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Regional effects of monetary policy

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Abstract

A key element of this dissertation is the examination of the regional and state level effects of monetary policy. The first essay compares two broad approaches to identifying the monetary policy shocks that are used to estimate the regional effects of monetary policy. One approach that has been used in the previous literature assumes that monetary policymakers respond to shocks to regional personal income but do not respond directly to shocks to national income. A second general approach assumes that monetary policymakers respond to shocks to national income but do not respond directly to region-specific income shocks. This assumption is based on descriptions of monetary policymaking that policymakers focus on the national economy and use regional information as a gauge to measure the national economy. The results show that the effects of monetary policy shocks on regional income differ across the two broad approaches to identifying policy shocks. Therefore, assumptions about whether monetary policymakers respond directly to regional shocks seem to matter for estimating the regional effects of monetary policy.

In the second essay, the analysis of the effects of monetary policy is extended to the state level. Using the same methods as in the first essay, we investigate whether responses of state-level income to monetary policy differ from one state to another, whether responses of state-level income differ from the region's overall response, and whether the method of identifying policy shocks matters. Comparisons of states' responses to monetary policy shocks show that each state's response is sometimes quite different from the response of the other states in that region and from the overall response of its region.

In the third essay, the robustness of the results in the first two chapters to the specification of model and the use of alternative definitions of national output are examined.

Chapter 1. Introduction

Vector autoregressive (VAR) models have been widely used in the literature of monetary economics to analyze the effects of monetary policy shocks. Although most studies of the effects of monetary policy effects focus on the aggregate economy, the regional effects of monetary policy have also been examined. Due to regional and state differences in the mix of industries and the size distribution of banks and firms, there is no reason to expect the effect of monetary policy to be the same across different regions and states.

As is the case for estimation of national effects, VAR models have typically been used to estimate the regional and state-level effects of monetary policy, and a critical element in estimating these effects is the identification of policy shocks. In some recent studies, the identification procedure assumes that the Fed responds directly to shocks to regional output rather than to aggregate output (Carlino and DeFina (1998, 1999a, 1999b), Owyang and Wall (2005, 2009), and Crone (2007)). Although regional information plays a role in policy decisions, descriptions of the policy process suggest that movements in aggregate output, rather than movements in regional output, better capture the Fed's response to output. Consequently, this dissertation adapts Lastrapes (2005)'s procedure for identifying and estimating the effects of monetary policy across different industries to identify and estimate the effects of monetary policy shocks in a VAR that includes regional output proxies as well as national variables like GDP, the aggregate price level, and commodity prices. The effects of monetary policy on regional output are estimated, and are compared to estimates that assume a direct Fed response to regional output shocks.

This dissertation's major focus is the robustness of the estimates of the regional and state-level effects of monetary policy shocks to alternative ways of identifying these policy shocks.

The results in this chapter indicate that assumptions about how monetary policymakers respond to shocks to real income seem to matter for estimating the effects of monetary policy on regional economic activity.

As just noted, one approach that has been used in the previous literature assumes that monetary policymakers respond to contemporaneous shocks to personal income in different regions but do not respond directly to shocks to national income: for this dissertation this approach will be called the Owyang-Wall-type approach. The Owyang-Wall (hereafter OW) approach is easy to implement, and allows regional variables to respond to lagged regional output in all regions, but has serious drawbacks: first, only relatively short lags in the VAR can be considered because of the large number of parameters estimated; second, it is not practical to extend the procedure to state-level estimation because of the large number of parameters that would need to be estimated, and lastly OW assumes that the Fed reacted contemporaneously to individual shocks to regional or state incomes rather than directly to a shock to national income. However, the appropriateness of this assumption is questionable given that the Fed responds to national variables and only indirectly to state or regional variables to the extent these variables affect the national economy. Although the Fed considers regional conditions (summarized in the Beige Book) in FOMC meetings, the information in the Beige Book as an indicator of the overall state of the economy (Federal Reserve Board (2004), Yucel and Balke (2001), and Ginther and Zavodny (2001)).

The second general approach noted earlier assumes that monetary policymakers respond to shocks to national income but do not respond directly to region-specific or state-specific income shocks. This assumption is based on descriptions of monetary policymaking that indicate that policymakers consider regional information as a guide to what is happening

nationally but respond just to developments in the national economy (Federal Reserve Bank of San Francisco (2004)). In this dissertation, a VAR that uses this assumption will be called a Lastrapes-type restricted VAR. The Lastrapes-type approach identifies monetary policy shocks using contemporaneous restrictions on national variables assuming no contemporaneous or lagged Fed response to regional or state-level variables. The approach reduces the number of parameters to be estimated by (1) assuming national variables depend on lagged values of other national variables, and (2) making assumptions about regional or state dynamics—output in one region or state depends on lagged output in that region or state and contemporaneous and lagged values of the national variables but not contemporaneous and lagged values of output in other regions or states. In the Lastrapes-type approach one region or state affects other regions or states only through that region or state's lagged effects on national variables. The Lastrapes-type approach generates a near-VAR which can be estimated using equation-by-equation ordinary least square (OLS).

One concern with the Lastrapes-type approach just described is that one region can affect other regions only through the first region's effects on the national economy. One might expect that economic activity in, for example, the Southwest region might have effects on adjoining regions like the Southeast region directly as well as through effects on national variables. A second Lastrapes-type approach suggested by Beckworth (2010) allows regional output to depend on its own lagged values as well as on the lagged values of economic activity in adjoining regions while maintaining the same assumptions about the national variables as before. It is called the "border-effects restricted VAR." In these conditions, OLS is not an efficient estimator since each regional equation has different right-hand-side variables. Consequently,

Seemingly Unrelated Regression (SUR) is used to estimate the border-effects restricted VAR.[1]

In addition to using different identification schemes to identify monetary policy shocks, previous studies have used different sets of variables in the VAR and have estimated the VARs over different samples. As might be expected, the magnitude and timing of the effects of monetary policy differ across studies, but it is not clear whether the differences stem from the different identification schemes or whether the differences result from different model specifications and different sample periods. The goal of this dissertation is to try to isolate the effects of different identification schemes from the effects of different model specifications and different samples by using a common set of model variables and a common sample to estimate the effects of monetary policy shocks identified using the schemes outlined above.

Both regional and state-level data for the 48 contiguous states are used. It is important to extend the analysis to state level data since the response across states in a particular region may differ from one another and from the region's overall responses.

The robustness of the results to the specification of model and the definitions of national output is considered. Specifically, robustness of the estimated regional and state-level effects of monetary policy is checked by: 1) including fiscal policy variables in the model; 2) including a measure of aggregate uncertainty in the model; and 3) considering two alternative measures of national economy activity.

The structure of dissertation is following: Chapter 2 examines the regional effects of monetary policy using the Bureau of Economic Analysis (BEA) regions data. We compare two broad approaches of identifying monetary policy shocks. Chapter 3 extends the analysis of the effects of monetary policy shock to state-level data. Using the same methods as in the Chapter 2,

[1] For a discussion of the SUR, see suggested by Judge, et. al (1988), Keating (2000) and Greene (2003).

we investigate whether responses to monetary policy different from one another and from the region's overall response. Chapter 4 examines the takes a robustness of the results reported in the previous two chapters to differences in model specification. Chapter 5 presents the conclusion.

Chapter 2. Eight Bureau of Economic Analysis (BEA) Regions Case[2]
2.1 Introduction

The nation's central bank conducts monetary policy; its main goal is to minimize economic fluctuations and keep inflation low. It could affect many economic and financial decisions people make, such as whether to get a loan to begin a business, to buy a new house or car, whether to invest in a business by expanding in a new plant or machine, and whether to put money in a bank, bonds, or the stock market. In formulating current monetary policy, the Federal Reserve focuses primarily on the state of the national economy, although Beige book information (periodic reports from the regional Federal Reserve Banks) about regional economic conditions also plays a role in monetary policy decision making; descriptions of the policy process suggest that this regional information is used merely as a gauge of the state of the national economy. However, it is clear that the focus on the national economy in executing monetary policy does not mean that the Fed neglects regional economic conditions. It relies on extensive regional data and information, along with statistics that directly measure developments in regional economies, to fit together a picture of the national economy's performance. To quote the Federal Reserve Bank of San Francisco (2004)'s phrase, "This is one advantage to having regional Federal Reserve Bank Presidents sit on the Federal Open Market Committee (FOMC): They're in close contact with economic developments in their regions of the country."

It is possible that a particular state or region is in recession while the national economy is booming. However, for two reasons, the Fed cannot concentrate its efforts on stimulating a weak state or region. Primarily, monetary policy works through credit markets, and since credit markets are linked nationally, there is no way for the Fed to change aggregate demand only in a

[2] See Appendix for the definition of eight regions of Bureau of Economic Analysis (BEA) and alternative definitions.

specific state or region that really needs help. Secondly, if the Fed stimulated whenever a particular state or region had economic hard times, even though the national economy was doing well it could result in excessive stimulus for the overall economy and higher inflation.

As mentioned earlier, estimates of the macroeconomic effects of monetary policy typically focus on the effects on national-level variables like aggregate output. However, due to regional and state differences in the mix of industries and the size distribution of banks and firms, there is no reason to expect the effect of monetary policy to be the same across different regions and states. In fact, almost 50 years ago, Walter Isard, founder of the Regional Science Association, stated that "since each of [the nation's] regions has different resource potential and confronts obstacles to growth, it follows that monetary policies alone generate both retarding factors for some regions and problem intensifying factors other regions." It is also important for the business people, civic leaders, government officials and ordinary people to understand how much their regions and states will be affected by changes in monetary policy relative to the rest of the country. The regional effects of monetary policy have been estimated by, among others, Carlino and DeFina (1998, 1999a, 1999b), Crone (2007), Owyang and Wall (2005, 2009) and Beckworth (2010). These estimates of the regional or state-level effects of monetary policy typically use vector autoregressive (VAR) model and generally suggest some differences across regions and states in the timing and magnitude of the effects of monetary policy.

