004	-0.004	0.035	0.028	0.017
Experiment 3								
GDP deflator -Weighted mean	Weighted	-0.064	-0.049	0.053	0.526	0.064	-0.011	-0.028
Fixed weight GDP deflator	Weighted	-0.061	-0.045	0.055	0.494	0.062	-0.020	-0.036
Experiment 4								
GDP deflator - Unweighted mean	Unweighted	0.005	0.065	0.175	0.492	0.020	-0.027	-0.037
GDP deflator -Weighted mean	Weighted	0.037	0.111	0.253	0.527	0.001	-0.073	-0.068
Fixed weight GDP deflator	Unweighted	0.009	0.067	0.173	0.395	0.009	-0.038	-0.048
Fixed weight GDP deflator	Weighted	0.021	0.084	0.219	0.485	0.006	-0.067	-0.067
Experiment 5								
GDP deflator - Unweighted mean	Unweighted	0.012	0.059	0.140	0.398	0.032	-0.009	-0.024
GDP deflator - Weighted mean	Weighted	0.028	0.088	0.179	0.382	0.033	-0.022	-0.023
Fixed weight GDP deflator	Unweighted	0.017	0.062	0.135	0.319	0.025	-0.014	-0.025
Fixed weight GDP deflator	Weighted	0.020	0.078	0.170	0.393	0.037	-0.024	-0.022

Notes to Table:

