RELATIVE PRICES AND AGGREGATE SHOCKS

by

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(Under the Direction of William D. Lastrapes)

ABSTRACT

This dissertation studies the effect of aggregate shocks on the relative prices across the industries. It focuses on identifying the dynamic response of the distribution of relative prices to money supply shocks and productivity shocks. Focusing on the effects of aggregate shocks on the distribution of relative prices enables us to sort out the sources of observed correlation between this distribution and aggregate variables, free from the implicit causal relationship assumed in most of the literature.

First study revisits the study by Hercowitz (1981), with VAR model to identify money supply shocks with long-run neutrality. It provides better estimates of money supply shocks than Hercowitz's ad hoc methods. Second study estimates the response of the entire distribution of relative prices to exogenous money supply and productivity shocks. Relative dispersion and cross-sectional skewness are computed from this distribution of responses. The empirical results on the relationship between inflation and the sample moments are consistent with those from most of the literature, and the responses of sample moments to aggregate shocks provide new implication to explain the behavior of relative prices to aggregate shocks.

INDEX WORDS: Relative Dispersion, Cross-Sectional Skewness, Money Supply Shocks, Productivity Shocks, Vector Autoregression, Long-Run Neutrality Restrictions, Impulse Response Functions

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CHAPTER 1

INTRODUCTION

This dissertation studies the effect of aggregate shocks on relative goods prices. It focuses on identifying the dynamic response of the distribution of relative prices across industries to money supply shocks and productivity shocks. There are two motives for this research. First, focusing on the effects of aggregate shocks on the distribution of relative prices enables us to sort out the sources of observed correlation between this distribution and aggregate variables, free from the implicit, and perhaps implausible, causal relationships assumed in most of the literature. Second, this study offers some empirical evidence for how nominal and real shocks are transmitted to real activity through the markets for produced goods.

Understanding the nature of the responses of relative goods prices to money supply shocks is important because, to the extent that such responses are not uniform, the resulting dispersion of relative prices may lead to inefficient resource allocation. In a world without frictions, purely nominal shocks will affect all nominal prices proportionately, so that relative prices will remain unchanged, resource utilization and allocation will be unaffected, and the shocks will be neutral. However, with the market frictions, nominal shocks can, at least temporarily, distort real prices and thus lead to an inefficient allocation of resources. In the face of these distortionary shocks, prices will less effectively signal scarcity, and the price system will become less effective in coordinating economic activity.

There is a large literature that examines the behavior of the distribution of relative goods prices over time; this literature will be surveyed below. Most of these studies focus on the relationship between the cross-sectional variance, or dispersion, of relative prices and the level or variability of inflation. However, this relationship likely depends on the source of shocks that may jointly effect both inflation and the dispersion of relative prices. By examining the responses to underlying money supply and productivity shocks, we can possibly determine the extent this relationship is due to distortionary money supply shocks, as opposed to productivity shocks that may be less distortionary.

To be more precise, much of the empirical research on this topic relies on single-equation models that make implausible exogeneity assumptions. For example, regressions of relative price dispersion on inflation typically presume that inflation is exogenous.[1] Yet, if dispersion and inflation are jointly determined because of joint dependence on common aggregate shocks, such regressions can lead to invalid causal inference and a misunderstanding of the relationship between the distribution of relative prices and inflation.

While many studies have attempted to deal with this identification problem, the identification strategies are often ad hoc and implausible. The main purpose of this dissertation is to take a systems approach to estimating how the cross-industry moments of relative prices jointly respond to underlying, fundamental shocks. We estimate vector autoregression (VAR) models with plausible identifying restrictions to isolate these shocks. We then focus on how these shocks are related to dispersion and other cross-sectional moments, using two different approaches.

[1] Vining and Elwertowski (1976), Parks (1977), Domberger (1987), Reinsdorf (1994), Silver and Ioannidis (1996), and Aarstol (1999) are some of the literature.

The first approach, contained in chapter 3, revisits the important study by Hercowitz (1981), who uses German hyperinflation data to examine the ability of his extended version of Lucas's (1973) model of imperfect information to explain the observed relationship between relative price dispersion and inflation. Hercowitz modifies Lucas's model by interpreting each "island" to be the market of a specific commodity, each commodity having its own excess demand elasticity in its market. Due to different demand elasticity across the markets, money shocks affect the price of each commodity differently. Therefore, relative dispersion is positively related to the magnitude of these shocks, not just the variance of these shocks.

We extend Hercowitz's empirical work in four ways. First, and most importantly, we use the identified VAR model in the first step to identify money supply shocks. In particular, we exploit the plausibility of long-run monetary neutrality to identify money supply shocks in the context of the VAR. Long-run monetary neutrality is consistent with most macroeconomic models, and perhaps qualified as a stylized fact. This set of identifying restrictions has been shown to yield plausible results regarding the response of the macro economy to money supply shocks. (Lastrapes and Selgin (1995), Lastrapes (1998), Loo and Lastrapes (1998), and Christiano et al. (1999)) This approach is likely to provide better estimates of money supply shocks than Hercowitz's ad hoc methods.

Second, we use updated U.S. data on relative prices, rather than the German hyperinflation period. Third, in addition to the role of money shocks, we consider the role of productivity shocks in explaining the determinants of relative price dispersion, which are ignored in Hercowitz's work. These shocks are also identified using a plausible long-run restriction, as in Gali et al. (2003): only productivity shocks can have long-run effects on measured productivity. And finally, we allow for the possibility that aggregate shocks have asymmetric effects on dispersion, depending on whether they are positive or negative. The main objective of chapter 3, then, is to refine our understanding of Hercowitz's model of the determinants of relative price dispersion.

While the analysis of chapter 3 is a potential improvement on previous studies, it follows these studies by focusing attention on the *sample moments* of the cross-sectional distribution of relative prices. That is, the cross-sectional sample moments are first computed from the data at each point in time, and are then regressed on potential explanatory variables such as the magnitude of money supply shocks or money variance. But this approach potentially ignores important information contained in the entire distribution of relative prices. Chapter 4 tries to incorporate this information into the analysis by estimating the response of the entire distribution of relative prices to exogenous money supply and productivity shocks. From this estimation, we can infer the behavior of the moments of the distribution, and better determine the uniformity of the responses across markets.

To fix ideas and to illustrate the nature of our approach, suppose that there are n markets, each of which determines the real equilibrium price p_{it}, and that each price is linearly related to a common factor, say x_t:

$$p_{it} = b_i x_t + e_{it}, \quad i = 1, \cdots, n \tag{1}$$

Such an equation is the implication of typical theoretical models in this literature, such as Hercowitz (1981, equation 13) and Bakhshi (2002). In principle, the effect of the common factor x on the distribution of relative prices can be estimated by running n time regression to determine each of the $\hat{a}$s, and then considering the cross-sectional distribution of these coefficients. For example, the sample standard deviation of $\hat{a}$s measures the uniformity of the responses of relative prices to x, that is, the effect of x on the dispersion of relative prices.

The common approach in the literature is to first compute the relevant cross-sectional moment of the price distribution, say the variance RPV, and then run a regression of the following form (see Hercowitz 1981), equation 14 and Bakhshi 2002, equation 4):

$$RPV_t = b x_t^2 + e_t \tag{2}$$

The presumed reason for the common approach is its tractability. But clearly, the former approach is more general and potentially informative, since it provides direct estimates of the relevant effects on the entire distribution of relative prices.

In chapter 4, we use the former strategy to estimate the effect of aggregate shocks on the dispersion and skewness of relative prices, but extended to a dynamic setting. In particular, we estimate a disaggregated VAR that contains each of the industry-level prices, in addition to aggregate variables. From this system, we compute the dynamic multipliers (or impulse response functions) for each of the individual prices with respect to money supply and productivity shocks. In this sense, we obtain the response of the *entire distribution* of relative prices. From this distribution of responses, we can compute summary measures, such as sample standard deviation and skewness.

This approach has several advantages over prior methods. Assuming linearity, it incorporates all the information about individual price responses to underlying shocks, unlike methods that directly estimate effects on sample moments. Importantly, directly estimating the response of prices to common shocks allows us to isolate the distinct underlying shocks that jointly effect all the moments of the relative price distribution. That is, the approach facilitates treatment of the potential simultaneity between, say, relative price dispersion and inflation. In addition, the approach allows straightforward computation of any moments from the distribution, so the effect of shocks on dispersion and skewness can be inferred from the same estimated model. Finally, the VAR model provides a natural framework for estimating the response of dispersion and skewness to underlying shocks over time – these measures can be computed for each forecast horizon used for the impulse response functions. Such dynamics are typically ignored in the literature.

The primary disadvantage of this empirical strategy is that estimating a fully unrestricted VAR is problematic for a large number of individual markets or industries, yet including a large sample of industries is essential for obtaining precise estimates. To make the disaggregate VAR feasible for a large industry sample, we follow Loo and Lastrapes (1998) by estimating a restricted VAR. We assume that individual industries are independent of each other at all lags after conditioning on the aggregated variables in the system, and that these aggregated variables are independent of the individual industries. The latter assumption implies that the sub-system of aggregate variables can be estimated efficiently independently of the industry prices, while the former implies that the industry-level price responses can be inferred from individual regressions of these prices on their own lags, and the contemporaneous and lagged values of the aggregate variables. As in chapter 3, we identify money supply and productivity shocks using the appropriate infinite-horizon restrictions discussed above, applied to the independent subsystem of macro variables.

CHAPTER 2

LITERATURE REVIEW

The sources and costs of inflation are often linked to the theoretical and empirical evidence on the relationship among the cross-sectional moments of relative prices, and there is a substantial amount of research on the changes of relative prices and inflation. Most of the research has focused on inflation and the dispersion of relative prices, or more precisely, the relationship between the first and the second moments of the cross-sectional distribution of relative prices over time.

There are neoclassical and new Keynesian theories to explain this relationship, and both predict the positive relationship between inflation and the relative prices dispersion. Shocks such as the OPEC shock or money supply shock cause the uneven changes in relative prices through the difference of supply elasticities or the existence of menu costs among the firms, and the overall price level is rising as relative prices become more volatile. The majority of empirical studies report evidence of the positive relationship between these two variables, but a significant amount of studies show that negative or no relationships are also possible.

Meanwhile, Ball and Mankiw (1995) revived interest in the asymmetric nature of the distribution of relative prices. The skewness of the distribution of relative prices, according to their conclusions, does a better job of explaining the sources of inflation than the variance. This chapter consists of two parts reviewing the theoretical aspects and empirical evidence of two important tools in explaining inflation and the relative prices behavior, dispersion and skewness.

2.1 Dispersion of Cross-sectional Distribution of Relative Prices

Early studies by Mills (1927) and Graham (1930) show that inflation and the dispersion of relative prices are positively related. After analyzing the U.S. wholesale price index, Mills (1927) suggests that "it may be that dispersion depends upon the violence of the price changes, regardless of direction." Graham (1930) extends Mills' study by adding the role of unexpected changes in prices from the German hyperinflation data. He argues that individual prices tend to disperse when the price begins to increase unexpectedly.

To explain the sources of inflation and the relative price changes, Lucas (1973) and Barro (1976) show that the aggregate demand shocks increase the dispersion of relative prices by making the prices prediction more uncertain. If there is greater variability of aggregate demand shocks, more real local shocks are interpreted as aggregate shocks. Accordingly, individual firms change their output level less in response to all shocks including the real local shocks. As the quantity supplied becomes less variable, more price adjustments are made and relative prices will become more dispersed with this price adjustment. This implies that the increase in the inflation variability caused by the aggregate shocks leads to the higher level of cross-sectional price dispersion.

Hercowitz (1981) and Cukierman (1979) extend the Lucas-Barro model by introducing the price elasticity of supply across the firms. Aggregate demand shocks affect the dispersion of relative price when the firms have different price elasticities of supply. Firms with a higher price elasticity of supply become less willing to adjust prices given aggregate demand shocks than firms with lower price elasticity of supply. As the aggregate shocks cause inflation, the dispersion of cross-sectional prices increases due to the different price elasticities of supply among the firms. It implies a positive relationship between inflation and the dispersion.

In Hercowitz's (1981) model, the difference between actual price and expected price is defined as the locally perceived relative price for each market. The difference in the supply elasticities of each good is due to the assumption of heterogeneous production functions in individual industries. By defining demand and supply in each market, and solving them for market clearing condition with money equation, the actual relative price from the model is obtained by the method of undetermined coefficients as follows:

$$P_t(z) - P_t = (1-q)\tilde{l}(z)\tilde{m}_t + [q + l(z)(1-q)]e_t(z) \qquad (3)$$

where $\tilde{l}(z) \equiv l(z) - l$ and $q \equiv s_m^2/[s_m^2 + (1/l)s_e^2]$. $l(z)$ is the reciprocal of sum of demand and supply elasticities in each market. s_m^2 is the variance of money stock, and s_e^2 is the variance of excess demand shift term. The realized values of the unexpected money supply appear in equation (3), and this is due to confusion between general money disturbance and local excess demand shift. Part of money shock is perceived by mistake to be a change of local excess demand.

The variance of relative price can be derived from equation (3), which is defined as $t_t^2 = 1/N\Sigma_{z=1}^{N}[P_t(z) - P_t]^2$.

$$t_t^2 = \{(1-q)^2 s_l^2 + [q + l(1-q)]^2\} s_e^2 + (1-q)^2 s_l^2 \tilde{m}_t^2 \qquad (4)$$

To test this equation empirically, a measure of relative prices dispersion needs to be obtained from price indexes of different industries. This variance is calculated from the levels of the price indexes, but long-run technological effects can have a long-run effect on relative prices dispersion.

To avoid this problem, price dispersion with the rate of change variables can be used as follows:

$$t_t^2 \equiv \frac{1}{N}\sum_{z=1}^{N}\{[P_t(z)-P_{t-1}(z)]-(P_t-P_{t-1})\}^2 \qquad (5)$$

which follows as

$$t_t^2 = 2(1-q)^2 s_l^2 s_e^2 + 2[q + l(1-q)]^2 s_e^2 + (1-q)^2 s_l^2 (\tilde{m}_t - \tilde{m}_{t-1})^2 \qquad (6)$$

Equation (6) is the final relative prices dispersion equation to be estimated from the model. It deals with the relative prices dispersion by the rate of changes of prices, the appropriate money shocks is the magnitude of changes in $\tilde{m}_t$. Based on these equations, actual regression models are introduced with empirical results in chapter 3.

Menu costs explain the positive relationship between the relative price dispersion and inflation without the assumption of imperfect information. Sheshinski and Weiss (1977) and Rotemberg (1982, 1983) utilize menu costs to derive this positive relationship. According to menu cost theory, it is costly for the firms to adjust their prices continuously because of the need of some fixed cost for the price adjustments. Therefore, the firms do not adjust prices unless the price changes exceed their (S, s) pricing boundaries. If a firm realizes that the real price drops below to its lower bound s, it changes the price up to the upper bound S. With this price adjustment mechanism, there is no synchronized price adjustment among firms. With the aggregate shocks, the dispersion of relative prices is increasing due to the different responses from the firms with different pricing boundaries.

Vining and Elwertowski's (1976) seminal study is the first modern literature regarding the relationship between higher moments of the cross-sectional distribution of relative prices and inflation. They used the wholesale price index on 100 items between 1947 and 1974, and found the positive relationship between the dispersion and inflation. The dispersion has been the focus of most studies following them. Parks (1978) shows that the unexpected inflation is positively related to the cross-sectional variability of relative prices, using a multisectoral equilibrium framework. He uses the extensive U.S. database between 1929 and 1975, and confirms Vining and Elwertowski's (1976) results.