A key element in the estimation of the effects of monetary policy is the identification of exogenous monetary policy shocks. Monetary shocks are changes in the monetary instrument that are predictable responses to other variables in the economy. Most previous VAR studies of the regional effects of monetary policy like those of Carlino and DeFina (1998, 1999a, 1999b) and Owyang and Wall (2005, 2009) used an identification scheme in which it was assumed that

the Fed reacted contemporaneously to individual shocks to regional or state incomes rather than directly to a shock to national income. However, the appropriateness of this assumption is questionable given that, as noted earlier, the Fed responds to national variables and only indirectly to state or regional variables to the extent these variables affect the national economy. Beckworth (2010) follows this current monetary policy description. He used an identification scheme that assumed a systematic response only to national variables rather than assuming the Fed directly responded contemporaneously to movements in state variables. All studies find asymmetric regional effects of monetary policy but magnitude and timing differ across studies.

The major focus in this chapter is the robustness of the estimates of the regional effects of monetary policy shocks to alternative ways of identifying these policy shocks. Unlike earlier studies in the literatures, we use the same sample and same set of variables, so the effects of different identification schemes can be identified. The next chapter examines the robustness of the state-level effects of monetary policy shocks to alternative identification schemes. Given the consensus that aggregate economic activity conditions monetary policy decisions, it is important to consider whether estimates of the regional effects of monetary policy shocks are sensitive to allowing a direct contemporaneous response of monetary policy to national output rather than assuming that the Fed reacts contemporaneously to individual shocks to regional or state-level economic activity.

We apply a procedure developed by Lastrapes (2005) for estimation of the effects of shocks in a large-scale restricted VAR in which there are two subsets of variables. One subset contains national variables, including the monetary policy variable, and the other subset includes regional variables. In the first block national variables are function only of lags of the national variables, but in second block the regional variables are function of their own lags and lags of the

national variables. Lastrapes (2005) showed that this VAR can be estimated efficiently by ordinary least squares (OLS). Loo and Lastrapes (1998) used this procedure to estimate the effects of money supply shocks on industry-level output in a model in which one block consisted of industry-level output variables and the second block contained national economic variables. Lastrapes (2006) also used this procedure to estimate the effects of money supply and productivity shocks on the distribution of relative commodity prices in a model in which one block consisted of individual commodity prices and the other block contained aggregate economic variables.

We use Lastrapes' technique to estimate the regional effects of monetary policy shocks within a large restricted VAR that comprises both national and regional variables and in which monetary policymakers respond only to contemporaneous and lagged movements in national variables. One block in this model includes only regional personal income (PI) measures, and, following Lastrapes (2005), the correlation among regional personal incomes is assumed to be due solely to a response of the regional variables to the national variables that are included in the second block. Thus, there is no direct effect of one region on another region. Monetary policy shocks are identified using a standard Choleski decomposition of the variables in the national block, and impulse response functions (IRFs) for the effect of a monetary policy shock on regional personal incomes are computed.

A concern about strict application of Lastrapes' procedure to estimating the regional effects of monetary policy is the assumption that economic activity in one region affects economic activity in other regions only indirectly to the extent that economic activity in one region affects the national economy which in turn affects the other regional economies. This assumption rules out "border effects" in which there is direct feedback among contiguous

regions. For example, one might expect that economic activity in the Southwest region might have direct effects on economic activity in the Southeast region as well as indirect effects. Consequently, we consider a restricted VAR model that allows direct feedback among contiguous regions. However, this change in specification means that the restricted VAR can no longer be estimated using OLS since the equations in the regional block have lags of contiguous regional PI as well as lags of the national variables, and the contiguous regional PI variables vary from region to region. First, since contiguous region's PI may be an explanatory variable in another region equation, that regional equation's error term may be correlated with other disturbances in other regional equations. Second, each regional equation is constrained due to the border effect, so each regional equation has different right-hand-side variables from the others. Because of this, Seemingly Unrelated Regression (SUR) improves the efficiency of the estimates (see Judge, et. al (1988), Keating (2000), and Greene (2003, p.343)), and SUR is used to estimate the VAR with border effects.

Section 2 describes the previous research on the regional effects of monetary policy. Section 3 explains the three statistical models and the set of identifying restrictions used to identify to monetary policy shocks. Section 4 describes the data and Section 5 reports the empirical results. This section examines the impulse responses of the national and regional variables in the model to a monetary shock. Section 6 examines the empirical result of Crone's alternative definition of eight regions. Section 7 is the conclusion.

2.2 Previous Research on the Regional Effects of Monetary Policy

2.2.1 Gerald Carlino and Robert DeFina (1998)

Carlino and DeFina use a quarterly structural vector autoregression (SVAR) to examine whether monetary policy shocks have symmetric effects across the eight BEA regions in the United States. The VAR includes the growth rates of real personal income in the eight BEA

regions, the rate of change the relative price of energy, and a monetary policy variable for the period 1958:1 to 1992:4. Following Bernanke and Blinder (1992), Carlino and DeFina use the Federal Funds Rate (FFR) for the monetary policy instrument. Carlino and DeFina also use alternative monetary policy instrument (nonborrowed reserves and a narrative measure by Boschen and Mills (1995)) to test the robustness of the results to the choice of policy indicator. Finally, an energy price variable was included in the system to account for aggregate supply shocks.

Carlino and DeFina do not use Choleski decomposition for the identification of the monetary policy shock. Choleski decomposition will be explained in detail later section. However, they use three sets of restrictions on the contemporaneous impact matrix. First, as in Carlino and DeFina (1995), they assume that a region-specific shock affects only the region of origin and there is no contemporaneous effect on other regions. That is, a shock to a region's real PI growth affects other regions' growth only after one-period lag. Second, Fed policy actions have monetary impact lags and shocks to the relative energy price have no contemporaneous effect on regional income. Third, regional income growth and policy actions do not have contemporaneous effect on the relative energy prices.

Sims (1980) shows that the impact of monetary policy can be summarized by computing impulse response functions (IRFs) which show the effect over time of a shock to a variable in the system on itself in the own variable. Both regular and cumulative IRFs for a shock to monetary policy are computed from the moving average representation (MAR) for structural system. The regular IRF shows the effect of a monetary policy shock on the rate of change of the other variables. The cumulative IRF adds up the effects of the regular IRF and shows the effect on the each of the other variables.

Carlino and DeFina used cumulative impulse response functions (IRFs) to show how the level of real personal income in a region changes over time because of a monetary policy shock and to classify regions into two groups. First is the core region – New England, the Mideast, the Plains, the Southeast, and the Far West – that responds to monetary policy shocks in ways that closely approximate the U.S. average response. Second is the noncore region – the Great Lakes, the Southwest and the Rocky Mountains – that responds to monetary shocks in ways that are different from the U.S. average response. The Great Lakes is found to be the most sensitive region to monetary policy shocks, while the Southwest and Rocky Mountains are found to be the least sensitive. They show the core and noncore results are robust to alternative measures of monetary policy, measures of economic activity, and model specification.

2.2.2 Owyang and Wall (2005, 2009)

For the sample period for 1960: I – 2002: IV, Owyang and Wall (hereafter OW) estimate the effect on personal income of an unanticipated increase of one percentage point in the federal funds rate. Their VAR includes the log level of the real personal income (PI) of the 8 BEA regions, the log CPI price level, the federal funds rates, the 10-year Treasury rate, and a commodity price index. They also include an exogenous oil shock dummy corresponding to the Hoover and Perez (1994) oil dates. Hamilton (1983) finds dates characterized by dramatic increases in the nominal price of oil not related to the state of the economy and identified exogenous oil-supply shocks with dummy variables associated with these dates. Hoover and Perez (1994) work with monthly data and extend the number of oil-shock dates originally suggested by Hamilton (1983). Hoover and Perez's ten oil price shocks are (monthly date followed by the corresponding quarter): (1) December, 1947 – 1947: IV, (2) June, 1953 – 1953: II, (3) June, 1956 – 1956: II, (4) February, 1957 – 1957: I, (5) March, 1969 – 1969: I,

(6) December, 1970 – 1970: IV, (7) January, 1974 – 1974: I, (8) March, 1978 – 1978: I, (9) September, 1979 – 1979: III, and (10) February, 1981 – 1981: I.

OW partition the VAR variables into three blocks and employ a standard Choleski recursive identification: the vector x_t includes variables that are assumed to not be affected contemporaneously by a monetary policy shock (log Consumer Price Index (CPI) price level and log level of real regional personal incomes), the vector r_t is the policy block and contains the monetary policy variable (FFR), and the vector z_t includes variables (10-year Treasury rate and a commodity price index) which are assumed to have a contemporaneous response to monetary policy shocks. That is, the ordering is $[x_t, r_t, z_t]$. Thus, OW assume that monetary policy responds contemporaneously to CPI and regional PI variables but affects these variables only with a lag. They also assume monetary policy affects the bond rate and commodity prices contemporaneously and responds to these variables only with a lag.

As in the previous literature, OW also assume that a regional income shock does not affect other regions contemporaneously.

For the Owyang and Wall VAR model, the ordering of the vector of variables is $[Y_t^{NE}, Y_t^{ME}, Y_t^{GL}, Y_t^{PL}, Y_t^{SE}, Y_t^{SW}, Y_t^{RM}, Y_t^{FW}, CPI_t, FFR_t, TB_t, COP_t]$. With respect to the ordering of COP, it is not the conventional ordering. Many studies order commodity prices before the monetary policy variable which means that monetary policy responds contemporaneously to movements in commodity prices. That is the whole point of Sims' inclusion of commodity prices in a VAR (see Sims (1986)).

For the full sample, Owyang and Wall's regional results are similar to those of Carlino and DeFina (1998). The Great Lakes region is the most sensitive region to monetary policy shocks, while the Southwest and Rocky Mountain regions are the least sensitive.