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Figure 1

Relationship between Asym10 and rate of PPI inflation

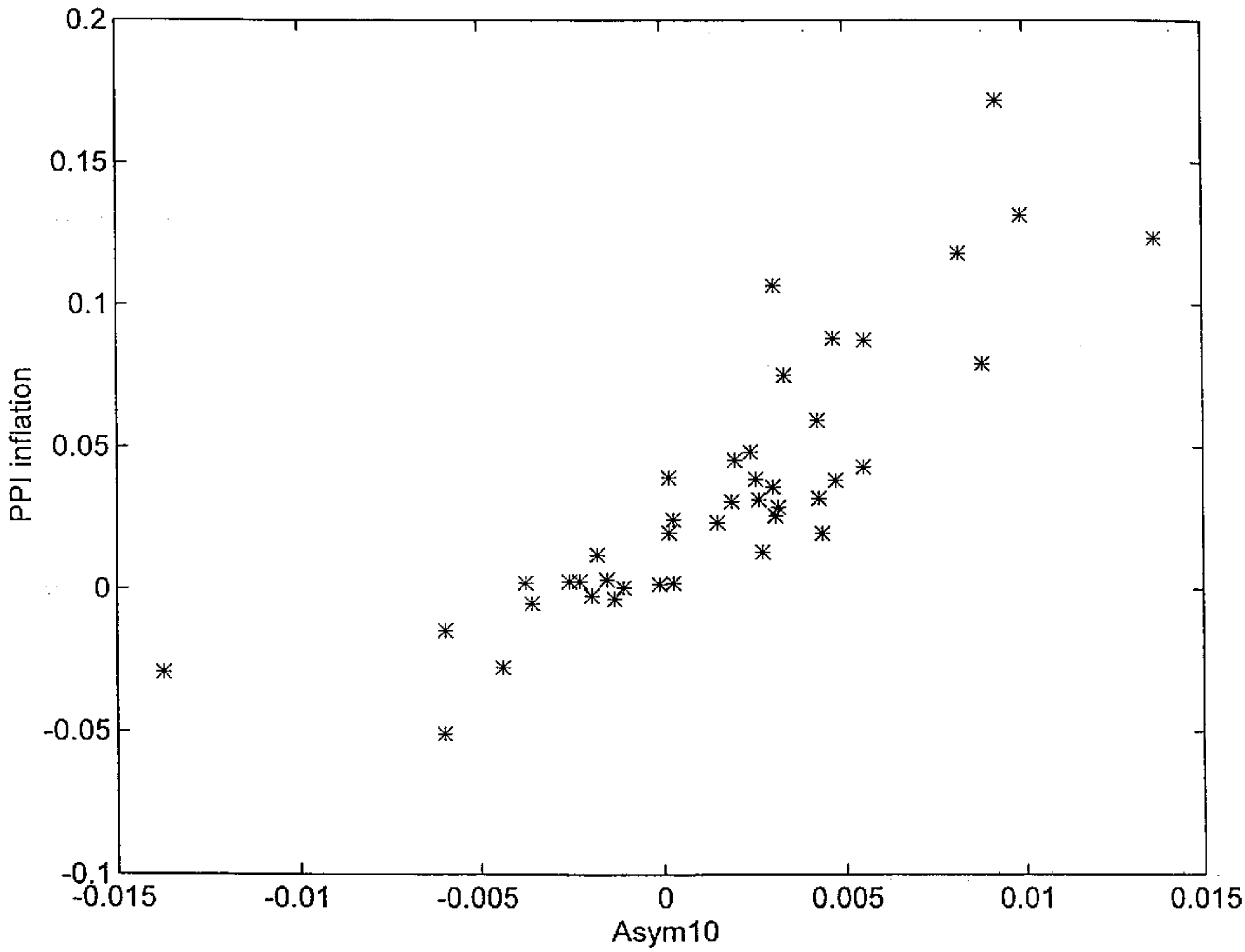


Figure 2

Response of cross-section distribution of price changes to a one-standard-deviation shock
Experiments 1 and 2