Numerous empirical studies on the positive relationship between inflation and the dispersion of relative prices can be found in past decades. The following are a few notable ones. Hercowitz (1981) includes money supply shock in the estimation of the dispersion of relative price, and shows the positive relationship with inflation. Cukierman and Wachtel (1982) use the rational partial information framework, an extended version of the Lucas signal-extraction model, and confirm the positive relationship. Balk (1983) reports the positive relationship with the different levels of price data aggregation. Marquez and Vining (1983) use the U.S. data between 1948 and 1975, confirming the positive relationship. They test the causality between inflation and the dispersion, and find no causality. Sellekaertz and Sellekaertz (1984, 1986) show that both expected and unexpected inflations have a positive relationship with the dispersion of relative prices. Jaramillo (1999) verifies Parks' (1978) results with the introduction of asymmetric responses of the dispersion of relative prices to the positive and negative inflations.

The well-established positive relationship between inflation and the dispersion of relative prices has been continuously challenged in many ways. Some studies report the strong negative relationship between inflation and the dispersion of relative prices. Hesselman (1983) uses the U.K. data and finds the negative relationship with the inclusion of output and unemployment variables in the estimations. Tommasi (1991) shows the strong negative relationship between inflation and the dispersion during the deflationary period in Argentina. Reinsdorf (1994) reports the negative relationship for the U.S. during the Volker deflation period. Silver and Ioannidis (2001) investigate the prices of nine European countries with the full range of exogenous macroeconomic variables. Their results from the coefficient of variation as the measure of the dispersion support the negative relationship. Results from the empirical models in both essays in this dissertation are used to support one of the above two contrasting empirical results.

Some studies argue that energy prices eliminate or weaken the strong positive relationship between inflation and the cross-sectional dispersion. Fischer (1981) suggests that the huge peaks are generated by OPEC shocks, and these shocks have a strong effect on the relationship between inflation and the dispersion of relative prices. Taylor (1981) also shows that the energy shocks are the driving force of the positive relationship. Bomberger and Makinen (1993) also show that the positive relationship between inflation and the cross-sectional dispersion disappears when the data from both OPEC shocks in 1974 and 1980 are excluded. They conclude that the positive relationship is dominated by the OPEC supply shocks.

Disaggregation of relative prices data is another important issue for the robustness of the empirical models. Danziger (1987) shows that the aggregation of the price data makes the relationship between inflation and the dispersion stronger than commonly supposed. He concludes that the highly disaggregated data show consistent results with those from the aggregated data. Disaggregation also explains part of the role of energy prices in contributing to the positive relationship between inflation and the dispersion. Chang and Cheng (2000, 2002) are able to reinstate Parks' results after controlling the OPEC shocks as outliers. They employ the very highly disaggregated price data with 203 subcategories to measure the dispersion of relative prices, and show the results of Bomberger and Makinen (1993) are sensitive to the levels of disaggregation and sample intervals.

2.2 Skewness of Cross-sectional Distribution of Relative Prices

Vining and Elwertowski (1976) are often cited in many studies on the positive correlation between inflation and the dispersion of the cross-sectional distribution of relative prices. However, they also suggest some evidence on the higher moments of the distribution in explaining the inflation behavior. With a positively skewed distribution, the inflation level is rising, and vice versa. When the prices change rapidly, the distribution tends to be skewed more, and cause higher inflation. In this period of the rapid price changes, the dispersion of relative prices is also increasing, and therefore inflation, the dispersion, and the skewness are expected to move in the same direction. This implication is examined in the empirical results in chapter 4.

Recent studies show that the skewness has a stronger explanatory power to the inflation behavior than the conventional dispersion measure of the cross-sectional relative prices. There are two separate approaches to explain the role of the cross-sectional skewness of the distribution of relative prices changes. Ball and Mankiw (1995) use menu cost theory to illustrate the positive correlation between inflation and the skewness of the relative price distribution. The sticky prices play a critical role in their model when the firms with skewed distribution face aggregate shocks. Balke and Wynne (2000) show the same positive correlation with perfectly flexible prices. They show that the productivity shocks are responsible for the positive mean-skewness relation.

The sticky price model by Ball and Mankiw (1995) assumes that the firms set their prices in the first period, and pay menu costs to change their prices in the next period. They face a mean-zero real shock with an asymmetric distribution. As menu costs exist, not all the firms adjust their prices according to the shocks. With this setting, the distribution of real shocks explains the direction of the aggregate price level. If the distribution of the real shocks is positively skewed, a few firms face large shocks and most firms have small shocks in the mean-zero distribution. As firms respond more quickly to the large shocks than the small shocks under the menu cost assumption, a few firms increase their prices and the overall prices are increasing. In short, the asymmetrical distribution of the cross-sectional relative prices causes the uneven responses of price changes among the firms from the shocks, and the fluctuation in inflation.

Ball and Mankiw (1995) can explain the OPEC shocks with this approach. The large increases in the prices of oil-intensive items create positive skewness in the distribution, and inflation rises. Bryan and Cecchetti (1999) point out that the positive relationship between inflation and the skewness by menu costs should be short-lived. In the long run, all firms adjust to their relative price shocks, and the correlation disappears.[2]

Balke and Wynne (2000) use a general equilibrium multi-sector model with flexible prices and money. Productivity shocks have two ways to affect the economy in their model. First, the productivity shock changes the aggregate output level, and the change in the aggregate

[2] Bryan and Cecchetti (1999) criticize the argument of Ball and Mankiw (1995) on the basis of small sample bias. If the sample size is small, the mean and the skewness in a distribution have to have a positive relationship.

output causes the changes in the aggregate price level. Second, through the input-output structure of the economy the productivity shock creates different effects on different sectors in the economy. The price in each sector changes differently according to the degree of the impact by the productivity shock on its average productivity. The cross-sectional distribution of relative prices is skewed due to the asymmetric input-output structure of the economy.

Using this setup, they can show the positive mean-skewness correlation. If a larger productivity shock hits the economy, the larger change of the aggregate price level happens. With the fixed coefficients of the input-output matrix, the larger productivity shock to the different sectors causes a more skewed effect on the cross-sectional distribution of relative prices. Putting these two arguments together, the positive correlation between inflation and the skewness is derived. In contrast to Ball and Mankiw (1995), the effect of the productivity shock needs not disappear in the long run, because this change is more likely coming from real shocks.

The contributions of this dissertation to the study of the relationship between inflation and the moments of cross-sectional distribution of relative prices are threefold. 1) Most previous studies assume an implicit causal relationship between inflation and the higher moments. They also fail to identify the aggregate shocks as the true sources of inflation and the moments of the cross-sectional price distribution. By using the VAR system, this dissertation identifies the aggregate shocks and shows their effects on relative prices and inflation. 2) To this end, this study is the first to utilize the VAR models with long-run restrictions and other macroeconomic variables in studying the effects of the aggregate shocks on the distribution of relative prices. 3) Previous studies use the moments of the distribution directly to investigate the relationship between inflation and the higher moments of the distribution. This study uses disaggregated individual prices to reflect the effect of the aggregate shocks on each sector, and impulse responses from these individual prices construct the higher moments.

CHAPTER 3

TIME SERIES EVIDENCE OF AGGREGATE SHOCKS TO RELATIVE PRICES

3.1 Introduction

Aggregate money supply shocks can change the relative prices, and the changes in relative prices cause the distortions in the economy. It is important to understand how aggregate shocks affect relative prices, and cause distortion of the resource allocation system. Hercowitz (1981) extends the imperfect information theory by Lucas (1973) and Barro (1976) to show that unexpected aggregate demand shocks affect relative prices. He also shows that the magnitude of aggregate demand shocks is positively related to variability of relative prices. This study tries to provide better understanding of the relationship between aggregate shocks and relative prices with new empirical evidence based on Hercowitz's study.

The objective of this chapter is to extend Hercowitz's empirical results, and shed light on some theoretical explanations of relative prices with the results. Imperfect information theory assumes that unanticipated money shock will affect the relative prices. The extension of Hercowitz's model will try to support imperfect information theory by showing that an unanticipated money supply shock has real effects on the relative prices.

I analyze time series evidence of aggregate shocks to the sample moments from the cross-sectional distribution of the relative goods prices. The aggregate shocks are the sources of this relationship, and money supply shock and productivity shock are used as aggregate shocks.

Hercowitz's idea is to show the time series evidence of the effect of money supply shock on relative variability. This study will begin by replicating his model, and extend Hercowitz's model in four ways. First, this study uses a longer range of sample data, and U.S. data instead of German hyperinflation data.[3]

Second, a VAR is used to identify money supply shocks instead of following Hercowitz's methods. Hercowitz derives the unanticipated money supply shock as the residuals from his linear regression equation on money. While his method is a partial analysis, a VAR allows full interactions of all macroeconomic variables along with money variables, and long-run restrictions used in the VAR incorporate money neutrality conditions on the economy. The VAR in this study will identify money supply shock better than Hercowitz's model.

Third, Hercowitz ignores the role of real aggregate shocks such as common productivity shocks. By adding productivity into the VAR, this study allows the productivity shock to have a role in explaining the changes in relative prices. Hercowitz argues that the productivity shock makes only a minor contribution to explaining changes in relative prices, and is mixed with errors in estimation equations. The statistical significance of productivity shocks in the results of this study will determine whether productivity shocks have significant impacts on the economy. I will include both the estimated money supply shocks and productivity shocks in the second-stage regression to explain relative dispersion. If productivity shocks do not have any significant role in explaining relative dispersion, this verifies Hercowitz's assumption of omitting productivity shocks from the list of explanatory variables.

Lastly, this extended model attempts to test asymmetric responses of relative dispersion according to negative and positive aggregate shocks. Jaramillo (1999) explores the possibility of asymmetric responses of relative dispersion to negative and positive inflation. According to his

[3] Hercowitz (1982) uses U.S. data for the relative dispersion and money shocks.

results, negative inflation has greater impact on the magnitude of relative dispersion by more than four times. Downward price rigidity explains this result due to the reluctance of downward price adjustment in some industries. Considering the positive relationship between money supply shock and inflation, this study will test the asymmetric responses of relative dispersion to positive and negative money supply shocks.

There are two ways to see the effects of aggregate shocks on relative prices. First is to extended the models in Hercowitz (1982) with aggregate shocks directly identified from the five-variable macroeconomic VAR. The second method is to use the disaggregated VAR by including all prices from individual markets with aggregate macroeconomic variables. Dynamic responses of the sample moments of relative price distributions will be derived from the responses of individual prices. This will be explained in detail in chapter 4.

Hercowitz (1982) analyzes the relationship between money supply shocks and relative dispersion by regressing the relative dispersion on money supply shocks and some other variables. Following his approach, I will use the estimated aggregate shocks to explain the time series behavior of sample moments to see the effects of sample moments on aggregate shocks. Asymmetric responses of sample moments from negative and positive money shocks can be also considered in this framework. By splitting money supply shock into two parts according to their signs, and including them together in the estimation equations, I can show the relative magnitude of responses of sample moments to these shocks.[4]

This chapter begins with the introduction of the five-variable macroeconomic VAR model to derive estimated aggregate shocks. It identifies the shocks with long-run neutrality restrictions. The data are described and the measures for the dispersion and the skewness are specified. Unit root tests for the variables and the model specification by the model selection criteria are performed to determine the proper lag length for the system. After estimation, the impulse responses of the variables to the money and productivity shocks are reported, and the relationship between inflation and the dispersion is verified with the summary of regression results.

3.2 Empirical Methods

3.2.1 VAR and Identification

This study uses a structural VAR model with long-run identifying restrictions.[5] Macroeconomic variables including monetary aggregates, interest rate, and output will be used to isolate and identify aggregate shocks with a set of valid identifying restrictions. Money supply shock and productivity shock, representing nominal shocks and real shocks respectively, are two types of structural disturbances to determine the sources of fluctuations in real and nominal macroeconomic variables.

Long-run identifying restrictions are sufficient to identify these two structural disturbances from the reduced-form VAR. To identify a money supply shock, a long-run monetary neutrality restriction is imposed. It assumes that a permanent money supply shock has no effect on the real variables in the long run. This long-run monetary neutrality restriction will

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[4] Parks (1978) and Jaramillo (1999) utilize dummy-adjusted inflation to specify the asymmetric response of dispersion to the aggregate shocks. Negative inflation reflects a negative money shock to the economy, and a positive money supply shock is assumed to generate positive inflation in their studies.

[5] See Blanchard and Quah (1989), and King et al. (1991) for their pioneering studies of this approach.

suffice for identifying the money supply shocks.[6] Another long-run restriction is used to identify productivity shock. Unlike a monetary neutrality restriction, a long-run restriction on productivity shock assumes that in the long run labor productivity is affected by productivity shock only. According to Gali et al. (2003), this restriction fits a broad range of business cycle models under standard assumptions. After identifying these two long-run restrictions, I can examine the dynamic responses of real variables in the VAR.

Fischer (1981) was the first to introduce the VAR approach in analyzing the dispersion of relative prices. He used six variables and eight variables including M2, inflation, the dispersion of relative prices, the growth rate, the T-bill rate, the full employment surplus divided by GNP, and energy and food price indexes. Fischer's VAR is one of the earliest applications of VAR technique and cannot reflect recent methodological developments such as long-run neutrality restrictions. Parsley (1996) checks the persistence of the effect of the aggregate shocks on inflation and the dispersion. For the relationship between the skewness of the cross-sectional distribution and inflation, Ratfai (2003) uses a bivariate structural VAR model with long-run restrictions. He uses inflation and the skewness in his model, and shows the positive relationship between inflation and the skewness at the store prices level. The advantage of the structural VAR is that it can identify the underlying aggregate shocks without imposing strong constraints on the joint dynamics of the variables in the system.

The vector of endogenous variables is defined as

[6] Faust and Leeper (1997) criticize the use of long-run monetary neutrality restrictions. Lastrapes (1998) shows that the long-run neutrality restrictions can survive the robustness problem suggested by Faust and Leeper.

$$\Delta x_t = \begin{bmatrix} \Delta a_t \\ \Delta y_t \\ \Delta r_t \\ \Delta m_t \\ \Delta M_t \end{bmatrix} \tag{7}$$

where Da_t is labor productivity, Dy_t is output, , Dr_t is the nominal yield-to-maturity on bonds, Dm_t is real money stock, and DM_t denotes nominal money stock. D means that all variables are logged and first-differenced. a_t is the difference between the log of GDP and the log of total employee hours in nonagricultural establishments.[7] As mentioned above, productivity is ordered first and nominal money is ordered last in this vector to reflect the long-run restrictions condition for money and productivity shocks.

The structural-form VAR with these variables is described as

$$A_0 \Delta x_t = A_1 \Delta x_{t-1} + A_2 \Delta x_{t-2} + \cdots + A_p \Delta x_{t-p} + u_t \tag{8}$$

where u is a 5×1 vector with mean-zero, serially uncorrelated shocks to the behavioral equations.

Equation (8) is rearranged as a moving average representation to describe the dynamic relationship with the endogenous variables in Dx_t from the structural shocks.

$$\begin{aligned} \Delta x_t &= (A_0 - A_1 L - A_2 L^2 - \cdots - A_p L^p)^{-1} u_t \\ &= (D_0 + D_1 L + D_2 L_2 + \cdots) u_t \\ &= D(L) u_t \end{aligned} \tag{9}$$

where $D(L)$ is a square summable lag polynomial matrix with stable roots. To normalize the scale of each shock, $Eu_t u_t'$ is set to an identity matrix. The model is first-differenced to impose stationarity if the elements of x_t have unit roots. With this assumption, the shocks have permanent effects on the levels of the endogenous variables. Direct estimation of the equation (8) is not possible because it is a structural-form VAR.

The reduced-form representation of the VAR from the structural form is as follows:

$$\Delta x_t = B_1 \Delta x_{t-1} + B_2 \Delta x_{t-2} + \cdots + B_p \Delta x_{t-p} + e_t \tag{10}$$

where $B_t = A_0^{-1} A_t$, $e_t = A_0^{-1} u_t$, and $E e_t e_t¢ = S = A_0^{-1} A_0^{-1}¢$.