2.2.3 Crone (2007)

Crone replicates Carlino and DeFina's original study using the alternative definition of regions. His alternative definition of regions (see Appendix) is based on Crone (2005) in which he groups contiguous states into eight regions based on the similarity of business cycles. In the 1950s, the BEA grouped eight regions based on economic and noneconomic social factors at that time. However, recent studies (Carlino and Sill (2001), and Crone (2006)) show that some states' business cycles are more closely matched with those in states in adjoining BEA regions than those in their own BEA region. For example, Louisiana is now grouped by Crone with Texas, Oklahoma and other states in which the main industries are oil-related industries. Crone estimates impulse response of U.S. aggregate personal income to a monetary policy shock as a benchmark for comparison to IRFs of 8 BEA regional PI. He finds the same basic patterns as in the original study, but the monetary policy effects are significantly different from the national average in more regions than in the original study. In Crone (2007), the Great Lakes region is the most significantly affected region and the Energy Belt which is made up portions of the BEA's Southwest and Rocky Mountain regions is the least affected region. We will examine this issue further in Section 6.

2.2.4 Beckworth (2010)

Beckworth uses Lastrapes' method (2005, 2006) to examine whether monetary policy shocks have symmetric effects across the 48 contiguous states in the United States. Beckworth uses an identification scheme that assumes a systematic response of the fed funds rate only to national variables rather than assuming the Fed directly responds contemporaneously to movements in state variables. He further assumes no direct effect of the state economic variables on the national economic variables, but assumes the state economies can be directly affected by

the national economy. Beckworth creates a 52-variable VAR. Then, he partitions this into two blocks. In the first block are the national macroeconomic variables that include a real economic activity measure, CPI price index, the commodity price index, and FFR. In the second block are state-level variables that include a real economic activity measure for the 48 contiguous states. In addition to allowing the national economy to affect state economies, Beckworth also allows state economies that border one another to affect each other.

As in Lastrapes (2005, 2006), to increase degrees of freedom and to enable estimation of the system, Beckworth imposes two sets of over-identifying restrictions on the VAR model. First, a state-specific shock affects economic activity only in that state and contiguous states. This reflects the assumption that there are no contemporaneous direct effects of one state on another unless they are adjoined. Second, it is assumed the state-level variables do not have a direct effect on the national macroeconomic variables.

Beckworth uses monthly data and the estimation period is 1983:1 to 2008:3. He finds there are different patterns of response to the monetary policy shock; 12 states' real economic activity declines less than the U.S., 8 states respond significantly more to the shock than does the aggregate economy, so their real economic activity measure decreases more than that for the U.S., and the rest of the states' responses are similar to the response for the entire U.S.

2.3 Empirical Framework

This section's major focus is the robustness of the estimates of the regional effects of monetary policy shocks to alternative ways of identifying these policy shocks. We want to compare two broad approaches to identifying the monetary policy shocks that are used to estimate the regional effects of monetary policy. The assumptions about how monetary

policymakers respond to shocks to real income seem to matter for estimating the effects of monetary policy on regional economic activity.

One approach that has been used in the previous literature assumes that monetary policymakers respond to contemporaneous shocks to personal income in different regions but do not respond directly to shocks to national income: this is called the Owyang-Wall-type standard VAR.

A second general approach assumes that monetary policymakers respond to shocks to national income but do not respond directly to region-specific income shocks. This assumption is based on descriptions of current monetary policy formulating that policymakers consider only regional information as a gauge for developments in the national economy. This is called the Lastrapes-type restricted VAR. The Lastrapes-type approach identifies monetary policy shocks using contemporaneous restrictions on national variables assuming no contemporaneous or lagged Fed response to regional. In the Lastrapes-type approach one region affects other regions only through that region lagged effects on national variables. The Lastrapes-type approach can be estimated using equation-by-equation ordinary least square (OLS).

One concern of the Lastrapes-type approach is that one region can affect other regions only through the first region's effects on the national economy. A second Lastrapes-type approach allows regional output to depend on its own lagged values as well as on the lagged values of economic activity in contiguous regions while maintaining the same assumptions about the national variables as before. It is called the "Border-Effects restricted VAR." In this condition, we use the SUR since OLS is not an efficient estimator.

Our goal is to compare the estimates of the monetary policy effects identified using a similar identification procedure and the same sample to see if the estimates are sensitive to

alternative ways of specifying the VAR. Hence, in this section we describe the VAR models estimated and the identification of monetary policy shocks.

If we suppress the intercept, a structural linear dynamic model can be written as $A_0 y_t = \sum_{i=1}^{n} A_i y_{t-i} + u_t$ where, in our case, y_t = vector of endogenous variables that can be partitioned into two blocks x_t and z_t, x_t = regional block which consists of the 8 regional personal income variables, z_t = national block, A_0 = matrix of contemporaneous effects, $A_i, i = 1, \cdots, n$, are matrices of lagged coefficients, u_t = vector of uncorrelated structural shocks, and $u_t \sim N(0, \Omega)$. The structural model can be written as a vector autoregressive (VAR) model by solving for y_t: $y_t = \sum_{i=1}^{n} A_0^{-1} A_i y_{t-i} + A_0^{-1} u_t$ or as $y_t = \sum_{i=1}^{n} \beta_i y_{t-i} + \varepsilon_t$ where $\beta_i = A_0^{-1} A_i$, ε_t = vector of reduced form shocks $= A_0^{-1} u_t$, $\varepsilon_t \sim N(0, \Sigma)$ and $\Sigma = A_0^{-1} \Omega A_0^{-1'}$. To estimate the dynamic effects of monetary policy shocks, the moving average representation of the VAR is derived. Derive MA from reduced form expression, $y_t = \beta_1 y_{t-1} + \beta_2 y_{t-2} + \cdots + \beta_n y_{t-n} + \varepsilon_t$ (1) or $\left(I - \beta_1 L - \beta_2 L^2 - \cdots - \beta_n L^n\right) y_t = \varepsilon_t$, where $L =$ lag operator. This can be written as: $y_t = C(L)\varepsilon_t$ where $C(L) = \left(I - \beta_1 L - \beta_2 L^2 - \cdots - \beta_n L^n\right)^{-1}$. In terms of the structural shocks, the moving average representation can be written as $y_t = C(L) A_0^{-1} u_t$, and the effects of a typical shock can be estimated from $y_t = C(L) A_0^{-1} \Omega^{1/2}$ where $\Omega^{1/2}$ is a diagonal matrix with the estimated standard deviations of the structural shocks on the diagonal. The elements of the MA representation are impulse response functions (IRFs) which show the dynamic effects of shocks on the variables in the model. IRFs based on reduced-form shocks (ε_t) are not meaningful. These shocks are non-linear

combinations of the structural shocks and hence are correlated across equations. As noted earlier, the reduced form shock is $\varepsilon_t = A_0^{-1} u_t$, which can be solved for u_t:

$$u_t = A_0 \varepsilon_t \tag{2}$$

Estimates of u_t can be obtained by placing restrictions on the elements of A_0. These restrictions can be based on economic theory, prior empirical evidence or assumption about policy makers' behavior.

Restrictions on A_0 also allow us to obtain an estimate of the structural variance-covariance matrix Ω, from the VAR variance-covariance matrix Σ.

We know that,

$$E[u_t u_t'] = \Omega$$

$\Omega = E[A_0 \varepsilon_t \varepsilon_t' A_0']$, from $u_t = A_0 \varepsilon_t$ in (2).

$$\Omega = A_0 E[\varepsilon_t \varepsilon_t'] A_0'$$

$$\Omega = A_0 \Sigma A_0', \text{ where } E[\varepsilon_t \varepsilon_t'] = \Sigma \tag{3}$$

Rearranging we get,

$$\Sigma = A_0^{-1} \Omega A_0^{-1'} \tag{4}$$

where Ω is the variance-covariance matrix of the structural errors. Given that the diagonal elements of A_0 are all unity, A_0 contains $n^2 - n$ unknown values. The variance-covariance matrix Ω contains n unknown values; these are the variances of the structural errors. Thus, the structural model contains $n^2 (= n^2 - n + n)$ unknown elements. In contrast, the variance-covariance matrix Σ of the reduced model contains only $(n^2 + n)/2$ elements because it has a symmetric nature. The equation (3) is under-identified since there is a total of n^2 parameters and

a total of $(n^2 + n)/2$ restrictions. Therefore, it cannot be solved. To identify the structural model from an estimated reduced VAR model, it is necessary to use economic theory in order to impose $(n^2 - n)/2$ $(= n^2 - (n^2 + n/2))$ restrictions on the structural model.

A method commonly used to impose restrictions is the Choleski decomposition. The Choleski decomposition imposes a recursive causal chain with variables placed higher in the vector of model variables assumed to contemporaneously cause changes in the variables lower in the ordering of variables. This is a standard assumption in monetary policy analysis which enables transformation of the errors of the reduced form of the VAR model into structural errors. This procedure is well explained in Bagliano and Favero (1998) and Eichenbaum, Christiano and Evans (1999).

Since both sides of equation (3) are equivalent, they must be the same element by element. Enders (2004) gives a numerical example of the Choleski decomposition: The structural errors show the following pattern:

$$
\begin{aligned}
u_{1,t} &= \varepsilon_{1,t} \\
u_{2,t} &= a_{21}\varepsilon_{1,t} + \varepsilon_{2,t} \\
u_{3,t} &= a_{31}\varepsilon_{1,t} + a_{22}\varepsilon_{2,t} + \varepsilon_{3,t} \\
&\;\;\vdots \\
u_{n,t} &= a_{n1}\varepsilon_{1,t} + a_{n-1,2}\varepsilon_{2,t} + \cdots + \varepsilon_{n,t}
\end{aligned}
$$

By using a recursive (Choleski) structure, the correlated disturbances ε are orthogonalized in the previous equation system. The Choleski decomposition implies a causal impact of the shocks: u_1 affects u_2, u_1 and u_2 affect u_3, and so on. This imposes the recursive causal ordering,

$$u_{1,t} \rightarrow u_{2,t} \rightarrow u_{3,t} \rightarrow \cdots \rightarrow u_{n,t} \qquad (5)$$

The ordering (5) means that the contemporaneous effects of the errors to the left of the arrow affect the contemporaneous values of the errors to the right of the arrow but the converse is not true. These contemporaneous effects are captured by the coefficients A_0. For example, the ordering $u_1 \rightarrow u_2 \rightarrow u_3$ imposes the restrictions: $u_{1,t}$ affects $u_{2,t}$ and $u_{3,t}$ but $u_{2,t}$ and $u_{3,t}$ do not affect $u_{1,t}$; $u_{2,t}$ affects $u_{3,t}$ but $u_{3,t}$ does not affect $u_{2,t}$. By the same token, the ordering $u_2 \rightarrow u_3 \rightarrow u_1$ imposes the restrictions: $u_{2,t}$ affects $u_{3,t}$ and $u_{1,t}$ but $u_{3,t}$ and $u_{1,t}$ do not affect $u_{2,t}$; $u_{3,t}$ affects $u_{1,t}$ but $u_{1,t}$ does not affect $u_{3,t}$ and $u_{2,t}$. This Choleski decomposition implies that A_0 is a lower triangular. Since the matrix is lower triangular, $(n^2 - n)/2$ elements of A_0 are set to zero and equation (3) is exactly identified.