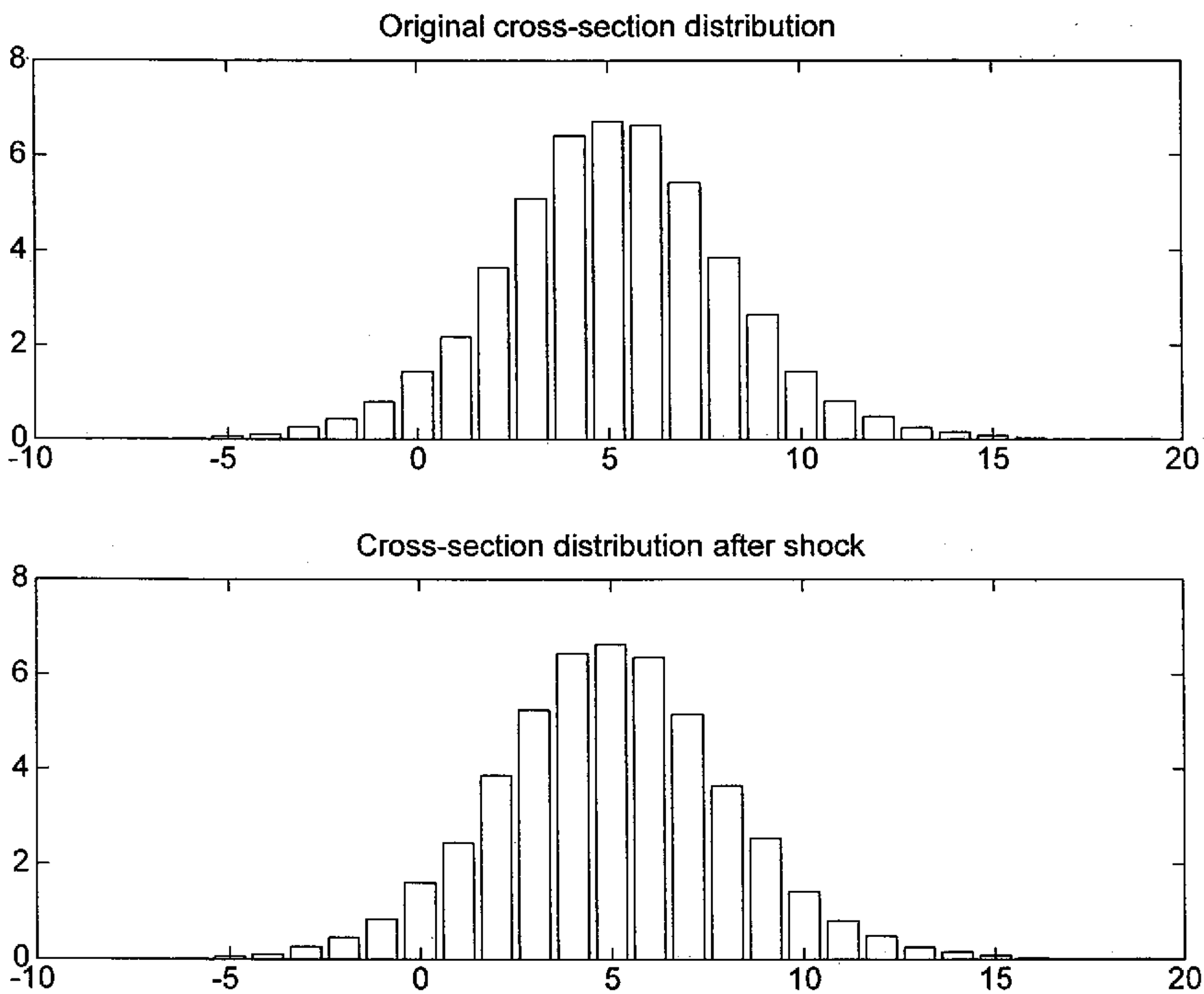


Figure 3

Response of cross-section distribution of price changes to a one-standard-deviation shock Experiments 3 and 4