From (10),

$$\begin{aligned} \Delta x_t &= (I - BL - B_2 L^2 - \cdots - B_p L^p) e_t \\ &= (I + C_1 L + C_2 L^2 + \cdots) e_t \\ &= C(L) e_t \end{aligned} \tag{11}$$

C(L) and S are estimated from the reduced-form VAR in equation (10), if the conditions for the invertibility are satisfied. The structural parameters in equations (8) and (9) cannot be recovered from the reduced-form VAR without more restrictions added to the structural model, as the correspondence between these two forms can be more than one. Long-run restrictions at the infinite horizon of a money supply shock or a productivity shock are used as restrictions for this identification problem.

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[7] The dispersion and the skewness are calculated from the level of prices. Therefore, they need to be differenced.

Following are the relationships of the original structural form and the matching reduced form. From equation (11),

$$C(L)e_t = C(L)A_0^{-1}u_t \,, \qquad (12)$$

This means the following relationship:

$$D(L) = C(L)A_0^{-1} \qquad (13)$$

where $D_0 = A_0^{-1}$. From equation (13),

$$D(1) = C(1)D_0 \qquad (14)$$

where $D(1) = \sum_{t=0}^{\infty} D_t$

From the above derivation, the final relationship between two forms of VAR is

$$D_i = C_i D_0 = C_i C(1)^{-1} D(1) \qquad (15)$$

$$D(1)D(1)' = C(1)D_0 D_0' C(1)' = C(1)\Sigma C(1)' \qquad (16)$$

D(1), the matrix of infinite-horizon dynamic multipliers for the levels of endogenous variables, x_l, can be written as

$$D(1) = \lim_{k \to \infty} \frac{\partial x_{lt}}{\partial u_{t-k}} \tag{17}$$

Two long-run identifying restrictions are imposed. For the identification of the money supply shock, a long-run neutrality restriction is used. Exogenous money supply shocks have no permanent impact on the level of real economic variables, but permanently affect the nominal money stock. This means that the money supply shock has no permanent impact on a_t, r_t, y_t, and m_t, and affects only M_t permanently. With this restriction, the last column of *D(1)* will be all zeros except for the last element. Price level response is calculated from the difference between the response of m_t and the response of M_t. Price level will be proportionally affected by a nominal money supply shock in the long run. Long-run money shock will not impact a_t, r_t, and y_t permanently by the long-run neutrality assumption.

To identify productivity shock, a long-run restriction on productivity is imposed. Only the productivity shock has a permanent effect on the labor productivity, a_t. In the long run, the shocks from r_t, y_t, m_t, and M_t will not have an impact on productivity. The first row of *D(1)* will be all zeros except for the first element.

The identifying restrictions are given by

$$D(1) = \begin{pmatrix} d_{11} & 0 & 0 & 0 & 0 \\ d_{21} & d_{22} & d_{23} & d_{24} & 0 \\ d_{31} & d_{32} & d_{33} & d_{34} & 0 \\ d_{41} & d_{42} & d_{43} & d_{44} & 0 \\ d_{51} & d_{52} & d_{53} & d_{54} & 0 \end{pmatrix} \tag{18}$$

It is important that the productivity shock should be ordered first, and the nominal money supply should be ordered last to achieve identification. Since productivity is ordered first and the nominal money last, the productivity shock will be the first one and the money supply shock will be the last one. I need only to identify the first column and the last column of each of the D_i. What I want to show is, therefore, that the zero restrictions in *D(1)* above are sufficient to identify the first column of D_i for all *i*, and the last column of D_i for all *i*. From equation (15), this means that I need to identify only the first column of *D(1)* because this will fully identify the first column of D_0, and in the same way the last column of *D(1)*.

To show how the first column of *D(1)* is identified, I partition *D(1)* and *R*, where *R* is the lower triangular Cholesky factor of *C(1)SC(1)¢*.

$$D(1) = \begin{pmatrix} d_{11} & 0 \\ D_{21} & D_{22} \end{pmatrix} \tag{19}$$

$$R = \begin{pmatrix} r_{11} & 0 \\ R_{21} & R_{22} \end{pmatrix} \tag{20}$$

where D_{21} is 4 by 1, ***0*** is 1 by 4, and D_{22} is 4 by 1. The submatrices in *R* have the same dimension, but R_{22} is lower triangular while D_{22} is not restricted at all. Equation (16) implies that

$$D(1)D(1)' = RR' \tag{21}$$

By multiplying both sides out using the partitions,

$$D(1)D(1)' = \begin{pmatrix} d_{11} & 0 \\ D_{21} & D_{22} \end{pmatrix} \begin{pmatrix} d_{11} & D'_{21} \\ 0 & D'_{22} \end{pmatrix} = \begin{pmatrix} d^2{}_{11} & d_{11}D'_{21} \\ d_{11}D_{21} & D_{21}D'_{21} + D_{22}D'_{22} \end{pmatrix} \tag{22}$$

$$RR' = \begin{pmatrix} r_{11} & 0 \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} r_{11} & R'_{21} \\ 0 & R'_{22} \end{pmatrix} = \begin{pmatrix} r^2{}_{11} & r_{11}R'_{21} \\ r_{11}R_{21} & R_{21}R'_{21} + R_{22}R'_{22} \end{pmatrix} \tag{23}$$

From (21), (22) and (23), $d_{11} = r_{11}$ and $D_{21} = R_{21}$. Therefore, the first column of *D(1)* is completely identified from the Cholesky factor of *C(1)SC(1)¢*, even though *D(1)* is not itself fully lower triangular. Given that the first column of *D(1)* is known, the first column of all D_i can be inferred. By a similar deduction, I can show that making the zero restrictions in the last column of *D(1)* is sufficient to identify the last column of D_i from the same Cholesky factor.[8]

I partition the long-run multiplier matrix *D(1)* as

$$D(1) = \begin{pmatrix} D_{11} & 0 \\ D_{21} & d_{22} \end{pmatrix} \tag{24}$$

where D_{11} is 4 by 4, ***0*** is 4 by 1, D_{21} is 1 by 4, and d_{22} is a scalar. From the ordering of the variables in the VAR, ***0*** implies monetary neutrality. Note that D_{11} is not restricted to being a lower triangular, *D(1)* is not lower triangular, but it is block recursive. From the correspondence between reduced and structure form, infinite-horizon multipliers are related to the zero-frequency covariance matrix from the VAR as follows:

$$D(1)D(1)' = C(1)D_0 D_0' C(1)' = C(1)\Sigma C(1)' \qquad (25)$$

I define R as the Choleski factor of the right-hand-side matrix of equation (25). Then, equation (25) can be rewritten as

$$RR' = C(1)\Sigma C(1)' \qquad (26),$$

where R is lower triangular. I partition R to conform with $D(1)$, and combine equations (25) and (26) to have the following equation:

$$\begin{pmatrix} D_{11}D_{11}' & D_{11}D_{21}' \\ D_{21}D_{11}' & D_{21}D_{11}' + d_{22}^2 \end{pmatrix} = \begin{pmatrix} R_{11}R_{11}' & R_{11}R_{21}' \\ R_{21}R_{11}' & R_{21}R_{11}' + R_{22}R_{22}' \end{pmatrix} \qquad (27)$$

where R_{11} is lower triangular, and the values of R are known from the estimation of the VAR.

If I can define d_{22} as a function of the partitioned matrices in R, I uniquely identify d_{22} given long-run monetary neutrality. From equation (27),

$$D_{11}D_{21}' = R_{11}R_{21}' \qquad (28)$$

[8] This follows the proof in the appendix of Lastrapes (1998).

From equation (27) and (28),

$$R_{21}R'_{21} = R_{21}R'_{11}(R_{11}^{-1})'R'_{21} = D_{21}D'_{11}(R_{11}^{-1})'R_{11}^{-1}D_{11}D'_{21} . \quad (29)$$

Equation (27) also implies that

$$D_{11}D'_{11} = R_{11}R'_{11} . \quad (30)$$

I premultiply by D_{11}^{-1}, postmultiply by $(D'_{11})^{-1}$, then invert to get

$$D_{11}(R_{11}^{-1})'R_{11}^{-1}D_{11} = I . \quad (31)$$

By substituting equation (31) into equation (29), I obtain

$$R_{21}R'_{21} = D_{21}D'_{21} . \quad (32)$$

Combining equation (32) and (27) shows that

$$d_{22} = R_{22}R'_{22} . \quad (33)$$

This result shows a unique identification of d_{22}, with the assumption of money neutrality, $D_{12}=0$.

Using the long-run restrictions of monetary neutrality seems quite popular in recent research, because it requires the minimum level of restrictions for identifying the model, and it is based on the well-established "quantity theory of money." The long-run restriction on the productivity shock used in this model is relevant for most business cycle models, as a part of standard assumptions.

Faust and Leeper (1997) suggest that this intuitively convenient restriction has a robustness problem according to how one chooses the statistical model for the restrictions, and some finite restrictions have to be used instead of a long-run restriction. Lastrapes (1998) examines the robustness of the long-run neutrality by comparing the long-run neutrality restrictions and some long- but finite-horizon restrictions. His finding is that the results from these two different restrictions are close enough in his case to use the long-run restrictions without justifying Faust and Leeper's criticism.

3.2.2 Data

To calculate the dispersion and the skewness of the cross-sectional distribution of relative prices used in this study, I obtained producer price index (PPI) data between 1947:01~2002:12 from the Bureau of Labor Statistics. The inflation rate is calculated from the log difference of the mean of subindex PPIs. The number of subindexes is 64 in total at the three-digit level, and this is over 60% of the total 105 subindexes in the PPI all-commodities price index. The codes of these indexes are listed in appendix 1.

This dissertation uses unweighted measures for the dispersion and the skewness, because the weights for the subindexes of PPI are not available in the monthly data. The cross-sectional mean of the rates of price change is described as

$$\Delta p_t = \frac{1}{k}\sum_{i=1}^{k}\Delta p_{it} \quad (34)$$

where p_{it} is the logarithm of the price index of subindex i for year t. $Dp = p_{it} - p_{it-1}$, and k is 64, the number of subindexes.

The dispersion and the skewness are calculated as follows:

$$RD_t = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(\Delta p_{it} - \Delta p_i)^2} \quad (35)$$

$$SK_t = \frac{\frac{1}{k}\sum_{i=1}^{k}(\Delta p_{it} - \Delta p_i)^3}{RD_t^3} \quad (36)$$

An alternative way to measure the cross-sectional sample moments in the price distribution is to use price levels rather than rates of change, as follows.

$$p_t = \frac{1}{k}\sum_{i=1}^{k} p_{it} \quad (37)$$

$$RDL_t = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(p_{it} - p_i)^2} \quad (38)$$

$$SKL_t = \frac{\frac{1}{k}\sum_{i=1}^{k}(p_{it} - p_i)^3}{RDL_t^3} \quad (39)$$

Both measures will be used in analyzing the effects of aggregate shocks on sample moments.

For other macroeconomic variables used in the VAR model, the 3-month US Treasury bill rate is used for proxying the nominal interest rate. Output is measured by the total index of industrial production. Labor hour data are total employee hours in nonagricultural establishments. Productivity is calculated by the log difference between the log output and the log labor hour. M2 is used for aggregate money supply. The real money stock is derived by deflating M2 by PPI. These monthly data between 1964:01~2002:12 were obtained from Economic Data FRED II at the Federal Reserve Bank of St. Louis.

I used the augmented Dickey-Fuller test and the Phillips-Perron test in testing the presence of unit roots in productivity, interest rate, output, real money, and money. If the test statistics is greater than the critical value for rejection, the process is stationary and has no unit root. Table 1 shows that all variables have single unit roots in levels. Lag length is four for the augmented Dickey-Fuller test, which is determined by automatic lag length selection using the Schwarz Information Criterion. Both trend and intercept are included in testing level variables, and only the intercept is included for differenced variables. Lag length for the Phillips-Perron test is five. For testing level variables, trend and intercepts are included, and only the intercept is used for differenced variables. For the possibility of cointegration, the Johanson cointegration test is performed. The test results of cointegration are reported in Table 2, and the max-eigen value test reports that no cointegration is found among these variables at the 1% level.

The deterministic component of the model contains constant and seasonal dummy variables. Akaike Information Criterion and Final Prediction Error methods are used to determine the lag length. As shown in Table 3, the lag length for the model is 13. I adopt Ljung-

Box Q-statistics to see if the residuals from an estimated VAR model behave as a white-noise process, and find no significant autocorrelation among residuals as shown in Table 4.

3.3 Dynamic Responses

3.3.1 Money Supply

Figure 1 reports the dynamic responses of each variable to a money supply shock. The impulse responses of price are calculated by the difference between nominal money responses and the real money responses. To show the degree of sampling error, the figure also reports standard error bands calculated from a bootstrap simulation. Error bands indicate the precision of the coefficient estimates, and they are estimated using the empirical density function from a bootstrap simulation with 500 replications. They are asymmetric because root mean square errors from empirical density are generated separately for simulated realizations that are larger than, and smaller than, the estimated values, following Blanchard and Quah (1989). These results are consistent with the results from the previous literature such as Lastrapes and Selgin (1995), Loo and Lastrapes (1998), and Christiano, Eichenbaum, and Evans (1999).

The responses support the stylized facts about the effects of expansionary money supply shocks. With an unanticipated nominal money shock, its initial effect is an increase in nominal money supply by 0.15% one month after the shock.[9] Its effect on the nominal money supply reaches the maximum level at almost 3% eight months after the shock with a steady state converged at around 3.5% thereafter. The t-bill rate falls in the short run, and gradually approaches the steady-state zero response in the long run. This is a consistent result expected from the liquidity effect by Lastrapes and Selgin (1995). It decreases by 3% one month after the shock, and in the long run gradually approaches to zero. Output shows a positive response in the short run by increasing 2% from the beginning and fades away due to the neutrality restriction with a peak of 5% 15 months after the shock. Real money value increases by 1.5% one month after the shock, and peaks at 3% in 10 months. It gradually fades away to zero in the long run due to long-run money neutrality. The initial response of productivity to money supply shock is negative, with a 3% decrease. It slowly increases and peaks at 2% 15 months after the shock. Since output shows initial positive response to the money shock, this implies that labor hours rise faster than output on impact. The price level is dropped by 0.05% with the initial money supply shock, and decreases more to 0.1% six months after the shock. In the long run, the price level gradually increases up to 0.4%. Nominal money supply increases exactly the same percentage of 0.4%, which is consistent with the monetary neutrality assumption.

3.3.2 Productivity

A restriction on the long-run effect of a productivity shock is imposed in the model. The productivity shock is identified as the only shock that can have a long-run effect on productivity.[10] Figure 2 reports the dynamic responses of each variable to a positive productivity shock. The confidence bands are also constructed from the bootstrap simulation with 500 draws. In the long run, the productivity shock has a permanent positive impact on each variable. This confirms that the productivity shock is a real shock to the economy, compared to the money supply shock, whose effects die off in the long run. The price level is falling in the short run as

[9] All percentage changes are in terms of basis points.
[10] See Gali et al. (2003) for more discussion on the restrictions on productivity shocks.

expected with the productivity shock. In the long run, the price level does not fall very much, because the nominal money stock accommodates the productivity shock.

Productivity is increased by 1% as an initial effect of productivity shock, and reaches the steady-state maximum level of 3% in the long run. The interest rate increases by 2% seven months after the shock, and maintains a 3% steady-state level after that. Output initially increases by 0.5% and is converged to 1% in the long run. Real money maintains the level of 0.7%, and nominal money is starting from 0.2% and approaches 0.6% in the long run. Price is initially falling by 0.25%, and reaches its minimum level of -0.38% 13 months after the shock. In the long run, the effect of productivity shock is diminished, and the rate of price change approaches to negative 0.12%. The price keeps falling with a positive productivity shock, but in the long run its effects are weakened.