It is important to note that the decomposition forces an asymmetry since not all shocks affect the variables contemporaneously. Therefore, the ordering of the variables in the VAR model is critical. Care should be taken in selecting the ordering in a Choleski decomposition.

For all the models we consider, a standard Choleski decomposition is used to obtain estimates of the effects of a structural shock to monetary policy. Contemporaneous feedback among the shocks is certainly possible, and there are alternative identification schemes that can account for contemporaneous feedback among the variables. However, since our main focus is on the effects of assuming a direct response by monetary policymakers to region-specific shocks rather than a direct response only to shocks to national variables, we focus just on the simple-to-implement and commonly used Choleski decomposition. In the next three sections, we will explain the Owyang-Wall-type standard VAR model, the Lastrapes-type Restricted VAR model, and the Border-effects Restricted VAR model.

2.3.1 Owyang-Wall-Type Standard VAR Model

We first consider an Owyang and Wall (hereafter OW)-type VAR and then discuss the restricted VARs. As shown by Owyang and Wall (2005, 2009), OW-type VAR model includes the regional personal incomes, but not national personal income. The OW-type VAR model assumes monetary policymakers respond directly to region-specific shocks using Choleski decomposition.

Following Owyang-Wall (2005, 2009), we consider a three-lag structural economic model,

$$A_0 y_t = \sum_{i=1}^{3} A_i y_{t-i} + \sum_{i=1}^{3} B_i w_{t-i} + u_t \,, \qquad (6)$$

From (6), we pre-multiply both sides by A_0^{-1} to get the reduced-form VAR:

$$A_0^{-1} A_0 y_t = A_0^{-1} \sum_{i=1}^{3} A_i y_{t-i} + A_0^{-1} \sum_{i=1}^{3} B_i w_{t-i} + A_0^{-1} u_t$$

$$y_t = A_0^{-1} \sum_{i=1}^{3} A_i y_{t-i} + A_0^{-1} \sum_{i=1}^{3} B_i w_{t-i} + A_0^{-1} u_t \qquad (7)$$

$$y_t = \sum_{i=1}^{3} \beta_i y_{t-i} + \sum_{i=1}^{3} \delta w_{t-i} + \varepsilon_t \qquad (8)$$

where, $\beta_i = A_0^{-1} A_i \,, i = 0,1,2,3,\ \delta = A_0^{-1} B_i \,, i = 1,2,3,\ \varepsilon_t = A_0^{-1} u_t \,,\ u_t \sim N(0,\Omega), \varepsilon_t \sim N(0,\Sigma)$ and $\Sigma = A_0^{-1} \Omega A_0^{-1'}$, where y_t is the period t vector of 12 variables which are partitioned into two blocks, w_t is a measure of exgenous shocks corresponding to the Hoover and Perez (1994) dates described earlier. We used a Choleski decomposition to indentify monetary policy shock. The vector of endogenous variables, y_t ,can be partitioned as follows: $y_t = [x_t, z_t]'$. The first block in an OW-type VAR is a regional block that consists of real personal income from the 8 BEA

regions, and the second block is a national block that includes the price level (PCE), a commodity price index (COP), the federal funds rate (FFR), and a long-term bond rate (TB). In this VAR, lags of each variable affect every other variable. Additionally, lags of an oil shock dummy are included as an exogenous variable in each equation of the model along with an intercept term. FFR is the monetary policy variable, and a structural monetary policy shock is identified using a Choleski decomposition using the ordering just described.

This ordering assumes that monetary policymakers respond contemporaneously to shocks to the regional personal income variables, the aggregate price level, and the commodity price index in setting the FFR, but policy actions affect these variables only with a lag. Although OW assume that within the regional block a shock to personal income in one region has no contemporaneous effect on personal income in other regions, since we are only interested in identifying monetary policy shocks and not regional shocks, whether a shock to personal income in one region does or does not have a contemporaneous effect on personal income in other regions does not affect the identification of the monetary policy shocks since we assume in either case that monetary policymakers respond contemporaneously to shocks to regional personal income. Consequently, we use a standard Choleski decomposition which implies that within the regional block shocks to personal income in regions higher in the ordering have contemporaneous effects on personal income in regions lower in the regional ordering. We also order commodity prices before the funds rate in order to allow a contemporaneous response by policymakers to shocks to commodity prices. We further assume that monetary policy actions affect the long-term bond rate within the period, but that policymakers respond to movements in the long-term bond rate only with a lag. Based on our assumptions, for the OW-type VAR, the vector of variables in the Choleski decomposition ordering is

$$y_t = \left[Y_t^{NE}, Y_t^{ME}, Y_t^{GL}, Y_t^{PL}, Y_t^{SE}, Y_t^{SW}, Y_t^{RM}, Y_t^{FW}, PCE_t, COP_t, FFR_t, TB_t\right]'.$$

2.3.2 Lastrapes-Type Restricted VAR Model

The specification of the first restricted VAR we consider is based on the assumptions in Lastrapes (2005) that allow estimation by ordinary least squares (OLS). In this model, we assume policy makers respond only to contemporaneous and lagged movements in national variables but policy actions affect both national and regional variables. We will explain more detail about this assumption using Choleski decomposition.

As shown by Lastrapes (2005), let $y_t = \begin{pmatrix} z_t \\ x_t \end{pmatrix}$ be a (13×1) vector stochastic process that can be partitioned into two blocks. z_t is a vector of national variable; it is our first block of model and is a (5×1) matrix that contains aggregate real personal income (PI) (which was not directly included in the OW-type VAR), followed by the price level (PCE), the commodity price index (COP), the federal funds rate (FFR), and Treasury bill rate (TB). x_t is an (8×1) matrix that contains a real economy activity measures for the regional economies (eight regions' real personal income).

Assume that this process is generated by the linear dynamic model:

$$A_0 y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t \qquad (9)$$

$$= B_1 y_{t-1} + \ldots + B_p y_{t-p} + \varepsilon_t, \qquad (10)$$

where $B_i = A_0^{-1} A_i$, A_i, $i = 0,1,\ldots,p$, is a (13×13) matrix that A_0 is coefficient matrix of contemporaneous effects, $A_i, i = 1,\cdots,p$ is coefficient matrices for lagged effects of y, and $u_t = \begin{pmatrix} u_{zt} \\ u_{xt} \end{pmatrix}$ is a (13×1) white noise vector process normalized so that $Eu_t u_t' = I$, $E\varepsilon_t \varepsilon_t' = \Sigma$.

Thus, $y_t = [z_t, x_t]'$ and the contemporaneous matrix of A_0 in the structural model can be written as: $\begin{bmatrix} A_{01z} & A_{01x} \\ A_{02z} & A_{02x} \end{bmatrix}$.

Following the logic of Lastrapes (2005, 2006), we consider two sets of over-identifying restrictions on the VAR. First, the regional economy variables are assumed not to affect the macroeconomic variables either contemporaneously or with lags. Thus, the (1, 2) element of the A_0 sub matrix ($A_{01x} = 5 \times 8$) is a null matrix. Second, a regional-specific shock affects only that region contemporaneously; the (1, 2) element of the A_0 sub matrix ($A_{02x} = 8 \times 8$) is diagonal. Lastrapes (2005) proves that under these conditions, equation-by-equation OLS estimation is efficient.

Let us examine our structural model in more detail. The (1, 1) element of the A_0 matrix, A_{01z} is a (5 × 5) matrix of national variables with 1's on the diagonal, non-zero coefficients below the diagonal, and 0's above the diagonal.

The (1, 1) element of the $A_0 = A_{01z} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{021z} & 1 & 0 & 0 & 0 \\ a_{031z} & a_{032z} & 1 & 0 & 0 \\ a_{041z} & a_{042z} & a_{043z} & 1 & 0 \\ a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 \end{bmatrix}$

This implies a recursive causal chain in which output, the price level, and commodity prices have contemporaneous effects on the funds rate, but the funds rate has no contemporaneous effects on output, the price level, and commodity prices. The funds rate has a contemporaneous effect on the long-term bond rate. We have discussed earlier that the element of the A_{01z} matrix do not have to have a recursive structure; contemporaneous feedback is

possible, but we specify a recursive structure since we use a Choleski decomposition to identify policy shocks.

The (1, 2) element of the A_0 matrix, A_{01x} is a (5 × 8) null matrix.

$$\text{The (1, 2) element of the } A_0 = A_{01x} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

It reflects the assumption that the regional variables do not have a direct effect on the national variables.

The (2, 1) element of the A_0 matrix, A_{02z} is an (8 × 5) matrix of coefficients that are all allowed to be non-zero.

$$\text{The (2, 1) element of the } A_0 = A_{02z} = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ a_{081z} & a_{082z} & a_{083z} & a_{084z} & a_{085z} \\ a_{091z} & a_{092z} & a_{093z} & a_{094z} & a_{095z} \\ a_{0101z} & a_{0102z} & a_{0103z} & a_{0104z} & a_{0105z} \\ a_{0111z} & a_{0112z} & a_{0113z} & a_{0114z} & a_{0115z} \\ a_{0121z} & a_{0122z} & a_{0123z} & a_{0124z} & a_{0125z} \\ a_{0131z} & a_{0132z} & a_{0133z} & a_{0134z} & a_{0135z} \end{bmatrix}$$

These coefficients represent the contemporaneous effects of the national variables on the regional variables.