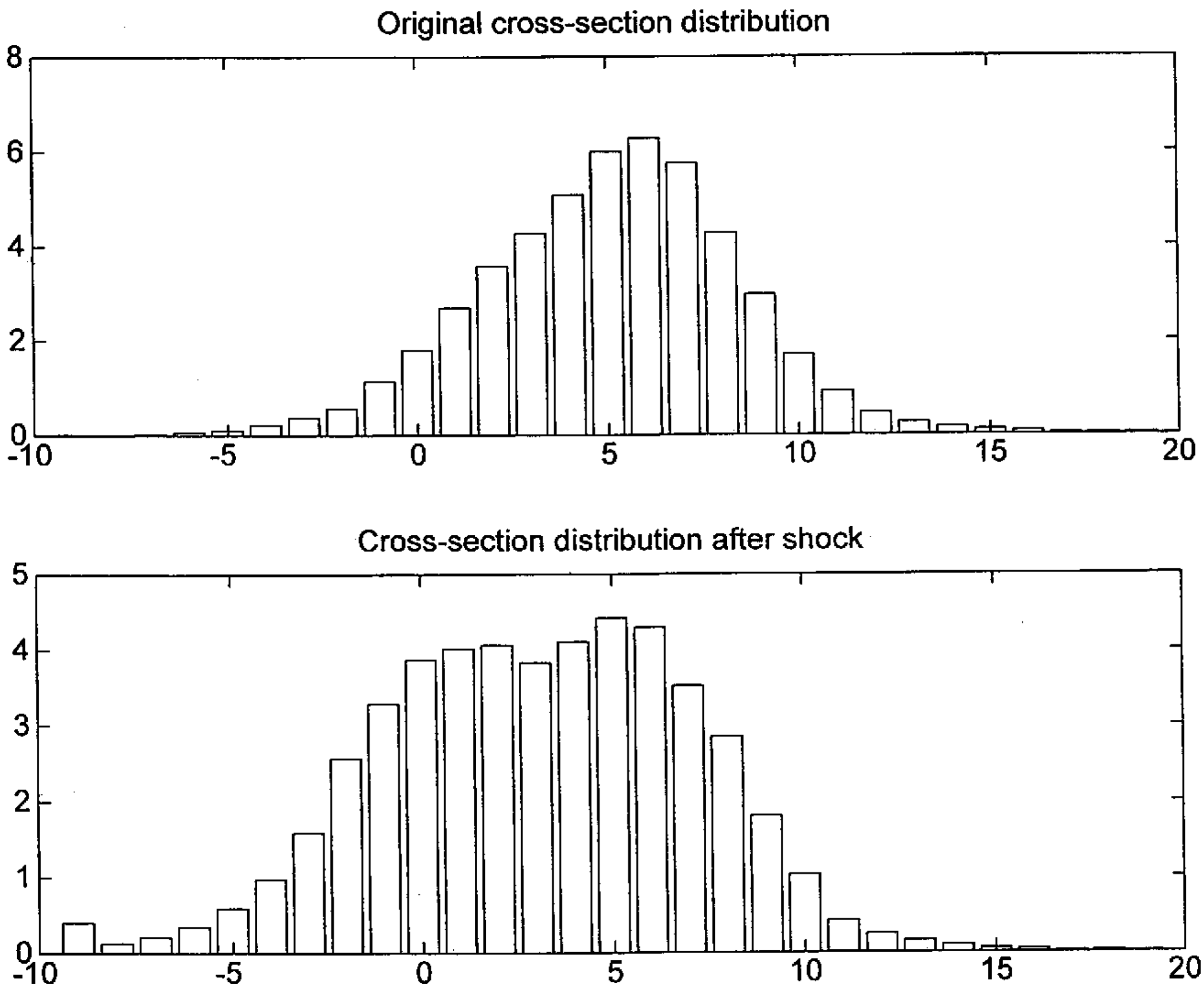


Figure 4

Response of skewness and mean of cross-section distribution of price changes to a one-standard-deviation shock
Experiment 2