3.3.3 Forecast Error Variance Decomposition

Table 5 and Table 6 shows that the variance decomposition for each variable to money supply and productivity shocks to the system to see how much and how long the money and productivity shocks have real effects on other macroeconomic variables. It represents the proportion of the movements in a sequence due to its own shocks versus shocks to other variables. The real effects of a money supply shock exist for a short period of time, and fade away eventually as other variables adjust to shocks.

At the one-month forecast horizon, money supply shock explains about 33% of variation in interest rate on average over the sample. Its effect dies off to about 1% in the long run. Meanwhile, the productivity shock explains about 37% of variation in output at the one-month forecast horizon. In the long run, the relative contribution of the productivity shock to output is still 26%, showing the real effect of the productivity shock to output in the long run.

3.4 Extension of Hercowitz's Empirical Research

3.4.1 Hercowitz's Models

Hercowitz (1981) tests the effects of unanticipated money supply shock on relative dispersion from German hyperinflation. The estimation models are modified from Lucas (1973) and Barro's (1976) imperfect information theory, by allowing excess demand elasticities in each market. In this setup, price dispersion has a positive relationship with the magnitude of unanticipated shocks. A money growth equation is estimated to derive unanticipated and anticipated money supply shocks. In this equation, explanatory variables are current government spending, current exchange rate, and lagged money stock. The final regression model to summarize his whole argument is as follows: the dependent variable is relative price variability, and explanatory variables are the magnitude of unanticipated money supply shock estimated from his money equation, and the variance of money supply

$$RD_t^2 = b_0 + b_{1t}\, \hat{e}^2_{m,t} - b_{2t}\, s^2_{m,t} + e_t \tag{40}$$

where RD_t^2 is relative price variability, $\hat{e}^2_{m,t}$ is estimated squared money shock from the five-variable VAR, and $s^2_{m,t}$ is money variance from the same VAR. In his estimation, b_1 is positive and significant, and b_2 is negative with low explanatory power. Money supply shock has a positive impact on relative price dispersion, and the negative sign for money variance is consistent with a Lucas-type effect of money variance on price dispersion.[11]

He tries to use other economic variables to explain the behavior of relative dispersion such as actual money growth and inflation. Actual money growth turns out to have no effect on relative dispersion, and inflation is somewhat related to relative dispersion. If unanticipated money growth is related to price deceleration and acceleration, Hercowitz's theory expects a positive relationship between relative dispersion and positive/negative inflation.

3.4.2 Extended Empirical Results

I replicate and extend Hercowitz's (1981) model regarding the effect of unanticipated money supply on relative variability. First, money supply shocks and productivity shocks are estimated from the five-variable VAR. Money variance of the unanticipated money supply is calculated from the estimated money supply shocks in the VAR, with dummy variables used in subperiods that have different variance. Second, I run estimation regressions of relative dispersion on money supply shocks, productivity shocks, and money variance. Third, money supply shocks and productivity shocks are separated into positive and negative shocks to see the possible asymmetric responses of relative dispersion on those shocks. Fourth, the same estimations are done with relative dispersion made from price levels, not from difference.

Following is the general regression equation I estimate with negative and positive money supply shocks and productivity shocks. All the regressions in this study are special cases from equation (35) below. Let y_t be the dependent variable, which is either relative dispersion in terms

[11] He also estimates the effect of actual money growth and inflation on relative price variability, and shows these variables have some effects on relative price variability.

of the rate of changes in relative prices or that in levels of relative prices, $\hat{e}_{m,t}$ the estimated money supply shocks from the VAR, $\hat{e}_{p,t}$ the estimated productivity shocks from the VAR, $s_{m,t}$ the estimated standard deviation of the money supply shocks which is estimated from the money equation in the same VAR, and x_t a vector of control variables such as lagged dependent variables.

$$y_t = b_0 + b_1 d_t \hat{e}_{m,t} + b_2(1-d_t)\, \hat{e}_{m,t} + b_3 d_t \hat{e}_{p,t} + b_4(1-d_t)\, \hat{e}_{p,t} + b_5 s_{m,t} + b_6 x_t + e_t \tag{41}$$

where d_t is zero if $\hat{e}_{m,t} \leq 0$ and $d_t = 1$ if $\hat{e}_{m,t} > 0$. d is an indicator variable that will separate positive and negative shocks from $\hat{e}_{m,t}$. This is a general relationship, and can be reduced to some special cases with additional restrictions on the coefficients. First, if $b_1 = b_2$, then the regression becomes linear in $\hat{e}_{m,t}$. I can show this as follows:

$$\frac{\partial y_t}{\partial \hat{e}_{m,t}} = b_1 d_t + b_2(1 - d_t) = b_1 \text{ if } b_1 = b_2 \tag{42}$$

If I use this restriction in equation (41), it is reduced to a linear regression on $\hat{e}_{m,t}$. The $b_3 = b_4$ restriction similarly implies linearity of productivity shocks. As the similar way, if $b_1 = -b_2$, it is equivalent to estimating

$$y_t = b_0 + b_1 \left|\hat{e}_{m,t}\right| + b_3 s_{m,t} + b_4 x_t + e_t \tag{43}$$

To show how these are the same, from equation (43)

$$\frac{\partial y_t}{\partial \hat{e}_{m,t}} = \frac{\partial y_t}{\partial |\hat{e}_{m,t}|} \frac{\partial |\hat{e}_{m,t}|}{\partial \hat{e}_{m,t}} = b_1 \cdot 1 \text{ for } \hat{e}_{m,t} > 0 \tag{44}$$

$$\frac{\partial y_t}{\partial \hat{e}_{m,t}} = \frac{\partial y_t}{\partial |\hat{e}_{m,t}|} \frac{\partial |\hat{e}_{m,t}|}{\partial \hat{e}_{m,t}} = b_1 \cdot (-1) \text{ for } \hat{e}_{m,t} \leq 0 \tag{45}$$

First, I estimate the equation on the effects of negative and positive money shocks with the use of dummy variable d_t, and do the same with the absolute value of $\hat{e}_{m,t}$. For the productivity, $b_3 = -b_4$ will be tested alternatively. In the following regressions, I use two variables for y_t in equation (41). RD_t is relative dispersion from price differences.

To replicate Hercowitz's model, I impose restrictions of $b_1 = b_2$ and $b_3 = b_4 = 0$ and make the money supply shocks squared. RD_t^2 is relative price variability used in Hercowitz, and it is the cross-sectional variance of the rate of changes in relative prices. The regression yields

$$\begin{aligned} RD_t^2 = \underset{(2.94)}{0.0001} + \underset{(2.39)}{2.82}\, \hat{e}_{m,t}^2 - \underset{(0.58)}{2.20}\, s_{m,t}^2 \\ + \underset{(8.48)}{0.39}\, RD^2_{t-1} + \underset{(5.75)}{0.27}\, RD^2_{t-2} + \underset{(3.97)}{0.16}\, RD^2_{t-5} + e_t \end{aligned} \tag{46}$$

Adjusted R^2 = 0.48
DW statistic = 2.02
F-statistic = 81.93

Three lags of dependent variables are used. Lags are selected from auto and partial auto-correlation functions of the dependent variable. The t-statistics of the coefficient estimates are reported in parentheses as the absolute value. As reported in Hercowitz (1981), a money shock has positive effect on relative dispersion, and an increase in money variance decreases relative dispersion. The 1% increase in estimated squared money supply shock from the VAR produces 2.82% increase in relative prices variability, and the 1% increase in money variance from the VAR lowers relative prices variability by 2.20%. In Hercowitz's empirical results, the effects of the increase in estimated squared money supply shock and money variance are bigger than those in equation (46). In his results, the squared money supply shock causes a 17.4% increase in relative variability, and the money variance decreases relative variability by 15.8%. Since these two empirical models are based on different assumptions and empirical methods, I cannot make a direct comparison between these two outcomes. The difference might be due to the scale difference between the money supply shocks used in Hercowitz's model and the VAR model in this study. I find that the signs of the coefficients in the two empirical models are the same.

Instead of following Hercowitz with exchange rates in Germany, I use an alternative simple approach to generate money variance. I divide a series of money supply shocks into six groups. Money supply shock changes its variance on 1970:03, 1973:05, 1976:11, 1981:04, and 2000:05, with the observation of the plot searching for obvious changes in the variance of money supply shocks. After being divided into six groups, the observations in each group are used to calculate the standard deviation of money supply shocks. The computed standard deviation stays the same until a new group begins.

To extend Hercowitz's model, I run a regression on equation (41) to test the following hypotheses: $b_1 = b_2$ for linearity of money supply shock effects, $b_3 = b_4$ for linearity of productivity shock effects, $b_1 = -b_2$ for symmetry of money supply shock effects which is consistent with the restriction in Hercowitz, $b_3 = -b_4$ for symmetry of productivity shock effects. Estimation results from running equation (41) are as follows.

$$RD_t = \underset{(3.81)}{0.005} + \underset{(1.86)}{0.43}\, d_t \hat{e}_{m,t} - \underset{(2.60)}{0.59}(1- d_t)\hat{e}_{m,t} - \underset{(0.90)}{0.11}\, d_t \hat{e}_{p,t} - \underset{(0.50)}{0.06}(1- d_t)\hat{e}_{p,t} - \underset{(0.53)}{16.96}\, s_{m,t}$$

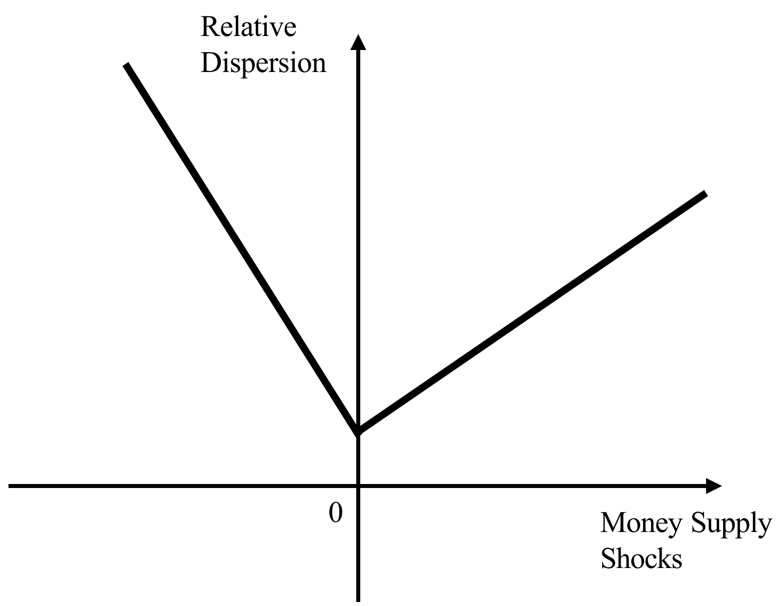
$$+ \underset{(8.22)}{0.38}\, RD_{t-1} + \underset{(3.76)}{0.18}\, RD_{t-2} + \underset{(5.38)}{0.22}\, RD_{t-5} + e_t \qquad (47)$$

Adjusted $R^2 = 0.42$
DW statistic = 2.06
F-statistic = 40.95

The magnitude of coefficients needs to be mentioned. The 1% increase in positive money supply shock will cause a 0.43% increase in relative dispersion, while a 1% increase in negative money supply shock results in a 0.59% decrease in relative dispersion. Positive and negative productivity shock with a 1% increase causes 0.11% and 0.06% decreases in relative dispersion respectively, but the effects are statistically insignificant with their low t-values. This means productivity shocks have a very small impact on relative dispersion with statistical insignificance as expected in Hercowitz's model. Money variance represented by the standard deviation negatively affects relative dispersion, but the estimated coefficient is statistically insignificant.

Negative money supply shocks have a larger impact on relative dispersion than positive money supply shocks do. In other words, it has more disturbing effects on the economy's resource allocation systems with prices than positive money supply shocks do, which is not expected from Hercowitz. These results of asymmetry are consistent with the findings of Jaramillo (1999). He found that negative inflation has more impact on relative dispersion. It is considered that a negative money supply shock creates negative inflation, and a positive money shock leads to positive inflation. Hence, larger responses of relative dispersion to negative money supply shocks found in the above regression support Jaramillo's findings that negative inflation has more impact on relative dispersion. Positive and negative productivity shocks show a different magnitude of effects on relative prices, but their effects are statistically insignificant.

These findings can be summarized in a graphical illustration as follows:



The vertical axis measures relative prices dispersion, and the money supply shock is on the horizontal axis. Asymmetry of the effects of negative and positive money supply shocks can be shown as the kinked curve in the graph. The slope of the curve is steeper for negative money supply shocks than that for positive money supply shocks. The intercept of this curve has to be positive from equation (47).

Wald's test is used to test the restrictions on coefficients of the above regression. Wald's statistic measures how close the unrestricted estimates are to satisfy the restrictions under null hypothesis. If the restrictions are true, the unrestricted estimates should come close to satisfying the restrictions. In Table 7, an F-statistic and a Chi-square statistic are reported along with p-values. I test a single restriction for each Wald test, so those two test statistics are the same. With the p-values, I can reject the null of linearity of money shock effects with a 1% significance level, but cannot reject the null hypotheses of linearity of productivity shocks, symmetry of money supply shocks, and symmetry of productivity shocks. From these test statistics, I found that relative dispersion has a nonlinear relationship with money supply shocks, and a symmetry assumption on money supply shocks by Hercowitz is consistent with the test results. For the productivity shocks, I cannot reject a linear relationship between relative dispersion and productivity shocks, nor a symmetry of productivity shocks to relative dispersion.

To see the effects of money supply shocks only, I run the second regression by dropping productivity shocks with the restriction of $b_3 = b_4 = 0$ from the above regression equation.

$$
\begin{aligned}
RD_t = \underset{(3.86)}{0.005} + \underset{(1.77)}{0.40}\, d_t \hat{e}_{m,t} - \underset{(2.61)}{0.59}(1- d_t)\hat{e}_{m,t} - \underset{(0.39)}{12.52}\, s_{m,t} \\
+ \underset{(8.28)}{0.38}\, RD_{t-1} + \underset{(3.62)}{0.17}\, RD_{t-2} + \underset{(5.51)}{0.23}\, RD_{t-5} + e_t \qquad (48)
\end{aligned}
$$

Adjusted $R^2 = 0.42$
DW statistic = 2.06
F-statistic = 54.37

The estimation results are similar to equation (47). This is expected because contributions from the dropped productivity shocks are not statistically significant from equation (47). Wald test for coefficient restrictions is reported in Table 8, and I can reject the null hypothesis of the linearity of money supply shocks, but cannot reject the null of symmetry of money supply shocks with a 1% significance level.

Another restriction imposed on equation (47) is to drop the money shock variance term with the restriction of $b_5 = 0$. The estimation results are as follows:

$$RD_t = 0.005 + 0.40\, d_t \hat{e}_{m,t} - 0.56(1- d_t)\hat{e}_{m,t} - 0.10\, d_t \hat{e}_{p,t} - 0.06(1- d_t)\hat{e}_{p,t}$$
(3.78) (1.79) (2.55) (0.84) (0.51)

$$+ 0.38\, RD_{t-1} + 0.18\, RD_{t-2} + 0.22\, RD_{t-5} + e_t \quad (49)$$
(8.21) (3.75) (5.36)

Adjusted $R^2 = 0.42$
DW statistic = 2.05
F-statistic = 46.84

The removal of money shock variance does not change the coefficients and other estimation results from equation (47). From equation (47), the money shock variance coefficient is reported as statistically insignificant. Wald test results for coefficients in equation (49) are available in Table 9. The results are similar to those from equation (47). Money supply shocks are nonlinear to relative dispersion, and the symmetry assumption of money supply shock in Hercowitz is verified.