The (2, 2) element of the A_0 matrix, A_{02x} is an (8 × 8) diagonal matrix with 1’s on the diagonal.

$$\text{The (2, 2) element of the } A_0 = A_{02x} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

This reflects the assumption that there are no contemporaneous direct effects of one region on another.

The A_1 matrix can be written as $\begin{bmatrix} A_{11z} & A_{11x} \\ A_{12z} & A_{12x} \end{bmatrix}$. The (1, 1) element of the A_1 matrix, A_{11z} is a (5 × 5) matrix of coefficients of the effects of the national variables lagged one period on themselves. All these coefficients are allowed to be non-zero.

$$\text{The (1, 1) element of the } A_1 = A_{11z} = \begin{bmatrix} a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} \\ a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} \\ a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} \\ a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} \\ a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} \end{bmatrix}$$

The (1, 2) element of the A_1 matrix, A_{11x} is a (5 × 8) null matrix, reflecting the assumption that the regional variables do not have a direct effect—contemporaneous or lagged—on the national variables.

$$\text{The (1, 2) element of the } A_1 = A_{11x} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The (2, 1) element of the A_1 matrix, A_{12z} is an (8 × 5) matrix of coefficients that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the regional variables.

$$\text{The (2, 1) element of the } A_1 = A_{12z} = \begin{bmatrix} a_{161z} & a_{162z} & a_{163z} & a_{164z} & a_{165z} \\ a_{171z} & a_{172z} & a_{173z} & a_{174z} & a_{175z} \\ a_{181z} & a_{182z} & a_{183z} & a_{184z} & a_{185z} \\ a_{191z} & a_{192z} & a_{193z} & a_{194z} & a_{195z} \\ a_{1101z} & a_{1102z} & a_{1103z} & a_{1104z} & a_{1105z} \\ a_{1111z} & a_{1112z} & a_{1113z} & a_{1114z} & a_{1115z} \\ a_{1121z} & a_{1122z} & a_{1123z} & a_{1124z} & a_{1125z} \\ a_{1131z} & a_{1132z} & a_{1133z} & a_{1134z} & a_{1135z} \end{bmatrix}$$

The (2, 2) element of the A_1 matrix, A_{12x} is an (8 × 8) diagonal matrix with non-zero coefficients on the diagonal.

The (2, 2) element of the $A_1 = A_{12x}$

$$= \begin{bmatrix} a_{166x} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_{177x} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{188x} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{199x} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{11010x} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{11111x} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{11212x} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{11313x} \end{bmatrix}$$

This reflects the assumption that there are no lagged direct effects of one region on another, and the lagged effects of one region on itself are captured in the diagonal coefficients. The other A_i matrices are defined in an analogous manner.

In summary, the structural form of Lastrapes-type VAR is the following linear dynamic model:

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{021z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{031z} & a_{032z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{041z} & a_{042z} & a_{043z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{081z} & a_{082z} & a_{083z} & a_{084z} & a_{085z} & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
a_{091z} & a_{092z} & a_{093z} & a_{094z} & a_{095z} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
a_{0101z} & a_{0102z} & a_{0103z} & a_{0104z} & a_{0105z} & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
a_{0111z} & a_{0112z} & a_{0113z} & a_{0114z} & a_{0115z} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
a_{0121z} & a_{0122z} & a_{0123z} & a_{0124z} & a_{0125z} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
a_{0131z} & a_{0132z} & a_{0133z} & a_{0134z} & a_{0135z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
Y_t^{US} \\ PCE_t \\ COP_t \\ FFR_t \\ TB_t \\ NE_t \\ ME_t \\ GL_t \\ PL_t \\ SE_t \\ SW_t \\ RM_t \\ FW_t
\end{bmatrix}
=
$$

$$
\begin{bmatrix}
a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{161z} & a_{162z} & a_{163z} & a_{164z} & a_{165z} & a_{166x} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{171z} & a_{172z} & a_{173z} & a_{174z} & a_{175z} & 0 & a_{177x} & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{181z} & a_{182z} & a_{183z} & a_{184z} & a_{185z} & 0 & 0 & a_{188x} & 0 & 0 & 0 & 0 & 0 \\
a_{191z} & a_{192z} & a_{193z} & a_{194z} & a_{195z} & 0 & 0 & 0 & a_{199x} & 0 & 0 & 0 & 0 \\
a_{1101z} & a_{1102z} & a_{1103z} & a_{1104z} & a_{1105z} & 0 & 0 & 0 & 0 & a_{11010x} & 0 & 0 & 0 \\
a_{1111z} & a_{1112z} & a_{1113z} & a_{1114z} & a_{1115z} & 0 & 0 & 0 & 0 & 0 & a_{11111x} & 0 & 0 \\
a_{1121z} & a_{1122z} & a_{1123z} & a_{1124z} & a_{1125z} & 0 & 0 & 0 & 0 & 0 & 0 & a_{11212x} & 0 \\
a_{1131z} & a_{1132z} & a_{1133z} & a_{1134z} & a_{1135z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{11313x}
\end{bmatrix}
\begin{bmatrix}
Y_{t-1}^{US} \\ PCE_{t-1} \\ COP_{t-1} \\ FFR_{t-1} \\ TB_{t-1} \\ NE_{t-1} \\ ME_{t-1} \\ GL_{t-1} \\ PL_{t-1} \\ SE_{t-1} \\ SW_{t-1} \\ RM_{t-1} \\ FW_{t-1}
\end{bmatrix}
+ \cdots + A_P y_{t-p} + u_t
$$

By the same reasoning, the reduced form of B_1 matrix in the restricted VAR can be written as $\begin{bmatrix} B_{11z} & B_{11x} \\ B_{12z} & A_{12x} \end{bmatrix}$. The (1, 1) element of the B_1 matrix, B_{11z} is a (5 × 5) matrix of reduced form coefficients of the effects of the national variables lagged one period on themselves. As in the case of the structural coefficient matrices, there are no lagged direct effects of the regional variables on the national variables so the (1, 2) element of the B_1 matrix, B_{11x} is a (5 × 8) null matrix. The (2, 1) element of the B_1 matrix, B_{12z} is an (8 × 5) matrix of reduced form coefficients

that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the regional variables. The (2, 2) element of the B_1 matrix, B_{12x} is an (8 × 8) diagonal matrix with non-zero reduced form coefficients on the diagonal that capture the one period lagged effect of a regional variable on itself. The other B_i matrices are defined in an analogous manner.

The restricted VAR is estimated, and Choleski decomposition is applied to the restricted VAR's estimated variance-covariance matrix with the ordering described above—national block first and regional block next. Even though the Choleski decomposition imposes a recursive structure on the entire A_0 matrix whereas the A_0 matrix described above is not totally recursive throughout the matrix, the monetary policy shock will be correctly identified since the national block is placed before the regional block. Placing the regional block after the national block means the regional variables will have no contemporaneous effects on the national variables, as specified in the A_0 matrix described above. The national block in the A_0 matrix above is recursive and the ordering listed above reflects the assumption that monetary policy responds contemporaneously to shocks to national output (as proxy by national personal income), the aggregate price level, and commodity prices but not to contemporaneous shocks to the long-term bond rate. The ordering further implies that monetary policy shocks affect the long-term bond rate contemporaneously but affect national output, the aggregate price level, and commodity prices only with a lag. For the Lastrapes-type restricted VAR, the vector of variables in the Choleski decomposition ordering is

$$y_t = [Y_t^{US}, PCE_t, COP_t, FFR_t, TB_t, Y_t^{NE}, Y_t^{ME}, Y_t^{GL}, Y_t^{PL}, Y_t^{SE}, Y_t^{SW}, Y_t^{RM}, Y_t^{FW}]' .$$

2.3.3 Border-Effects Restricted VAR Model

One concern with the Lastrapes-type approach just described is that one region can affect other regions indirectly only through the first region's effects on the national economy. One might expect that economic activity in, for example, the Southeast region might have effects on bordering regions like the Southwest, Plains, Great Lakes and Mideast regions directly as well as indirectly through effects on national variables. A second Lastrapes-type approach allows regional output to depend on its own lagged values as well as on the lagged values of economic activity in bordering regions while maintaining the same assumptions about the national variables as before.

For the restricted VAR model with "border effects" (Border-Effects Restricted VAR model), the matrix A_0^B of contemporaneous effects is the same as for the A_0 matrix in the first restricted VAR model.

The (1, 1) element of the $A_0^B = A_{01z}^B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{021z} & 1 & 0 & 0 & 0 \\ a_{031z} & a_{032z} & 1 & 0 & 0 \\ a_{041z} & a_{042z} & a_{043z} & 1 & 0 \\ a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 \end{bmatrix}$

The (1, 2) element of the $A_0^B = A_{01x}^B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

The (2, 1) element of the $A_0^B = A_{02z}^B = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ a_{081z} & a_{082z} & a_{083z} & a_{084z} & a_{085z} \\ a_{091z} & a_{092z} & a_{093z} & a_{094z} & a_{095z} \\ a_{0101z} & a_{0102z} & a_{0103z} & a_{0104z} & a_{0105z} \\ a_{0111z} & a_{0112z} & a_{0113z} & a_{0114z} & a_{0115z} \\ a_{0121z} & a_{0122z} & a_{0123z} & a_{0124z} & a_{0125z} \\ a_{0131z} & a_{0132z} & a_{0133z} & a_{0134z} & a_{0135z} \end{bmatrix}$

The (2, 2) element of the $A_0^B = A_{02x}^B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$

Likewise, for the A_1^B matrix, the A_{11z}^B, A_{11x}^B, and A_{12z}^B sub-matrices are the same as for the first restricted VAR.