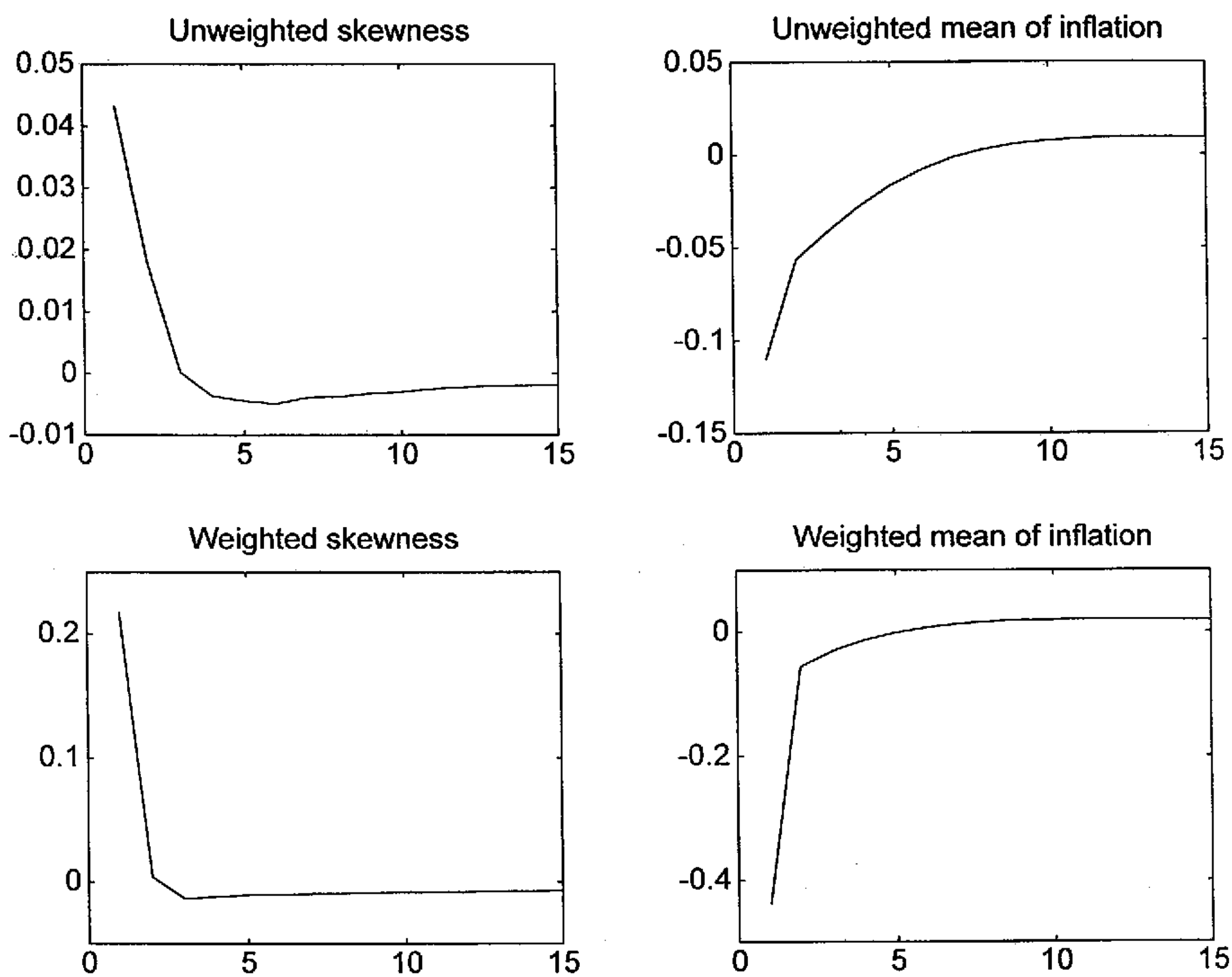
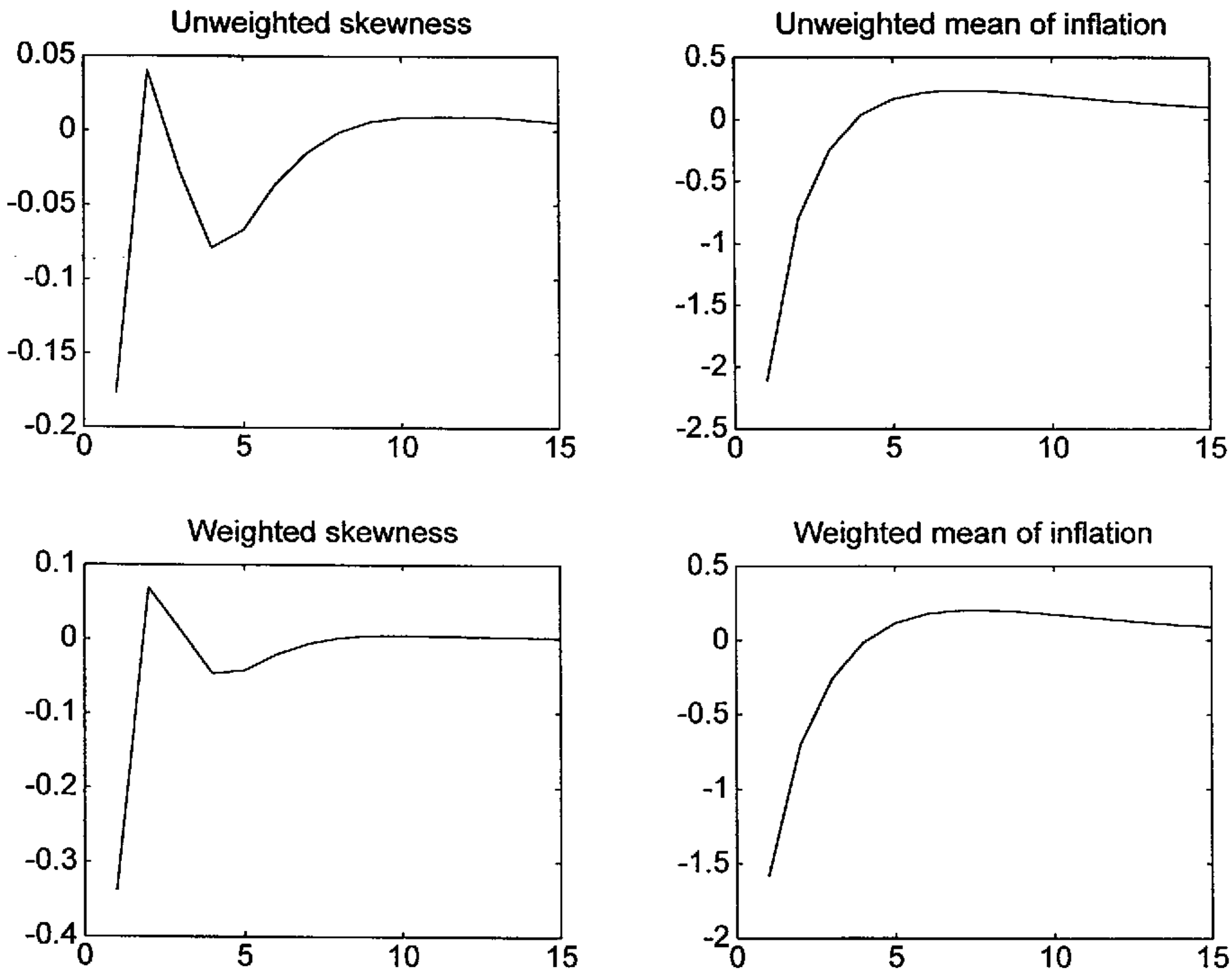


Figure 5

Response of skewness and mean of cross-section distribution of price changes to a one-standard-deviation shock
Experiment 4



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