3.5 Conclusion

The motivation of this study is to find another channel of the effects of money supply shocks into the economy. By disturbing relative prices in different sections of the economy, money supply shocks distort the resource allocation system, creating inflation and increased relative dispersion of prices. I follow and extend Hercowitz's (1981) model to see the effects of money supply shocks on relative dispersion. My replication of Hercowitz's model is consistent with his findings except that the effect of money variance on relative dispersion is statistically insignificant. Hence, the results in this study support Hercowitz's model over the Lucas-Barro model which assumes the same elasticities across different markets.

This study extends Hercowitz's model, and makes some contributions. The first contribution of my study is to include productivity shocks in the estimations. According to Hercowitz, productivity shocks representing real shocks have no effect on relative price dispersion. His model is based on the Lucas-Barro imperfect information model, where only nominal shocks can fool people in the economy. The results from the estimation regressions verify this argument. Compared to money supply shocks, productivity shocks have negligible effects on relative dispersion with statistical insignificance. This provides supporting evidence to the imperfect information theory.

The second contribution of this study is to investigate the asymmetric responses of positive and negative money supply shocks as well as the nonlinear relationship between relative dispersion and money supply shocks. Hercowitz predicts that money supply shocks have a positive impact on relative dispersion regardless of the signs of the shocks. Any shocks can disturb the price information system, and disturb the economy. The estimation results in this study show the asymmetric relationship between relative price dispersion and money supply shocks. Meanwhile, the magnitude of positive and negative money supply shocks are significantly different, and negative money supply shocks have a larger impact on relative dispersion. Productivity shocks have different impacts on relative price dispersion, but they are statistically insignificant. This nonlinear response is not expected from Hercowitz. Jaramillo (1999) reports the similar nonlinear responses of relative dispersion on inflation. According to his results, negative inflation has a larger effect on relative dispersion. Hence, the asymmetric responses of relative dispersion to negative and positive money supply shocks support the results from Jaramillo.

The results in this chapter have more theoretically legitimate meanings because, unlike those of Hercowitz or Jaramillo, money supply shocks and productivity shocks are directly derived from a five-variable macroeconomic VAR with long-run identifying restrictions. Policy implications are as follows: stable money supply helps reduce the level of relative price dispersion. This means a less distorted resource allocation system with a stable relative price system. The monetary authority should try to maintain money policy anticipated and stable to eliminate any disturbance on relative dispersions from unexpected money supply shocks to the economy.

Table 1: Unit Root Tests

Variables	Augmented Dickey-Fuller		Phillips-Perron	
	Level	Difference	Level	Difference
Productivity	-1.170313	-7.111348	-1.368064	-16.06717
Interest Rate	-1.834821	-9.261604	-2.164283	-14.61924
Output	-0.108049	-6.886566	0.350572	-15.07071
Real Money	1.676359	-6.588434	2.608267	-17.57522
Money	1.657142	-3.972683	7.741621	-19.83896

* MacKinnon 5% critical values for rejection of hypothesis of a unit root is -2.8684.

Table 2: Johansen Cointegration Test

Trend assumption: Linear deterministic trend

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	1 Percent Critical Value
None	0.078359	35.98530	38.77
At most 1	0.045166	20.38182	32.24
At most 2	0.028536	12.76736	25.52
At most 3	0.021926	9.77683	18.63
At most 4	4.64E-05	0.02046	6.65

Max-eigenvalue test indicates no cointegration at 1% level

Table 3: VAR Lag Order Selection Criteria

Lag	AIC	FPE
0	-30.083	5.92E-20
1	-30.49	3.94E-20
2	-30.607	3.51E-20
3	-30.927	2.55E-20
4	-31.071	2.21E-20
5	-31.095	2.15E-20
6	-31.077	2.20E-20
7	-31.076	2.20E-20
8	-31.067	2.22E-20
9	-31.116	2.12E-20
10	-31.136	2.08E-20
11	-31.142	2.07E-20
12	-31.559	1.37E-20
13*	-31.714	1.17E-20
14	-31.667	1.23E-20
15	-31.671	1.23E-20

* indicates lag order selected by the criterion
AIC: Akaike information criterion
FPE: Final prediction error

Table 4: VAR Residual Tests for Autocorrelation

H_0: no residual autocorrelations up to lag h

Lags	Q-Stat	Prob.
1	1.4672	NA*
6	23.5093	NA*
11	82.4945	NA*
12	95.3391	NA*
13	112.0036	NA*
14	139.2804	0.0000
15	159.7420	0.0000
16	171.3882	0.0000
17	192.7280	0.0000
18	196.7456	0.0000
19	214.3557	0.0004
20	247.5110	0.0003
21	262.4080	0.0020
22	283.0330	0.0052
23	299.5114	0.0173
24	342.3708	0.0035
25	359.6848	0.0102
26	376.0571	0.0267
27	435.5315	0.0012
28	455.7686	0.0027
29	479.3292	0.0039
30	517.2165	0.0014
31	538.2884	0.0026
32	571.7279	0.0015
33	594.0489	0.0024
34	605.1629	0.0087
35	635.3580	0.0067
36	664.6330	0.0056

* The test is valid only for lags larger than the VAR lag order.

Table 5: Variance Decomposition of Five-Variable VAR with Money Supply Shocks

Period	Relative Contribution of Money Shock to				
	Productivity	Interest Rate	Output	Real Money	Money
1	4.169418	32.879742	6.265224	3.093111	8.209732
2	2.918855	25.537101	5.315343	3.817502	9.819472
3	2.359241	19.737236	4.794899	4.168884	11.110504
4	1.992012	16.339502	4.926820	4.256010	11.608233
5	1.601729	14.790055	5.711913	4.475277	12.114291
6	1.246698	13.689311	6.631579	4.742521	12.802641
7	1.012083	12.427261	7.290344	4.997446	13.768256
8	0.844457	11.257444	7.564389	4.868057	14.230294
9	0.727659	10.205106	7.870374	4.627431	14.260104
10	0.646908	9.132156	8.129636	4.399191	13.888656
11	0.618178	8.117644	8.055078	4.073540	13.392885
12	0.599570	7.160276	7.996718	3.738848	12.942404
13	0.621311	6.370245	7.830278	3.416375	12.441570
14	0.640670	5.735310	7.616755	3.090908	11.775810
15	0.646004	5.213342	7.363309	2.794208	11.173778
16	0.641155	4.784069	7.076024	2.548415	10.705612
17	0.630893	4.414757	6.789121	2.341320	10.294084
18	0.612579	4.098573	6.476448	2.156753	9.937701
19	0.582362	3.812348	6.156167	1.998498	9.636880
20	0.548682	3.551781	5.824969	1.852872	9.353295
21	0.516773	3.313651	5.519653	1.727709	9.109184
22	0.486877	3.107686	5.222959	1.615126	8.867657
23	0.457761	2.927174	4.950086	1.513140	8.638166
24	0.432340	2.767608	4.696797	1.422514	8.458252
25	0.409483	2.622711	4.458662	1.342014	8.297005
26	0.388457	2.493541	4.232069	1.268099	8.124820
27	0.369441	2.379495	4.021245	1.201691	7.978698
28	0.352122	2.275560	3.828629	1.142638	7.848397
29	0.335777	2.179467	3.647324	1.088678	7.724521
30	0.320616	2.090235	3.476158	1.039199	7.622050
35	0.262403	1.735072	2.780266	0.846935	7.242764
40	0.222222	1.484252	2.285762	0.715305	7.049204
45	0.192029	1.296034	1.919933	0.618681	6.936718
50	0.168484	1.148788	1.641380	0.544724	6.869264

Table 6: Variance Decomposition of Five-Variable VAR with Productivity Shocks

Period	Relative Contribution of Productivity Shock to				
	Productivity	Interest Rate	Output	Real Money	Money
1	41.62563	0.58710	36.44333	48.79475	48.64486
2	42.70020	0.17921	39.81607	47.93434	52.75010
3	41.42847	0.14049	39.42149	43.87466	52.97130
4	43.00985	0.17288	38.84207	39.98518	49.93890
5	46.49090	0.38105	40.78068	36.86992	47.87412
6	49.56301	0.74093	41.90614	34.02917	45.23895
7	53.03973	1.61736	42.55822	31.66205	42.20562
8	57.06763	2.17435	42.78253	29.22918	39.41598
9	60.83451	2.46212	43.39387	27.46798	37.19691
10	64.04695	2.66034	43.62790	26.23465	35.64332
11	66.84623	3.04046	43.81041	25.37755	34.49631
12	69.49023	3.44367	43.82068	24.57233	33.19436
13	72.05501	3.72588	43.84577	24.09703	32.34571
14	74.18239	4.02445	43.53047	23.56600	31.83083
15	75.96544	4.29834	42.81261	22.86270	31.27257
16	77.68003	4.64184	42.07322	22.16259	30.59659
17	79.19970	4.95449	41.41761	21.58548	29.92437
18	80.57318	5.23094	40.73329	21.07634	29.26890
19	81.83111	5.54961	40.08575	20.67367	28.71198
20	82.96496	5.83612	39.41171	20.22128	28.12153
21	84.02164	6.14232	38.84824	19.85234	27.54346
22	84.99429	6.45729	38.26502	19.52961	27.07755
23	85.85482	6.73999	37.65216	19.20461	26.66813
24	86.63652	6.99195	37.02214	18.88363	26.24158
25	87.35448	7.27554	36.42479	18.63754	25.88677
26	87.98969	7.53894	35.79492	18.39548	25.55939
27	88.56588	7.77657	35.15489	18.15615	25.24176
28	89.09922	7.99903	34.55914	17.95189	24.94924
29	89.58979	8.20268	34.00802	17.77245	24.66612
30	90.04489	8.40356	33.48569	17.61678	24.40009
35	91.85238	9.27991	31.08943	17.02049	23.36623
40	93.13106	9.96593	29.03781	16.62245	22.57552
45	94.08619	10.50063	27.29057	16.33653	21.95544
50	94.81999	10.93276	25.76074	16.11573	21.45447

Table 7: Wald Coefficient Restriction Test in Equation (47)

Null Hypothesis: $b_1 = b_2$			
F-statistic	6.9747	Probability	0.0086
Chi-square	6.9747	Probability	0.0083

Null Hypothesis: $b_3 = b_4$			
F-statistic	0.0756	Probability	0.7834
Chi-square	0.0756	Probability	0.7833

Null Hypothesis: $b_1 = -b_2$			
F-statistic	0.4504	Probability	0.5025
Chi-square	0.4504	Probability	0.5022

Null Hypothesis: $b_3 = -b_4$			
F-statistic	1.6379	Probability	0.2013
Chi-square	1.6379	Probability	0.2006

Table 8: Wald Coefficient Restriction Test in Equation (48)

Null Hypothesis: $b_1 = b_2$			
F-statistic	6.7608	Probability	0.0096
Chi-square	6.7608	Probability	0.0093

Null Hypothesis: $b_1 = -b_2$			
F-statistic	0.6200	Probability	0.4315
Chi-square	0.6200	Probability	0.4310

Table 9: Wald Coefficient Restriction Test in Equation (49)

Null Hypothesis: $b_1 = b_2$			
F-statistic	6.7912	Probability	0.0095
Chi-square	6.7912	Probability	0.0092

Null Hypothesis: $b_3 = b_4$			
F-statistic	0.0534	Probability	0.8173
Chi-square	0.0534	Probability	0.8172

Null Hypothesis: $b_1 = -b_2$			
F-statistic	0.4244	Probability	0.5151
Chi-square	0.4244	Probability	0.5147

Null Hypothesis: $b_3 = -b_4$			
F-statistic	1.5260	Probability	0.2174
Chi-square	1.5260	Probability	0.2167