The (1, 1) element of the $A_1^B = A_{11z}^B = \begin{bmatrix} a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} \\ a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} \\ a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} \\ a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} \\ a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} \end{bmatrix}$

The (1, 2) element of the $A_1^B = A_{11x}^B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

The (2, 1) element of the $A_1^B = A_{12z}^B = \begin{bmatrix} a_{161z} & a_{162z} & a_{163z} & a_{164z} & a_{165z} \\ a_{171z} & a_{172z} & a_{173z} & a_{174z} & a_{175z} \\ a_{181z} & a_{182z} & a_{183z} & a_{184z} & a_{185z} \\ a_{191z} & a_{192z} & a_{193z} & a_{194z} & a_{195z} \\ a_{1101z} & a_{1102z} & a_{1103z} & a_{1104z} & a_{1105z} \\ a_{1111z} & a_{1112z} & a_{1113z} & a_{1114z} & a_{1115z} \\ a_{1121z} & a_{1122z} & a_{1123z} & a_{1124z} & a_{1125z} \\ a_{1131z} & a_{1132z} & a_{1133z} & a_{1134z} & a_{1135z} \end{bmatrix}$

However, the (2, 2) element of the A_1^B, A_{12x}^B matrix differs. It is no longer simply a diagonal matrix with the own lag coefficients on the diagonal because the coefficients on the lag of the regional income of contiguous regions are now included in this matrix. For example, for the equation for the New England region, the own lag coefficient as well as a coefficient for the lag on income for the Mideast region that is contiguous to the New England region is included in the A_{12x}^B matrix. In these conditions, OLS is not an efficient estimator since each regional equation has different right-hand-side variables. We use SUR suggested by Judge, et. al (1988), Keating (2000) and Greene (2003).

The (2, 2) element of the $A_1^B = A_{12x}^B$

$$= \begin{bmatrix} a_{166x} & a_{167x} & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{176x} & a_{177x} & a_{178x} & 0 & a_{1710x} & 0 & 0 & 0 \\ 0 & a_{187x} & a_{188x} & a_{189x} & a_{1810x} & 0 & 0 & 0 \\ 0 & 0 & a_{198x} & a_{199x} & a_{1910x} & a_{1911x} & a_{1912x} & 0 \\ 0 & a_{1107x} & a_{1108x} & a_{1109x} & a_{11010x} & a_{11011x} & 0 & 0 \\ 0 & 0 & 0 & a_{1119x} & a_{11110x} & a_{11111x} & a_{11112x} & a_{11113x} \\ 0 & 0 & 0 & a_{1129x} & 0 & a_{11211x} & a_{11212x} & a_{11213x} \\ 0 & 0 & 0 & 0 & 0 & a_{11311x} & a_{11312x} & a_{11313x} \end{bmatrix}$$

The other A_i^B matrices are defined in the same manner.

In summary, the structural form of Border-Effects Restricted VAR is the following linear dynamic model:

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{021z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{031z} & a_{032z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{041z} & a_{042z} & a_{043z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{081z} & a_{082z} & a_{083z} & a_{084z} & a_{085z} & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
a_{091z} & a_{092z} & a_{093z} & a_{094z} & a_{095z} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
a_{0101z} & a_{0102z} & a_{0103z} & a_{0104z} & a_{0105z} & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
a_{0111z} & a_{0112z} & a_{0113z} & a_{0114z} & a_{0115z} & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
a_{0121z} & a_{0122z} & a_{0123z} & a_{0124z} & a_{0125z} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
a_{0131z} & a_{0132z} & a_{0133z} & a_{0134z} & a_{0135z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
Y_t^{US} \\ PCE_t \\ COP_t \\ FFR_t \\ TB_t \\ NE_t \\ ME_t \\ GL_t \\ PL_t \\ SE_t \\ SW_t \\ RM_t \\ FW_t
\end{bmatrix}
$$

$$
=
\begin{bmatrix}
a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{161z} & a_{162z} & a_{163z} & a_{164z} & a_{165z} & a_{166x} & a_{167x} & 0 & 0 & 0 & 0 & 0 & 0 \\
a_{171z} & a_{172z} & a_{173z} & a_{174z} & a_{175z} & a_{176z} & a_{177x} & a_{178x} & 0 & a_{1710x} & 0 & 0 & 0 \\
a_{181z} & a_{182z} & a_{183z} & a_{184z} & a_{185z} & 0 & a_{187x} & a_{188x} & a_{189x} & a_{1810x} & 0 & 0 & 0 \\
a_{191z} & a_{192z} & a_{193z} & a_{194z} & a_{195z} & 0 & 0 & a_{198x} & a_{199x} & a_{1910x} & a_{1911x} & a_{1912x} & 0 \\
a_{1101z} & a_{1102z} & a_{1103z} & a_{1104z} & a_{1105z} & 0 & a_{1107x} & a_{1108x} & a_{1109x} & a_{11010x} & a_{11011x} & 0 & 0 \\
a_{1111z} & a_{1112z} & a_{1113z} & a_{1114z} & a_{1115z} & 0 & 0 & 0 & a_{1119x} & a_{11110x} & a_{11111x} & a_{11112z} & a_{11113x} \\
a_{1121z} & a_{1122z} & a_{1123z} & a_{1124z} & a_{1125z} & 0 & 0 & 0 & a_{1129x} & 0 & a_{11211x} & a_{11212x} & a_{11213x} \\
a_{1131z} & a_{1132z} & a_{1133z} & a_{1134z} & a_{1135z} & 0 & 0 & 0 & 0 & 0 & a_{11311x} & a_{11312x} & a_{11313x}
\end{bmatrix}
\begin{bmatrix}
Y_{t-1}^{US} \\ PCE_{t-1} \\ COP_{t-1} \\ FFR_{t-1} \\ TB_{t-1} \\ NE_{t-1} \\ ME_{t-1} \\ GL_{t-1} \\ PL_{t-1} \\ SE_{t-1} \\ SW_{t-1} \\ RM_{t-1} \\ FW_{t-1}
\end{bmatrix}
+ \cdots + A_p y_{t-p} + u_t
$$

The reduced form of B_1^B matrix for the border-effects restricted VAR is similarly modified. As before, the (1, 1) element of the B_1^B matrix, B_{11z}^B is a (5 × 5) matrix of reduced form coefficients of the effects of the national variables lagged one period on themselves. The (1, 2) element of the B_1^B matrix, B_{11x}^B is a (5 × 8) null matrix. The (2, 1) element of the B_1^B matrix, B_{12z}^B is an (8 × 5) matrix of non-zero reduced form coefficients for the one-period lagged effects of

the national variables on the regional variables. The (2, 2) element of the B_1^B matrix, B_{12x}^B is an (8×8) matrix with non-zero reduced form coefficients on the diagonal for the one period lagged effect of a regional variable on itself and non-zero coefficients on lagged income in contiguous regions. The other B_i^B matrices are defined in an analogous manner.

2.4 Data

The OW-type VAR and two restricted VARs are estimated using quarterly data for the period 1960: I-2007: III. We want to compare three approaches IRFs using the same lags and sample period. We simply extended the OW sample from its starting point to a period that ended just before the current recession. Although there are certainly questions about stability that arise over this period, we use data from 1960-2007 since we are estimating large VARs and since our main focus is examination of the effects, for a given sample period, of assumptions about monetary policy response directly to region-specific shocks vs. direct response only to national shocks. Again, following OW, all lags in the VARs were 3 quarters, although the results were not sensitive to lags of 2, 4, and 5 quarters. Data comes from the Bureau of Economic Analysis, quarterly US (Y^{US}) and regional personal income ($Y^{NE}, Y^{ME}, Y^{GL}, Y^{PL}, Y^{SE}, Y^{SW}, Y^{RM}$, and Y^{FW}, where the superscript indicates the Bureau of Economic Analysis region) and the quarterly personal consumption expenditures deflator (PCE) [Bureau of Economic Analysis web site]. Real personal income is calculated by deflating by PCE quarterly data on nominal personal income for each region. As mentioned by Hubbard and O'Brien (2008), "The most widely used measure of the price level is the consumer price index (CPI); however, the CPI overstates the true price level and has a severe price puzzle. An alternative measure of changes in consumer prices is GDP deflator, which can be measured from the GDP. Since the GDP deflator include prices of goods, such as industrial equipment, that are not widely purchased, the changes in the

GDP deflator are not good measure of the price level by the typical consumer, worker, or firm. The personal consumption expenditures price index (PCE) is a measure of the price level that is similar to the GDP deflator, except it includes only the prices of goods from the consumption category of GDP." Also, in 2000, the Fed announced that it would rely more on the PCE than on the CPI in tracking the price level. Hence, we used the PCE for measuring the price level. Other data includes the quarterly average of the monthly Federal Funds Rate (FFR) and the quarterly average of the 10-year Treasury bond rate (TB) [Board of Governors of the Federal Reserve web site], and the quarterly average of the monthly CRB spot index (COP) [Commodity Research Bureau web site].

For the OW-type standard VAR the vector of variables in the Choleski decomposition ordering is $y_t = [Y_t^{NE}, Y_t^{ME}, Y_t^{GL}, Y_t^{PL}, Y_t^{SE}, Y_t^{SW}, Y_t^{RM}, Y_t^{FW}, PCE_t, COP_t, FFR_t, TB_t]'$, and for the restricted VARs the vector of variables in the Choleski decomposition ordering is

$$y_t = [Y_t^{US}, PCE_t, COP_t, FFR_t, TB_t, Y_t^{NE}, Y_t^{ME}, Y_t^{GL}, Y_t^{PL}, Y_t^{SE}, Y_t^{SW}, Y_t^{RM}, Y_t^{FW}]' .$$

2.5 Empirical Results

2.5.1 Impulse Response Function (IRF)

We want to trace out the time path of the effect of structural shocks on the dependent variables of the model. For this, we first need to transform the VAR into a MA representation. All stationary VAR (p) models can be written as a Moving Average process of infinite order (MA (∞)), where the current value of the variables is a weighted average of all historical innovations. The MA (∞) representation is used to calculate the dynamic effects.