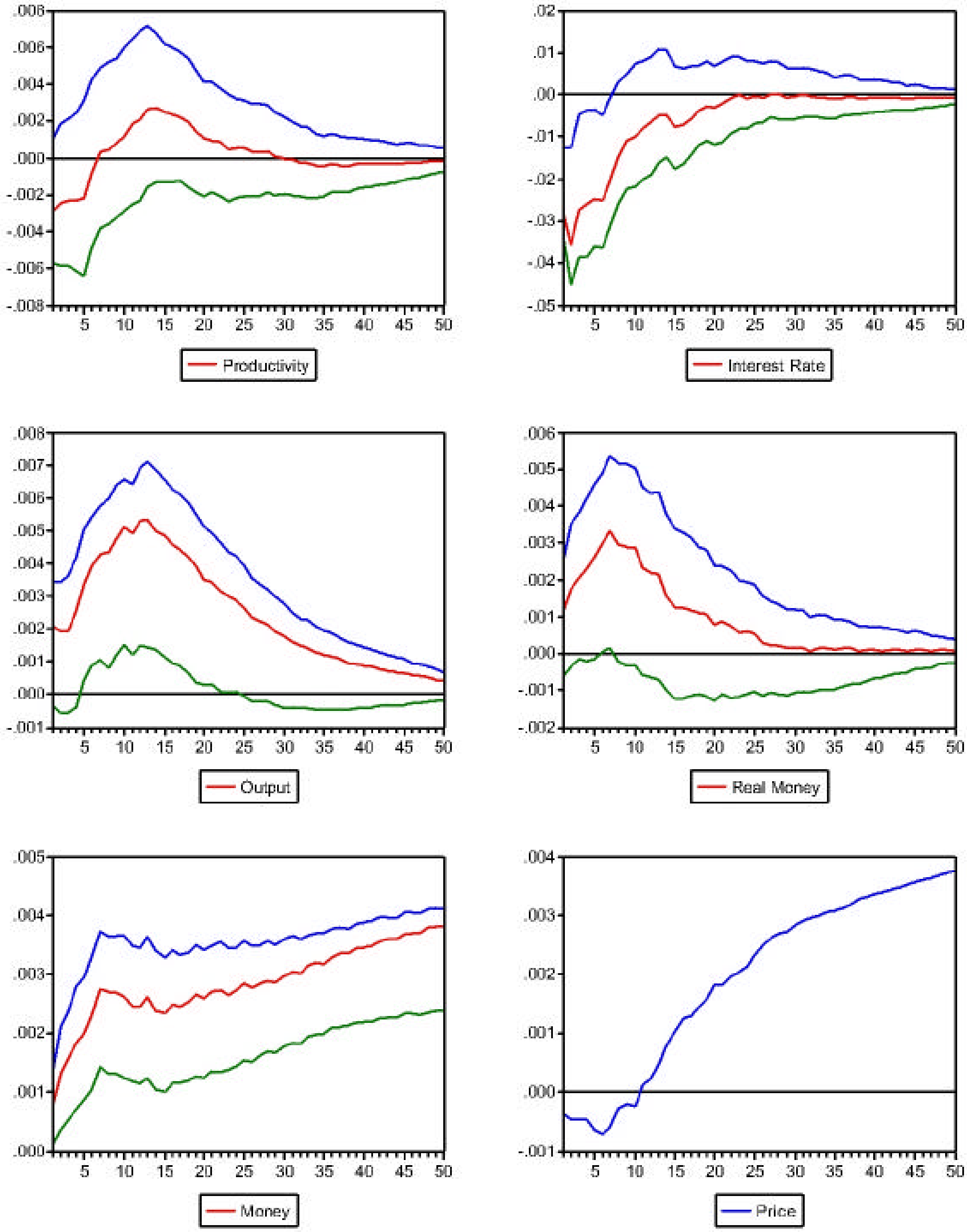


Figure 1: Dynamic Responses to Money Supply Shocks

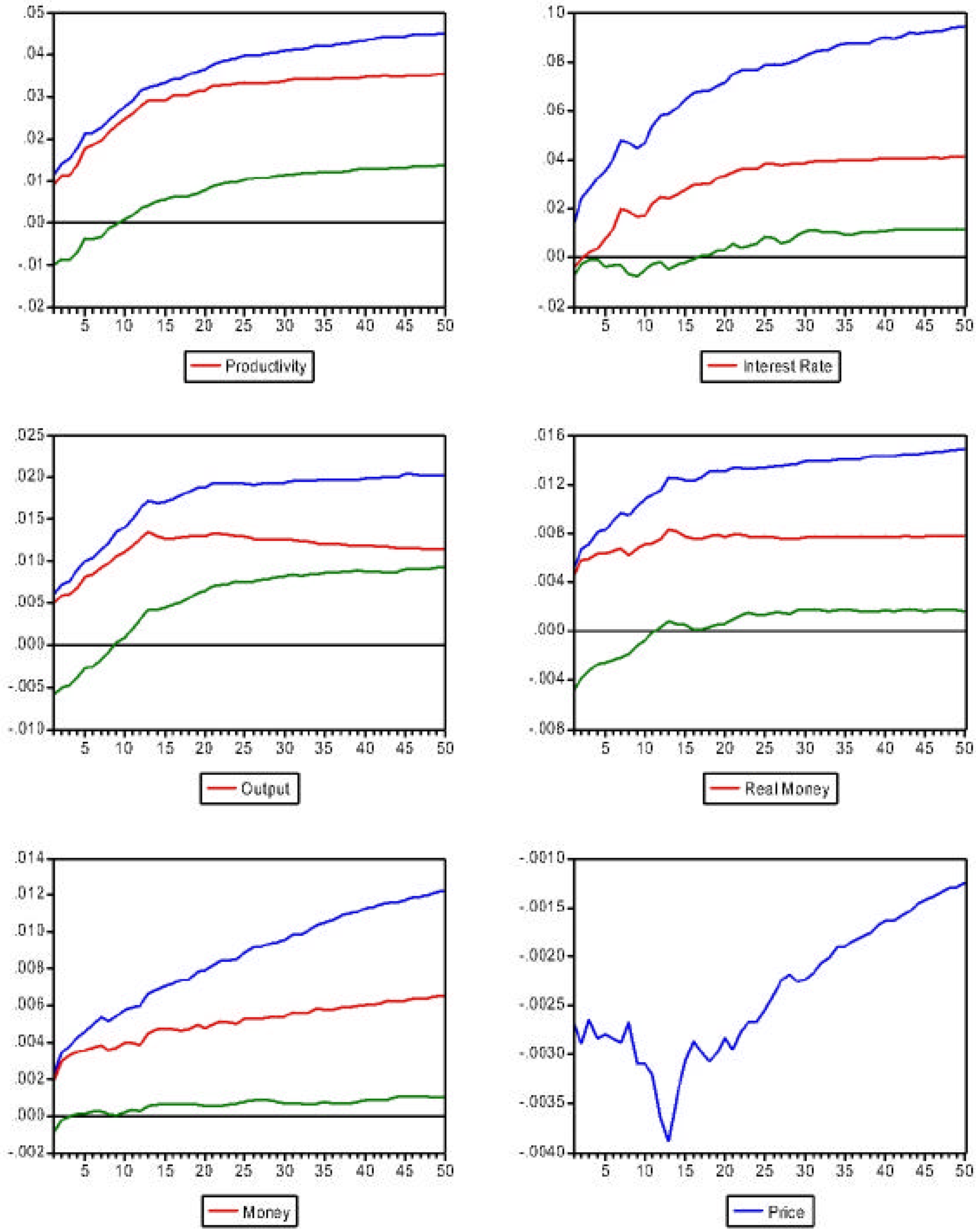


Figure 2: Dynamic Responses to Productivity Shocks

CHAPTER 4

DYNAMIC EFFECTS OF SHOCKS ON RELATIVE PRICES WITH A DISAGGREGATED VAR

4.1 Introduction

In understanding the distortionary nature of the responses of relative goods prices to money supply shocks, most of previous studies focus on the relationship between the cross-sectional variance of relative prices and the level or variability of inflation. However, this relationship can depend on the source of shocks that may jointly affect both inflation and the dispersion of relative prices. Because the identification strategies in many studies are often ad hoc and implausible, this study takes a systems approach to estimating how the cross-sectional moments of relative price distributions jointly respond to underlying aggregate shocks. After we estimate VAR with plausible identifying restrictions to isolate these shocks, we focus on how to relate these shocks to dispersion and other cross-sectional moments with two different approaches. The first approach is discussed in chapter 3, by revisiting the important study by Hercowitz (1981).

The approach in chapter 3 potentially ignores important information contained in the entire distribution of relative prices, because it focuses on the sample moments of the cross-sectional distribution of relative prices. This chapter tries to incorporate this important information into the analysis by estimating the responses of the distribution of relative prices to exogenous aggregate shocks.

The common approach in the literature is to regress the relevant cross-sectional moments on some explanatory variables such as inflation or other macro variables. This approach has a problem of implicit causality and loss of important information in entire distribution of relative prices. We use a different approach here to avoid these problems. This approach is to regress each price on common factors, and the effect of common factors on the distribution of relative prices can be estimated by running n time regressions. Considering the cross-sectional distribution of the coefficients from these n regressions will be used to show the effect of common factors on the distribution of relative prices.

This chapter is based on the VAR model with the disaggregated relative price information. The producer price index in this study has 64 categories. Each of these categories is included as a variable in the VAR system, and the impulse response of each price series to the aggregate shocks is generated. Instead of summarizing the distribution of relative prices into the sample moments in the estimation models, I use the entire distribution itself with the disaggregated prices in this approach. I call this system a disaggregated VAR model.

This approach has some advantages over previous approaches. By incorporating all the information about individual price responses to underlying aggregate shocks, it allows us to isolate the distinct fundamental shocks that jointly affect all the moments of the relative price distribution. Second, this approach allows straightforward computation of any moments from the distribution, so that effect of shocks on dispersion and skewness can be inferred from the same estimated model. Finally, the VAR model used in this approach provides a natural setting for investigating the dynamic response of sample moments to aggregate shocks.

Estimating a fully unrestricted VAR with a large number of markets is the primary disadvantage of this empirical approach. To make the estimation of this disaggregated VAR feasible, we follow Loo and Lastrapes (1998) by estimating a restricted VAR. We need to assume that individual industries are independent of each other at all lags after conditioning on the aggregated variables in the system. The latter assumption means that the macro sub-system can be estimated efficiently independently of the industry prices, while the former implies that the industry-level price can be estimated from individual regressions of these prices on their own lags, and the contemporaneous and lagged values of the macro variables. For identification, we use the same money supply and productivity shocks with the appropriate long-run restrictions used in chapter 3.

4.2 Empirical Methods

4.2.1 Disaggregated VAR and Identification

The common approach in the literature is to compute the cross-sectional moments of relative price distribution first, and then regress these moments on some common factors. For example, relative price variability can be regressed on variability of inflation and some macro variables. Inevitably, this approach has to impose implicit causal relationship between relative price variability and inflation. However, if we have common underlying shocks to affect both of these variables, the result from this regression can be misleading.

This chapter suggests a solution to this problem with a systems approach. Instead of regressing sample moments on some macro variables, we regress relative price in each industry on macro variables. The effect of the common factors on the relative price distribution can be estimated by running the regression with the number of markets. The VAR allows us to follow this method in a dynamic setting, and in our model each price responds to underlying shocks to the system, and the dynamic response of these prices to the shocks can be used to compute impulse responses of cross-sectional moments of relative price distribution.

The disaggregated VAR has 69 variables in total. 64 variables are relative nominal prices coming from individual markets, and 5 variables are the same macroeconomic variables used in chapter 3. For the identification of this large system, two strong restrictions are required, following Loo and Lastrapes (1998). The first restriction is that individual markets are independent, after conditioning on aggregate variables. In effect, this imposes a "diagonality" restriction on the VAR, so that observed correlations across markets depend only on their joint dependence on the aggregate variables. Market-specific shocks are not correlated across industries. The second restriction is the block exogeniety assumption: the aggregate variables are independent of the relative prices from individual markets. With these two assumptions, this system can be identified and estimated by two steps.

The first step is to estimate the 5-variable macroeconomic VAR separately from all individual prices by block exogeneity. Second, by the diagonality assumption, individual prices equations in the disaggregated VAR can be estimated by regressing each price on its own lags, the lags of the aggregate variables, and the contemporaneous values of the aggregate variables. In effect, the large 69 variable VAR can be efficiently decomposed into a 5-varible VAR (the macro system), and 64 independent regressions of industry price on contemporaneous values of the macro variables and lags of all variables. Without loss of generality, the notation below will consider the case of one industry as it relates to the macro system; it should be kept in mind that such a system will hold for each of the individual markets under consideration.

I assume the following linear, dynamic structural model,

$$A\Delta x_t = B(L)\Delta x_{t-1} + u_t \tag{50}$$

where Dx_t is the 6×1 vector of endogenous variables and u_t is a 6×1 vector with mean-zero, serially uncorrelated shocks to the behavioral equations. The Dx_t vector has the individual price changes from each market (Dp_t), labor productivity (Da_t), nominal yield-to-maturity (Dr_t), output (Dy_t), the real money stock (Dm_t), and the nominal money stock (DM_t). The labor productivity variable, a_t, is measured by the difference between the log of industrial production index and the log of total employee hours in nonagricultural establishments. The dynamic interactions among the endogenous variables are summarized in the lag polynomial matrix, *B(L)*.

To show how the system is estimated and identified, I expand the system in equation (50) as

$$\begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} \Delta p_t \\ \Delta z_t \end{pmatrix} = \begin{pmatrix} B_{11}(L) & B_{12}(L) \\ B_{21}(L) & B_{22}(L) \end{pmatrix} \begin{pmatrix} \Delta p_{t-1} \\ \Delta z_{t-1} \end{pmatrix} + \begin{pmatrix} u_{pt} \\ u_{zt} \end{pmatrix} \tag{51}$$

where Dp_t is a scalar of industry-level price variable because it is for only one industry, and Dz_t is the 5×1 vector of the macroeconomic variables following the order of Da_t, Dr_t, Dy_t, Dm_t, and DM_t. u_{pt} contains market-specific shocks, and the 5×1 vector of u_{zt} has aggregate shocks for the above five macroeconomic variables. Specifically, the first element of u_{zt} represents the aggregate productivity shock, and the last element of u_{zt} is the money supply shock to the system. To implement the long-run identifying restrictions, productivity is ordered first and nominal money stock is ordered last as in the macroeconomic VAR in chapter 3.

The coefficient matrices are partitioned as follows:

$$A = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix}, \tag{52}$$

$$B(L) = \begin{pmatrix} B_{11}(L) & B_{12}(L) \\ B_{21}(L) & B_{22}(L) \end{pmatrix}. \tag{53}$$

A_{11} and $B_{11}(L)$ are scalars. The second assumption of the independence of market-specific shocks and the aggregate variables implies that A_{21} and $B_{21}(L)$ are zero matrices with the dimension of 5×1. A_{12} and $B_{12}(L)$ is 1×5 matrices, and A_{22} and $B_{22}(L)$ have the dimension of 5×5.

Solve the structural model for the reduced form as follows:

$$\begin{aligned} \Delta x_t &= A^{-1} B \Delta x_{t-1} + A^{-1} u_t \\ &= \Phi \Delta x_{t-1} + e_t \end{aligned} \tag{54}$$

With the partitioned-inverse rule for A^{-1}, F matrix is written as

$$\Phi = \begin{pmatrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Phi_{22} \end{pmatrix} = \begin{pmatrix} A_{11}^{-1} B_{11} & A_{11}^{-1} B_{12} - A_{12} A_{22}^{-1} A_{11}^{-1} B_{22} \\ 0 & A_{22}^{-1} B_{22} \end{pmatrix} \tag{55}$$

Note that $A_{11}^{-1}B_{11}$, is a scalar.

The reduced form covariance matrix of the system is

$$Ee_te_t' = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{12}' & \Sigma_{22} \end{pmatrix} = A^{-1}A^{-1\prime} \quad (56).$$

As the system has block-recursive restrictions, the sub-system with the macroeconomic variables can be estimated independently of the industry-level equations without loss of efficiency.[12] The equations for individual industry-level price are also efficiently estimated by separate least squares when conditioned on the contemporaneous values of the macroeconomic variables. The system of conditional regression by rewriting the $D\, p_t$ vector in terms of conditional and marginal densities is as follows:

$$\Delta p_t = \Phi_{11}\Delta p_{t-1} + \Sigma_{12}\Sigma_{22}^{-1}\Delta z_t + (\Phi_{12} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{22})\Delta z_{t-1} + u_t \quad (57)$$

$$\Pi = Eu_tu_t' = \Sigma_{11} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{12}' . \quad (58)$$

From equation (56) and the partitioned-inverse of the matrix A, equation (58) can be rewritten as the following diagonal matrix:

$$\Pi = A_{11}^{-1}A_{11}^{-1\prime} \quad (59)$$

[12] FIML is the general approach to estimate the system efficiently, but the block-recursiveness of the system allows the independent estimations of the two separate sub-systems.

By estimating equation (57) for each industry, along with the macro system, the full set of reduced form parameters in (55) and (56) can be inferred. Such estimation is fully efficient, given the diagonality and block-exogeneity restrictions.

To analyze the dynamic responses of the endogenous variables to the aggregate shocks, the reduced-form VAR in equation (54) has been converted into the moving average representation.

$$\begin{aligned}\Delta x_t &= [I - A^{-1}BL]^{-1}A^{-1}u_t \\ &= (D_0 + D_1 L + \cdots)u_t \\ &= D(L)u_t\end{aligned} \tag{60}$$

The *D(L)* measures the dynamic responses from the aggregate exogenous shocks. The problem in this representation is that the *D(L)* is not identified unless the system has more restrictions. The long-run restrictions are used to identify the *D(L)*. For the long-run restrictions, I assume that the money supply shock has no impact on real variables in the long run, and only the productivity shock has a permanent effect on the labor productivity, a_t.

To show how the long-run restrictions with the independence restrictions of macroeconomic variables from the industry-level shocks can identify the dynamics of equation (60), I rewrite equation (60) as

$$\begin{aligned}\Delta x_t &= (I + C_1 L + C_2 L^2 + \cdots)\boldsymbol{e}_t \\ &= C(L)\boldsymbol{e}_t\end{aligned} \tag{61}$$

where E$u_t u_t'$ = I and E$e_t e_t$¢ = S. D(1) contains the long-run responses of the levels of endogenous variables, x_l, to the impact of the aggregate exogenous shocks.

$$D(1) = \lim_{k \to \infty} \frac{\partial x_{lt}}{\partial u_{t-k}} \tag{62}$$

The estimation procedure is performed in two steps: first, the five macroeconomic variables are jointly estimated independently of the industry-level prices. Second, the industry-level prices are estimated conditional on the contemporaneous and lagged macroeconomic variables and lags of own price. By estimating industry-level prices and five-variable VAR, I can infer the parameters of the reduced-form disaggregated VAR.

For estimation purposes, the partition of the following matrices separates the industry-level prices changes from the aggregate macroeconomic variables.

$$D_j = \begin{pmatrix} {}_jD_{11} & {}_jD_{12} \\ {}_jD_{21} & {}_jD_{22} \end{pmatrix}, \; C_j = \begin{pmatrix} {}_jC_{11} & {}_jC_{12} \\ {}_jC_{21} & {}_jC_{22} \end{pmatrix},$$

$$\Sigma_j = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{12} & \Sigma_{22} \end{pmatrix}, \; D(1) = \begin{pmatrix} \tilde{D}_{11} & \tilde{D}_{12} \\ \tilde{D}_{21} & \tilde{D}_{22} \end{pmatrix}, \text{ and } C(1) = \begin{pmatrix} \tilde{C}_{11} & \tilde{C}_{12} \\ \tilde{C}_{21} & \tilde{C}_{22} \end{pmatrix}. \tag{63}$$

The structure of these partitioned matrices is as follows: the upper-left element is a scalar, the upper-right element is a 1×5 vector, the lower-left element is a 5×1 vector, and the lower-right element is a 5×5 matrix. To identify the system, the responses of all variables to money supply shocks and productivity shocks in the second and last column of each of D_i need to be identified. Price will be put in the first variable in the system, and the macroeconomic variables follow. Once the estimates of *C(L)* and *Ó* are calculated, identifying restrictions on money supply shocks and productivity shocks are imposed, and the impulse responses to both aggregate shocks are inferred. This approach will not impose any identifying restrictions on the individual price changes. I will use nominal prices in the system to see if money supply shocks have permanent effects on relative price dispersion.

To identify the money supply shock, the following two restrictions are needed: the first is $\tilde{D}_{21} = 0$, which is already implied by the block recursiveness of the macroeconomic system, and the second is that $\tilde{D}_{22}$ is lower triangular, which contains the just-identifying restrictions based on long-run neutrality. The corresponding mapping from the structural form to the reduced form implies $D_j = C_j D_0$. With this mapping, the first restriction above implies $\tilde{C}_{21} = 0$, which means the block-recursive form of the estimated VAR. The following implication is also from the mapping of the structural form and the reduced form.

$$\Sigma = D_0 D_0' \tag{64}$$

$$C(1)\Sigma C(1)' = D(1)D(1)' \tag{65}$$

From the partitioned matrices in equation (63) and the first identifying restriction above, equation (65) can be rewritten as

$$\tilde{D}_{22}\tilde{D}_{22}' = \tilde{C}_{22}\Sigma_{22}\tilde{C}_{22}' \tag{66}$$

The lower triangular from the second restriction implies that the unique identification of $\tilde{D}_{22}$ can be made by the Cholesky factor of the observed matrix on the right-hand side of equation (66). The nature of block-recursiveness enables to determine this by separate estimation of the subsystem with macroeconomic variables.

With the zero restrictions in $C(1)^{-1}$ which are carried over from $C(1)$, the following relationship is implied by the partitioned matrices, the first restriction, and the partitioned inverse rule.

$$ {}_0D_{22} = \tilde{C}_{22}^{-1}\tilde{D}_{22} \tag{67} $$

With the first restriction and the partitioned matrices in equation (63), equation (64) implies

$$ \Sigma_{12} = {}_0D_{12}\,{}_0D_{22}' \tag{68} $$

From equation (68), the following relation is obtained.

$$ {}_0D_{12} = {}_0D_{22}^{-1}\Sigma_{12}' \tag{69} $$

With ${}_0D_{12}$ determined from equation (69), ${}_0D_{11}$ is obtained from the partitioned matrices in equation (63) and equation (64) as

$$ {}_0D_{11} = (\Sigma_{11} - {}_0D_{12}\,{}_0D_{12}')^{\frac{1}{2}} \tag{70} $$

The unknown parameters in D_0 are determined from equation (68), (69), and (70). From the knowledge of $D_i = C_i D_0$, the set of dynamic responses is sufficiently identified by D_0 and the VAR estimation.

The empirical results from this model are conditional on the over-identifying restrictions of the model that are diagonality and block exogeneity. With the current systematic setting, it is not easy to test these restrictions. One possible excuse of using these restrictions without testing them is that these restrictions are reasonable and necessary for estimating a large system like this.

4.2.2 Data

The same set of data from chapter 3 is used in this chapter. To generate the industry-specific price changes, I obtained monthly producer price index (PPI) data between 1966:04 ~ 2002:12 in 64 subcategories from the Bureau of Labor Statistics. Each price change is the log difference between two periods in these subcategories.

All macroeconomic variables are obtained from the Federal Reserve Bank of St. Louis. The 3-month US Treasury bill rate is used for the nominal interest rate. Output is obtained from the total index of industrial production. Total employee hours in nonagricultural establishments make labor hour data. Productivity is calculated by making log difference between the log output and the log labor hour. M2 represents aggregate money supply. The real money stock is from deflating M2 by PPI. These are monthly data between 1966:04 ~ 2002:12.

Individual prices in this VAR are nominal prices, because no long-run neutrality is imposed on individual prices. Before estimating the system, I use the augmented Dickey-Fuller test for the existence of a unit root in every relative nominal price variable in the system. Table

12 shows the unit root test results for all 64 prices in levels and the rates of change. All 64 prices have a single unit root in their levels. A lag length of four is used for the augmented Dickey-Fuller test, which is calculated from the Schwarz Information Criterion for lag length selection. To test level variables of prices, trend and intercept are included, and for differenced variables only the intercept is included. A lag length of five is selected for the Phillips-Perron test. Trend and intercepts are included to test level variables, and only the intercept is included for testing differenced variables. For a proper lag length for the VAR, Akaike Information Criterion and Final Prediction Error methods are employed in chapter 3, and table 3 reports that the proper lag length is 13. As in chapter 3, the model in chapter 4 may be misspecified due to cointegration; we ignore that problem here.

4.3 Estimation Results

4.3.1 Money Supply

Figure 3 shows the 64 dynamic responses of nominal price in each sector to money supply shocks. Because of lagged nominal prices in the VAR system are rates of changes and nominal. To see the impulse responses of relative price levels, we accumulate the impulse responses from the rate of changes to obtain the level responses of nominal prices. No long-run neutrality restriction is imposed on relative prices, and as a result individual prices show different reactions in the long run from money supply shocks without converging to zero or the same level. Positive initial responses are found in 57 out of 64 prices, and 58 out of 64 prices approach stable and positive price increases in the long run. Most of the prices reach their peaks in response to money supply shocks 15 months after the shocks. In the long run, individual prices approach different levels.

Dynamic responses of other macroeconomic variables in the system are identical to the results from chapter 3. Figures 1 and 2 have the impulse responses of those macroeconomic variables to money supply shocks and productivity shocks. This is because I assume that the macroeconomic system is independent of the individual markets. The models in chapter 3 and chapter 4 use the same macroeconomic variables to derive aggregate shocks, and the two models are based on the same macroeconomic VAR.

In chapter 3, money supply shocks and productivity shocks are derived from the estimated VAR, and they are used to test the relationship between aggregate shocks and relative dispersion. In chapter 4, relative prices are directly added to the macroeconomic VAR, and these price variables are allowed to move freely to both aggregate shocks without long-run restrictions. Dynamic responses of relative dispersion and cross-sectional skewness to money supply shocks and productivity shocks are generated from the dynamic responses of the individual prices to both aggregate shocks.

4.3.2 Productivity

Figure 4 reports impulse responses of all 64 nominal prices differences to productivity shock. To focus on cross-sectional sample moments of the relative price distribution, confidence intervals by standard errors are not reported here. Productivity shock has permanent effects on individual nominal price differences. Negative reactions to the initial productivity shocks are found in 38 out of 64 markets, in the long run 48 out of 64 prices approach negative values, showing permanent responses to the shocks. Like the responses to money supply shocks, most prices have their responses peaked within 15 months after the initial shocks. Impulse responses of macroeconomic variables to productivity shocks are the same as the results reported in chapter 3.

4.3.3 Relative Dispersion, Skewness, and Inflation

Dynamic responses of relative dispersion and cross-sectional skewness are derived from the individual impulse responses of 64 nominal relative prices in the disaggregated VAR as follows. First, impulse responses of nominal price differences in all 64 sectors in the model are calculated. Second, these responses are collected all together, and cross-sectional standard deviation and cross-sectional skewness are calculated by each month, just as I calculated relative dispersion and skewness of the relative prices in equations (38) and (39) in chapter 3. Instead of actual prices, response coefficients are used to derive the dynamic responses of relative dispersion and cross-sectional skewness.

The cross-sectional mean of the dynamic response coefficients is described as

$$c_t = \frac{1}{k}\sum_{i=1}^{k} c_{it} \tag{71}$$

where c_{it} is the dynamic responses coefficient of price level of subindex i for year t. Dispersion and cross-sectional skewness are calculated as follows:

$$RD_t = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(c_{it} - c_i)^2} \quad (72)$$

$$SK_t = \frac{\frac{1}{k}\sum_{i=1}^{k}(c_{it} - c_i)^3}{RD_t^3} \quad (73)$$

Third, these relative dispersion and cross-section skewness are plotted with the time horizon to show dynamic responses of these sample moments of relative price distribution to money supply shocks and productivity shocks.

Figure 5 reports dynamic responses of price, relative dispersion, and cross-sectional skewness to money supply shock.[13] First, I use a cross-sectional mean of individual prices to generate price in this figure. Relative price dispersion is calculated following the above argument. Relative dispersion is high when the price level is low, and as price level starts to rise the dispersion is decreasing because all prices begin to move together.

In the short run, both impulse responses of relative price dispersion and price to money supply shocks can be said to be increasing functions to the time horizon. In the long run, relative price dispersion becomes flattened out to remain a stable level. With unanticipated money supply shock, its initial effect is an increase in relative price dispersion by 0.58%, and its effect on relative dispersion reaches its maximum level at almost 0.64% 13 months after the initial shocks.

[13] Cross-sectional standard deviation of the impulse response coefficients can show the extent to which these responses are uniform across industries. In some cases, relative prices dispersion does not have to be necessarily the same as this uniformity measure. For example, relative prices dispersion can actually decrease even though uniformity is large, when high prices fall and low prices rise in response to a shock. To make inference about the responses of relative price dispersion in the disaggregated VAR model, I need to follow the following steps: 1) For each industry at each forecast horizon, I will get what prices are estimated to be after a positive shock on average, by adding the estimated impulse response function for nominal price to the sample mean of that price. 2) At each forecast horizon, I need to take the cross-sectional sample standard deviation for the new series calculated in the first step. 3) Then I can compare this to the sample mean of relative price dispersion for the sample at each horizon.

In the long run, relative dispersion approaches a stable 0.47%. Money supply shock has a permanent effect on relative dispersion, making a channel of real effect to the economy from money supply shocks. A permanent effect on the distribution of relative prices would potentially permanently effect the allocation of resources. Alternative interpretation to this result is that the relative price dispersion converges to reasonably small number, even if it does not converge to zero as expected. Then money supply shocks are relatively neutral in the long run with a convergence to a number close to zero.

The dynamic responses of skewness also seems to approach a constant value in the long run, even though it shows lots of fluctuations in the short run. Initial money supply shocks lead to a decrease by 60%, and in the long run the response of money supply shocks is a stable increase of 40%. I get mostly positive skewness responses except initial negative skewness. This means that individual price responses above the mean responses are greater than those below the mean. According to Ball and Mankiw (1995), if the initial relative price distribution is skewed left, positive aggregate shock causes more of prices above the mean to be pushed outside of their range of inaction. Then we can have more price responses above the mean responses than those below the mean, which confirms the empirical findings in this study. General price level is also increased because of increases in individual prices above the mean.

Figure 6 reports dynamic responses of relative dispersion and cross-sectional skewness to productivity shocks. With productivity shocks, its initial impact on relative price dispersion is an increase by 0.69%, and reaches its maximum level of 0.78% about 14 months after the shock. Like the impulse responses to money supply shocks, impulse responses of relative dispersion do not die out to zero, remaining a 0.62% increase in the long run. This implies that the productivity shocks have real impact on the economy, and price structures are permanently changed due to this real shock.

In the same figure, cross-sectional skewness shows its initial responses of a 40% decrease, and rapidly increases and hits a maximum of 180% 6 months after the shock. Unlike the response of cross-sectional skewness to money supply shock, it shows a gradual decrease in the long run, while maintaining a 30% increase in the long run. As with the response of relative price dispersion to productivity shocks, productivity shock has a real effect on skewness in the long run. Like money supply shock, productivity shock creates more positive price responses above the mean responses than those below the mean.

Comparing the relative magnitude of responses of relative price dispersion to money shock reveals that productivity shock has a larger initial impact on relative price dispersion than money supply shock does. In the long run, responses of relative dispersion are greater with productivity shocks, and the responses of relative dispersion under both money supply and productivity shocks remain stable in the long run. Both responses show the real effect of aggregate shocks on relative price distribution.

To see the correlation between aggregate price level and relative price dispersion due to aggregate shocks, I need to regress relative price dispersion on price level or inflation with squared variables. Since I use two aggregate shocks in the system, I can break down this correlation into what is due to money supply shocks and what is due to productivity shocks, by computing the sample correlation between the absolute value of the estimated response of relative dispersion and the estimated response of the price level across the forecast horizon in the impulse response function.[14] These sample correlations from money supply shocks and productivity shocks can be rough measures of the contribution of each shock to the correlation between relative price dispersion and the aggregate price level. I will repeat the same computation on inflation, the first-differenced level of prices.

Money supply shocks explain 96% of correlation between relative price dispersion and sample price level, and 41% of correlation between dispersion and inflation from the sample price level. Productivity shocks explain 93% and 26% respectively. The contributions of money supply shocks to correlation between relative price dispersion and aggregate price level is 94%, and money supply shocks contribute 33% of correlation between dispersion and inflation from the aggregate price. For productivity shocks, they are 89% and 14%. Overall money supply shocks contribute more in explaining the relationship between relative price dispersion and price level (and inflation) whether it is calculated from sample prices or aggregate price.

The implications of these findings are as follows. First, following the identification scheme of disaggregated VAR, no restrictions are imposed on individual prices, and money supply shocks and productivity shocks have permanent effects on the structure of relative prices in the long run. This means the disturbance caused by money shocks could have a persistent effect in the long run. Second, menu cost theory can explain the relationship between dynamic responses of relative dispersion and price levels to money supply shocks. In the short run, the magnitude of relative dispersion remains high because price levels are low and their responses to the money supply shocks are sticky. Once price levels are moving up all together, however, relative dispersion shows a rapid decrease. In the long run, relative dispersion remains at a certain level, which implies a permanent effect of money supply shocks on the real economy.

[14] I treat the mean as zero, when I compute the correlation between impulse responses.

Table 10: Augmented Dickey-Fuller Unit Root Tests for Prices

Variables	Level	Difference	Variables	Level	Difference
P1	-2.921492	-13.478660	P33	-2.750900	-7.573587
P2	-2.008866	-9.955630	P34	-1.167540	-9.458887
P3	-1.727697	-10.587570	P35	-1.187870	-8.437949
P4	-3.515293	-12.055840	P36	-0.291293	-9.892298
P5	-3.105276	-9.688939	P37	-1.465982	-7.714139
P6	-1.583442	-11.032150	P38	-2.336406	-8.074939
P7	-3.049141	-10.056110	P39	-2.290804	-8.892509
P8	-2.073488	-9.534075	P40	-0.797027	-8.815696
P9	-2.052147	-9.907868	P41	-1.289312	-7.824886
P10	-2.276920	-10.562160	P42	-1.251595	-8.437416
P11	-2.795895	-8.985833	P43	-1.401000	-8.014825
P12	-4.445387	-7.017431	P44	-1.113710	-8.092520
P13	-2.549793	-8.697814	P45	-2.170805	-7.837478
P14	-2.086742	-8.710724	P46	-1.219342	-8.496581
P15	-1.932985	-10.579380	P47	-1.226936	-8.631368
P16	-1.536830	-8.899427	P48	-4.432964	-9.133709
P17	-1.658955	-7.874415	P49	-1.588727	-7.973155
P18	-2.211261	-8.383188	P50	-1.826386	-9.694386
P19	-1.936758	-7.107396	P51	-0.609221	-9.748729
P20	-1.317704	-7.945337	P52	-1.390359	-8.482423
P21	-1.922734	-9.306466	P53	-1.717084	-8.359055
P22	-2.438240	-5.949193	P54	-1.206948	-9.229635
P23	0.516462	-6.851113	P55	-2.026675	-9.355328
P24	-2.503827	-9.181663	P56	-2.471482	-7.363959
P25	-3.448537	-7.052973	P57	-1.947542	-9.940231
P26	-3.281764	-6.954128	P58	-1.359892	-8.252030
P27	-2.347313	-8.036092	P59	-1.897823	-10.326450
P28	-2.622789	-8.848111	P60	-1.686404	-8.329216
P29	-1.186047	-8.270573	P61	0.978992	-9.537733
P30	-2.821898	-11.137020	P62	-2.453911	-9.783820
P31	-2.615115	-8.530256	P63	-1.462316	-10.223140
P32	-2.117139	-7.583650	P64	-1.707070	-8.380333

* MacKinnon 5% critical values for rejection of hypothesis of a unit root is -2.8684.