The structural Moving Average (MA) representation in (1),

$$y_t = (I - B_1 L - B_2 L^2 - \cdots - B_p L^p)^{-1} \varepsilon_t = C(L)\varepsilon_t = \sum_{i=0}^{\infty} \Theta_i \varepsilon_{t-i} \text{ , where } \varepsilon_t \sim N(0, \Sigma).$$

We use the partitioned endogenous variable and it is as follows:

$$y_t = \begin{bmatrix} z_t \\ x_t \end{bmatrix} = \Theta_0 \begin{bmatrix} \varepsilon_{z,t} \\ \varepsilon_{x,t} \end{bmatrix} + \Theta_1 \begin{bmatrix} \varepsilon_{z,t-1} \\ \varepsilon_{x,t-1} \end{bmatrix} + \Theta_2 \begin{bmatrix} \varepsilon_{z,t-2} \\ \varepsilon_{x,t-2} \end{bmatrix} + \cdots$$

where Θ_0 is the identity matrix and the vector Θ_i indicates the effect of an innovation at time $t-i$ on the current value of z_t and x_t.

The previous MA process consists of the estimated disturbances of the reduced form of the model. As discussed, the error vector, ε_t, is correlated and an isolated analysis of the effects of the disturbances is not possible. Thus, the disturbance has to be replaced with the orthogonal shocks u_t by the use of the relationship in $u_t = A_0\varepsilon_t$ in (2):

$$y_t = \begin{bmatrix} z_t \\ x_t \end{bmatrix} = A_0^{-1} \begin{bmatrix} u_{z,t} \\ u_{x,t} \end{bmatrix} + A_0^{-1}\Theta_1 \begin{bmatrix} u_{z,t-1} \\ u_{x,t-1} \end{bmatrix} + A_0^{-1}\Theta_2 \begin{bmatrix} u_{z,t-2} \\ u_{x,t-2} \end{bmatrix} + \cdots$$

The response of a variable of $y_t = \begin{bmatrix} z_t \\ x_t \end{bmatrix}$ to a monetary policy shock is calculated as below:

$$\frac{\partial z_{t+i}}{\partial FFR_t} = \lambda_{i,1} \frac{\partial z_{t+i}}{\partial FFR_t} + \cdots + \lambda_{i,k} \frac{\partial z_{t+i}}{\partial FFR_t} \qquad \text{(11a)}$$

$$\frac{\partial x_{t+i}}{\partial FFR_t} = \lambda_{i,1} \frac{\partial x_{t+i}}{\partial FFR_t} + \cdots + \lambda_{i,k} \frac{\partial x_{t+i}}{\partial FFR_t} \qquad \text{(11b)}$$

where $\frac{\partial z_{t+i}}{\partial FFR_t}$ and $\frac{\partial x_{t+i}}{\partial FFR_t}$ is the i - period ahead responses of national and regional variables to a shock in the federal funds rate, calculated from the MA process consisting of the structural errors. Equation (11a) and (11b) enable calculation of impulse response functions for all variables of the model.

In our model, the Impulse Response Functions (IRFs) for a one unit shock to the federal funds rate were computed for each model and are presented in the following Figures. In each figure, the solid line is the median estimate from the simulation, and the dotted lines are the

upper and lower bounds which represent the 84th and 16th percentiles, respectively. Thus, as is common in the literature, approximate one-standard deviation confidence bands are plotted.

The confidence bands are derived from Monte Carlo simulations with 2500 draws. Loo and Lastrapes (1998) and Sims and Zha (1999) recommend this method. All figures report the estimated IRFs for the macro variables and regional real personal income for a positive one unit shock to the federal funds rate. The effects of monetary policy on regional output are compared across identification schemes. The patterns of effects are often similar: a U-shaped output response, decrease in the price level even though we have a price puzzle, and a temporary rise in the interest rate. Significant differences in the magnitude of the effects, however, are found; although the general pattern of effects is similar across the three approaches, the magnitude of the point estimates differ across the schemes.

2.5.2 Owyang-Wall-Type Standard VAR Model

The results from the OW-type VAR are presented in Figure 2.1 and 2.2. Figure 2.1 presents the results for the national variables, and Figure 2.2 presents the results for the regional variables. The funds rate displays substantial inertia but returns to its initial value after 10 quarters. The 10-year Treasury bond rate rises by a smaller amount than the fed funds rate for an extended period of time, but returns to its initial value 11 quarters after the shock. For the aggregate price level, we note a prolonged “price puzzle” initially, but the effect eventually becomes negative. However, the effect is not significant at any horizon. The median effect on the commodity price index is negative but is only very briefly significant. For the OW-type VAR model, the fact that there are essentially no significant effects on either aggregate prices or commodity prices is problematic.

For regional personal income, there are some significantly negative effects at some horizons for all regions except New England and the Mideast. The regions with the most extended periods of significant effects are the Great Lakes and the Far West. In Carlino and DeFina (1998) and Crone (2007), the Great Lakes region is found to be the most sensitive to monetary policy changes. For the Great Lakes the effect becomes significant after 4 quarters and remains significant until the 16 quarters after the shock. For the Far West, the effect becomes significant with a somewhat longer lag than the Great Lakes, but remains significant thereafter for the rest of 5 year horizon reported. (If the horizon is extended beyond 5 years, personal income in the Far West returns to its initial value.) The effects are only marginally significant for the Plains, Southeast, Southwest, and Rocky Mountain regions. For the Rocky Mountain region, the effect becomes marginally significant 4 quarters after the monetary policy shock, but personal income returns to its initial value 9 quarters after the shock. For the Plains and the Southeast, the effect becomes marginally significant 4 quarters after the monetary policy shock, and personal income returns to its initial value about 14 quarters after the shock. For the Southwest, the effect becomes marginally significant with a very long lag of about 15 quarters and personal income returns to its initial value only after 5 years.

The Great Lakes, Plains, and Southeast regions reach their trough around 12 quarters after shock and the Southwest, Rocky Mountain, and Far West regions hit their trough at the end of sample period. Except for the New England and Mideast regions, all other six regions have the difference in the magnitudes of the personal income declines at the troughs. The Great Lakes has the largest decline of PI.