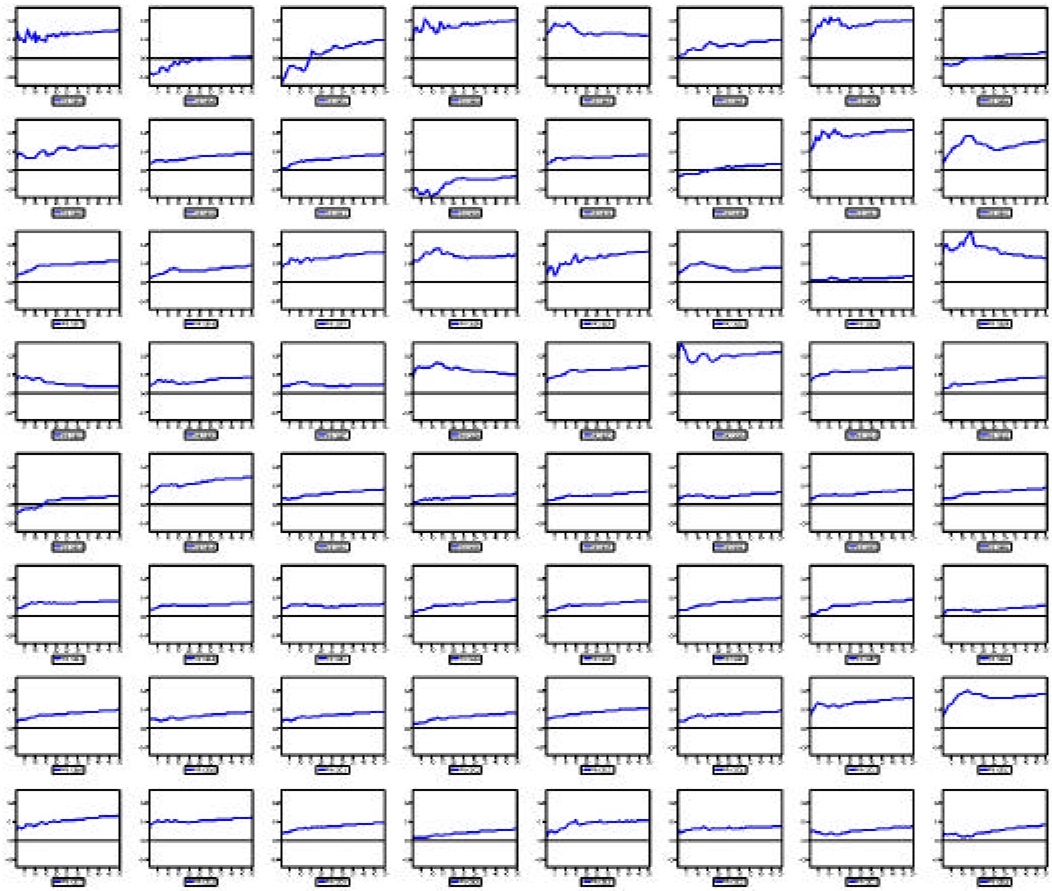


Figure 3: Dynamic Responses of Relative Prices to Money Supply Shocks

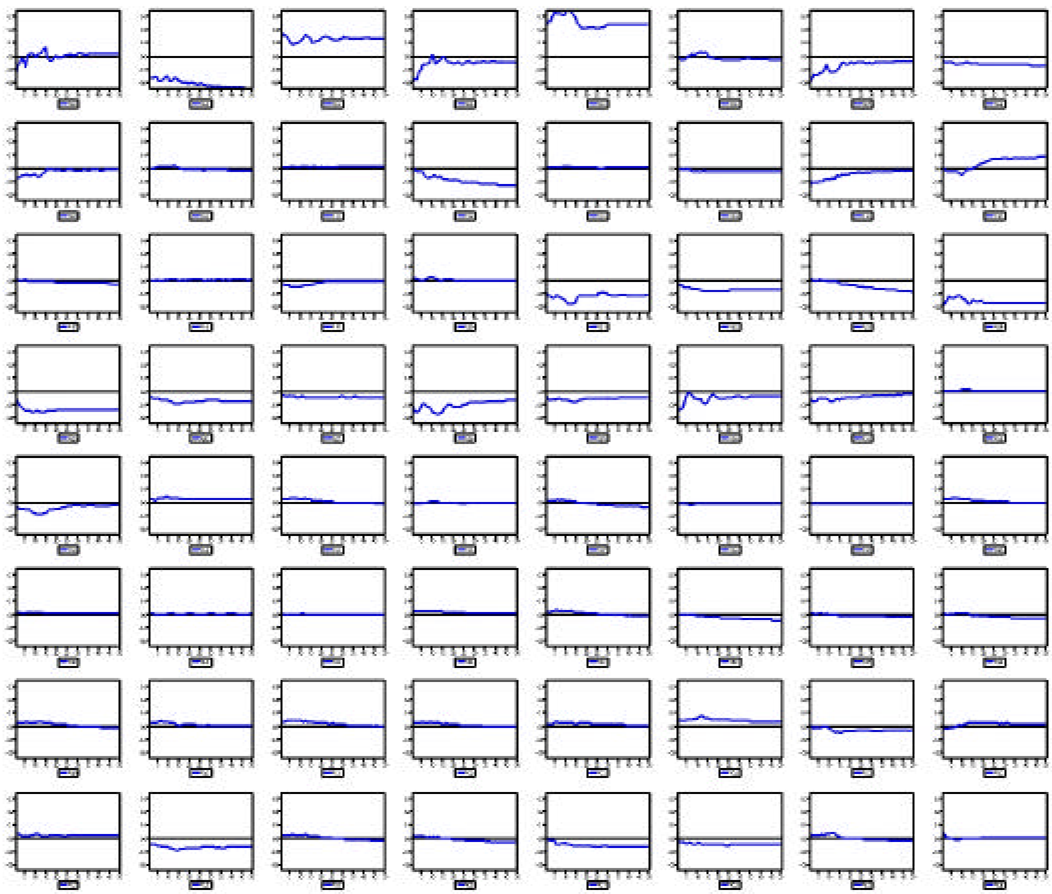


Figure 4: Dynamic Responses of Relative Prices to Productivity Shocks

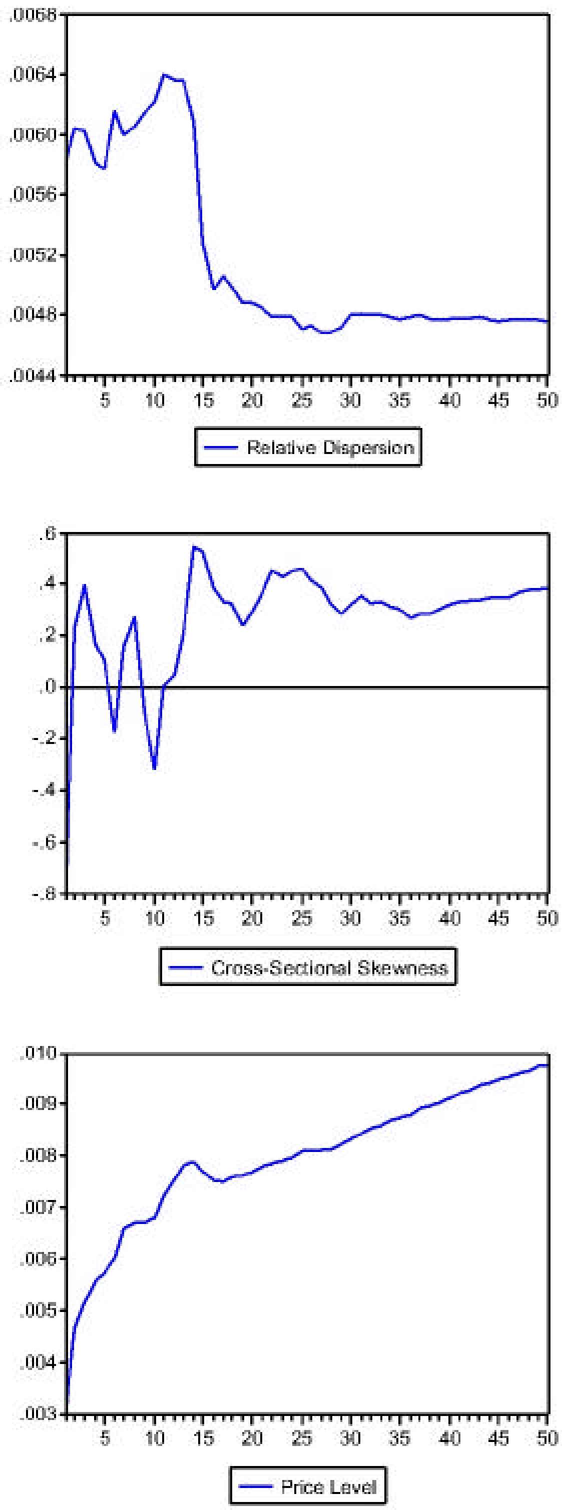


Figure 5: Derived Dynamic Responses to Money Supply Shocks

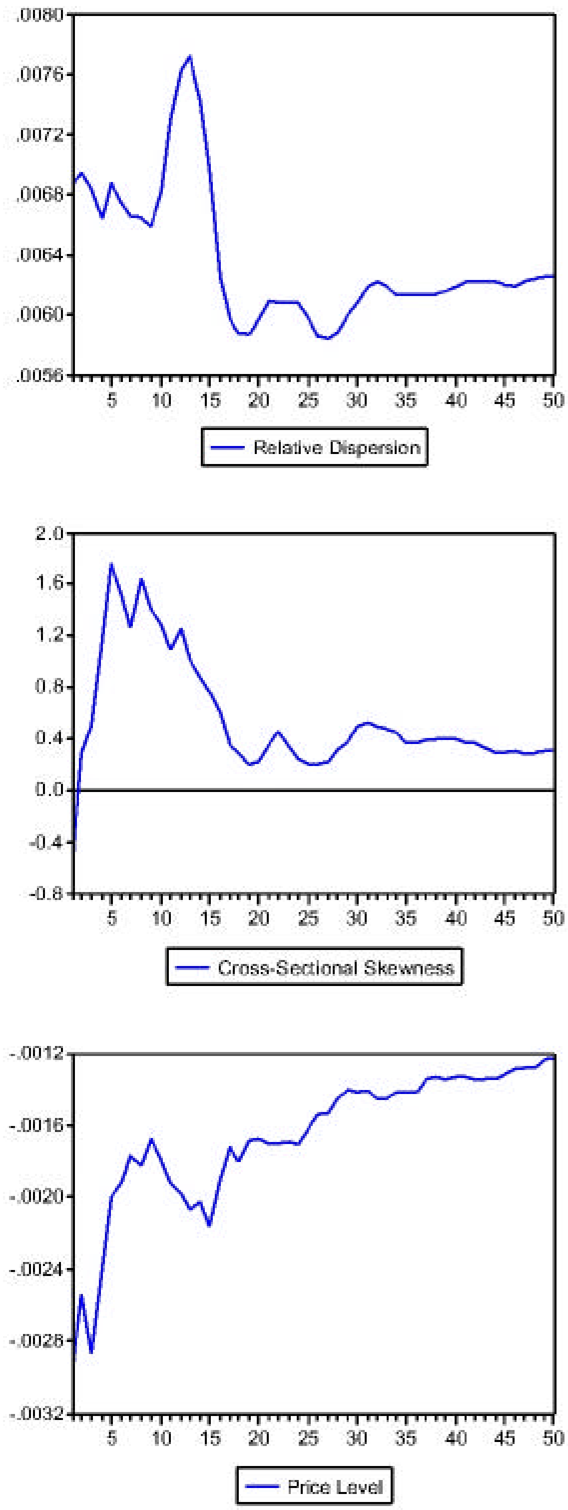


Figure 6: Derived Dynamic Responses to Productivity Shocks

CHAPTER 5

CONCLUSION

The focus of this study is to check the effects of money supply shock and productivity shock on relative dispersion and cross-sectional skewness in a VAR. Its advantage is to sort out money supply shock and productivity shock, which are the real sources of the changes of relative dispersion and cross-sectional skewness.

Two competing theories explain the relationship between the sample moments of relative price distribution and aggregate shocks. Imperfect information theory assumes that only unanticipated money supply shock will affect the relative price dispersion. Menu cost theory allows both money supply shocks and productivity shocks, whether anticipated or unanticipated, to affect the relative price dispersion and cross-sectional skewness.

In chapter 3, I extend Hercowitz's study by using both money supply shock and productivity shocks. Money shock and productivity shock are derived from a conventional five-variable VAR with long-run restrictions. I could replicate Hercowitz's original results, and add some additional findings. First, productivity shocks have little explanatory power for the relative price dispersion, which is consistent with Hercowitz's arguments. This implies that imperfect information theory is explaining the relationship between relative dispersion and money supply shocks better than menu cost theory is. Second, the symmetry problem suggested by Hercowitz is verified. Using positive and negative aggregate shocks, I find that both shocks have effects of the same directions on relative price dispersion. Third, the nonlinear responses of relative price dispersion on money supply shocks are found. This supports Jaramillo's (1999) results. The magnitudes of the responses of positive and negative money supply shocks are different, and negative money supply shocks have much larger effects on relative price dispersion.

Second, the disaggregated VAR is introduced in this study of relative dispersion and cross-sectional skewness for the first time. I use individual relative prices as endogenous variables in the system as well as other macroeconomic variables. Severe restrictions are used for identification as well as long-run restrictions. The dynamic responses of relative dispersion and cross-sectional skewness are derived from the impulse responses of individual relative nominal prices in the rate of change in the system. Then I check the implied relationship between inflation and relative dispersion and inflation and skewness with money supply shocks and productivity shocks.

Productivity shock has a significant effect on the sample moments of relative price distributions, while money supply shock has strongly affected those too. This result supports menu cost theory, because it suggests that both aggregate shocks, whether anticipated or unanticipated, can affect relative price distributions due to the cost of price adjustment.

This study, for the first time, allows the individual relative prices to respond to aggregate shocks, and derives the cross-sectional moments from their impulse response functions. This is a better way to reflect the real economy situation, where all individual prices are responding to aggregate shocks, considering that relative dispersion and cross-sectional skewness are simply summary statistics to describe the distributional changes of prices in the face of aggregate shocks.

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APPENDICES

A. THE CODES OF THE PPI INDICES

The codes of the PPI subindices for RPV computation are as follows:

wpu011, wpu012, wpu013, wpu014, wpu015, wpu016, wpu018, wpu021, wpu022, wpu023, wpu024, wpu025, wpu026, wpu028, wpu029, wpu042, wpu043, wpu044, wpu051, wpu052, wpu057, wpu061, wpu063, wpu064, wpu065, wpu066, wpu067, wpu081, wpu082, wpu083, wpu092, wpu101, wpu102, wpu103, wpu104, wpu105, wpu106, wpu107, wpu108, wpu111, wpu112, wpu113, wpu114, wpu117, wpu119, wpu121, wpu122, wpu123, wpu124, wpu126, wpu132, wpu133, wpu134, wpu135, wpu136, wpu137, wpu138, wpu139, wpu141, wpu151, wpu152, wpu153, wpu154, wpu159.

The codes are the first three-digit numbers in wpu00000000 from the PPI indices of Bureau of Labor Statistics. This database can be accessed at www.bls.gov.