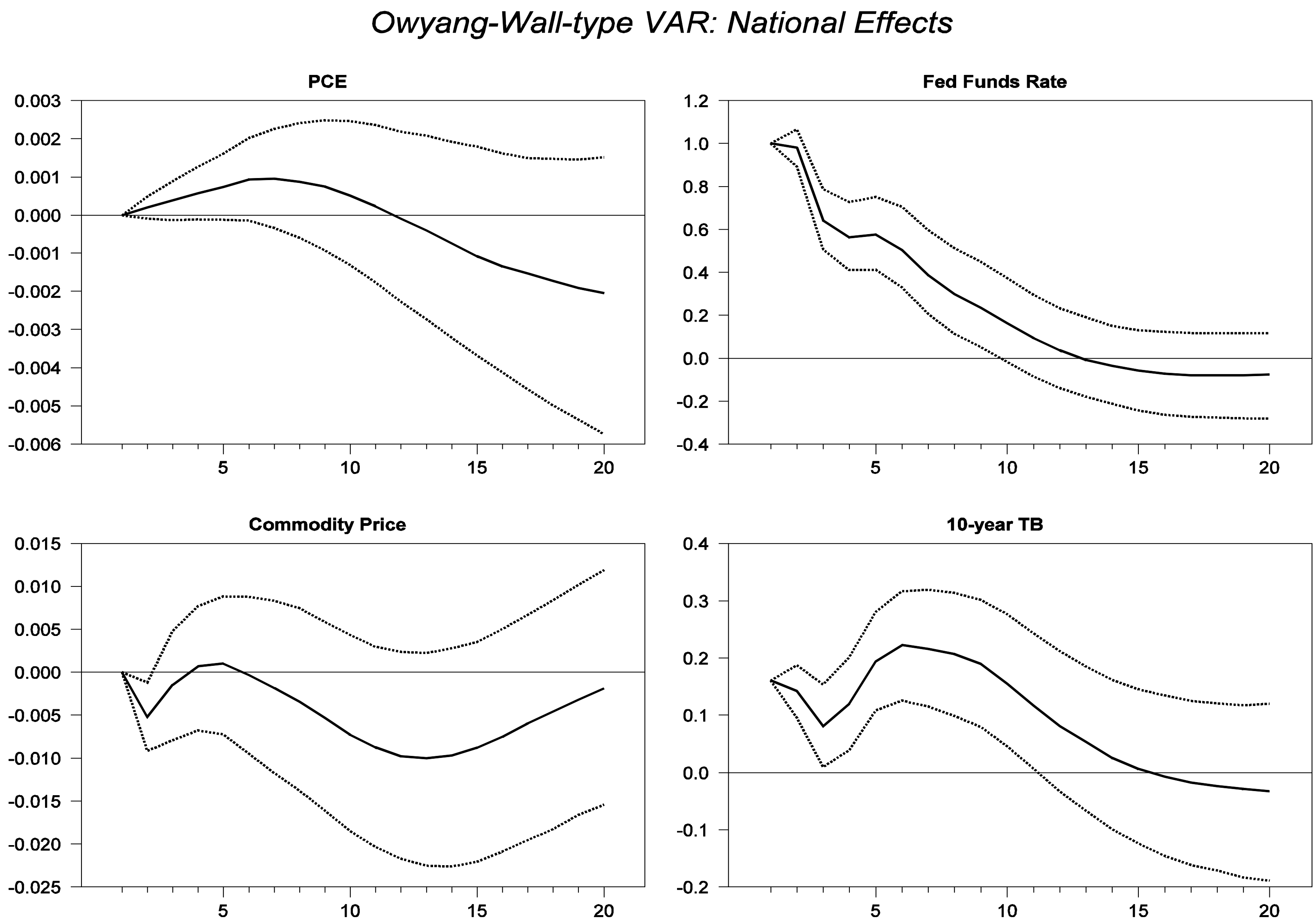


Figure 2.1 — OW-Type VAR: National Effects

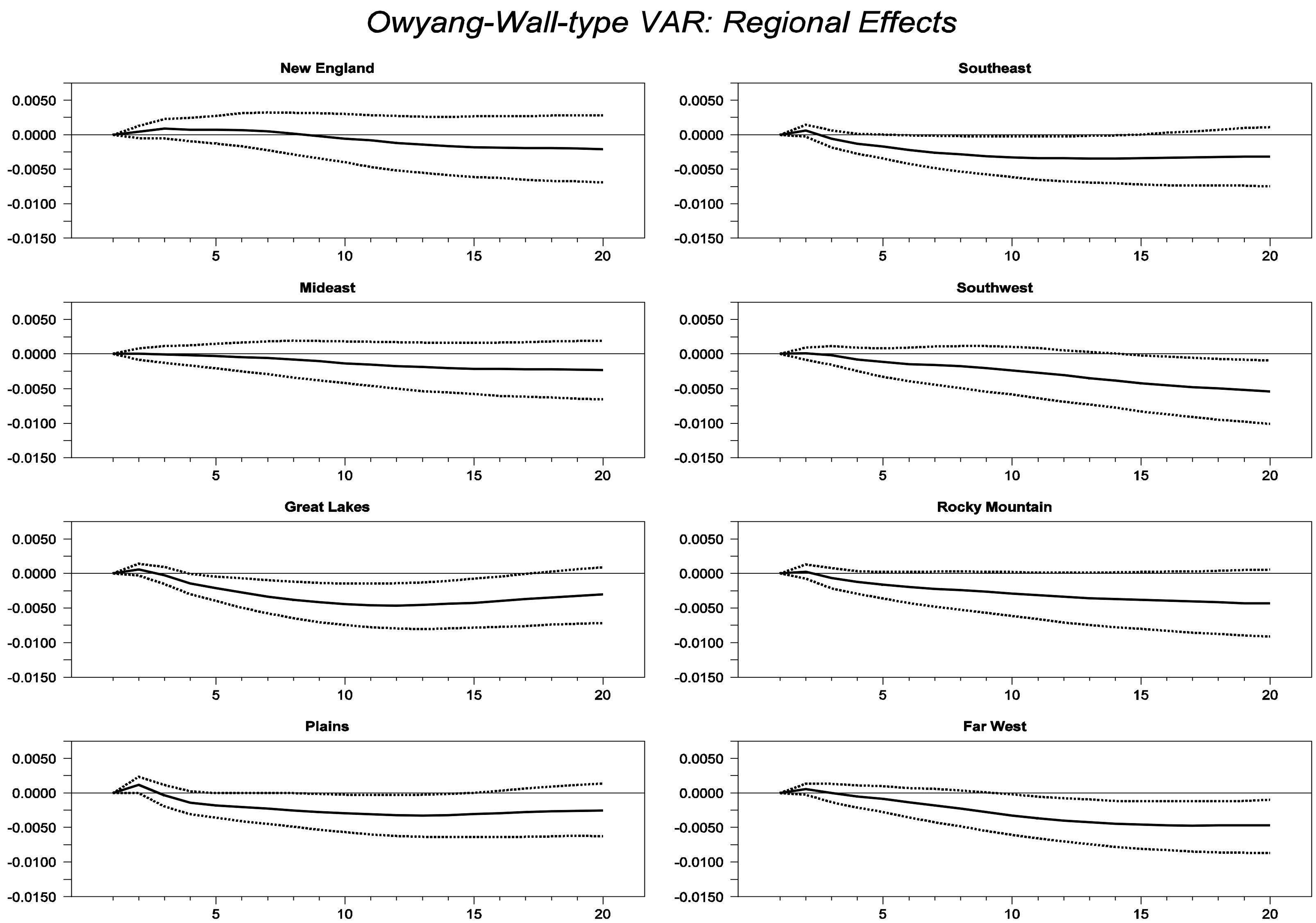


Figure 2.2 — OW-Type VAR: Regional Effects

The results from the OW-type VAR thus suggest some differences in the timing, duration, and magnitude of the effects of monetary policy shocks across regions. However, the results for the aggregate price level and commodity prices raise some concerns about this model.

2.5.3 Lastrapes-Type Restricted VAR Model

Figures 2.3 and 2.4 present results from the Lastrapes-type restricted VAR. The shape and magnitude look similar to the OW-type VAR results. However, from Figure 2.3 we see that the persistence in the funds rate after a shock is less than in the OW-type model and the Treasury bond rate returns to its initial value more quickly than in the OW-type model. There are long-lived significant negative effects on national personal income which returns to its initial level only after 5 years. Commodity prices fall significantly after one quarter, and the effects are very long-lived. Even though we have a smaller price puzzle than the OW-type model, there are significant negative effects on the aggregate price level after approximately two years. This is essentially the same lag as found by Romer and Romer (2004) who identify monetary policy shocks using a very different technique. The negative effects on the aggregate price level are very long-lived.

Figure 2.4 presents the regional effects from the Lastrapes-type restricted VAR. Compared with the OW-type model, the monetary policy shocks have long-lived effects in the Lastrapes-type restricted VAR.

Again we see there are no significant effects on personal income in the New England and Mideast regions. However, there are significant effects in all other regions, even in regions in which the upper confidence interval is only marginally below zero in the OW-type model. The effects become significant more quickly than in the OW-type model and the effects are also more persistent. The effects are very persistent for the Southwest, Rocky Mountain, and Far

West regions, but eventually personal income returns to its initial level beyond the 5 year horizon shown.

The magnitudes of the personal income losses look similar to OW-type VAR model, but Lastrapes-type VAR model has larger declines of PI than OW-type VAR model. The Great Lakes, Plains, and Southeast regions reach their trough around 12 quarters after shock and the Southwest, Rocky Mountain, and Far West regions hit their trough at the end of sample period. Except for the New England and Mideast regions, all other six regions have the difference in the magnitudes of the personal income declines at the troughs. The Great Lakes has the largest decline of PI.

We plot the point estimates of OW-type VAR into Lastrapes-type VAR confidence interval to check the magnitudes of the PI declines. Figure 2.5 shows these results. Except the Great Lakes and Plains regions, the six regions' point estimates of OW-type VAR fit well in the Lastrapes-type VAR's confidence interval. For the Great Lakes and Plains regions, the point estimates hit the upper bound around 4 quarters and return to the inside of confidence interval 7 quarters after shock. Thereafter, they stay inside the confidence interval for the whole sample period. The point estimates of most regions stay closely to the upper bound. It shows the magnitudes of PI loses are larger in the Lastrapes-type VAR model.

The results for the Lastrapes-type restricted VAR are substantially different from the results for the OW-type VAR. With the Lastrapes-type restricted VAR, there are now significant negative effects on the aggregate price level and commodity prices, and, for the six regions affected by monetary policy, the timing, duration and magnitudes of the effects of monetary policy shocks on personal income are different from the OW-type VAR.

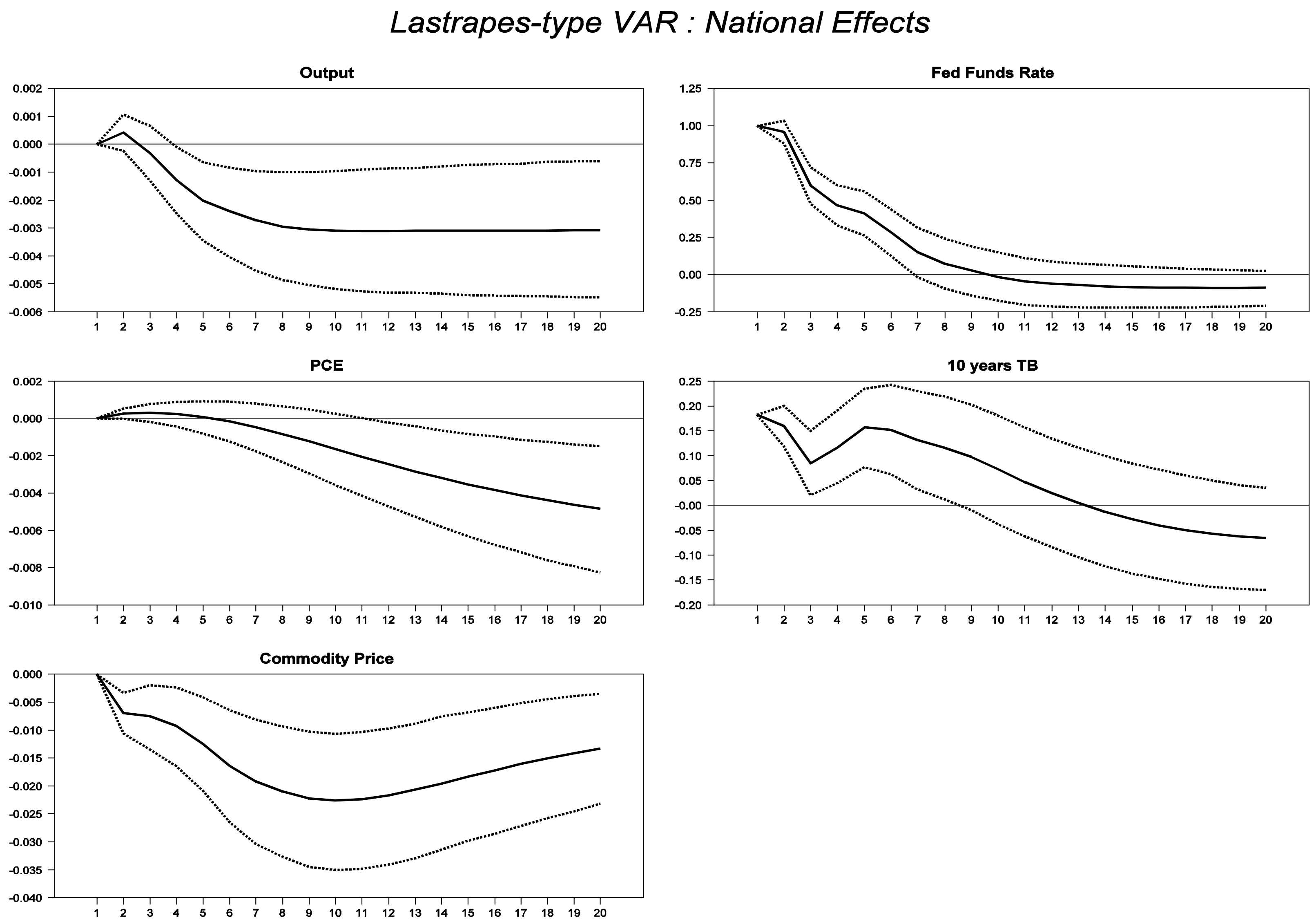


Figure 2.3 — Lastrapes-Type VAR: National Effects

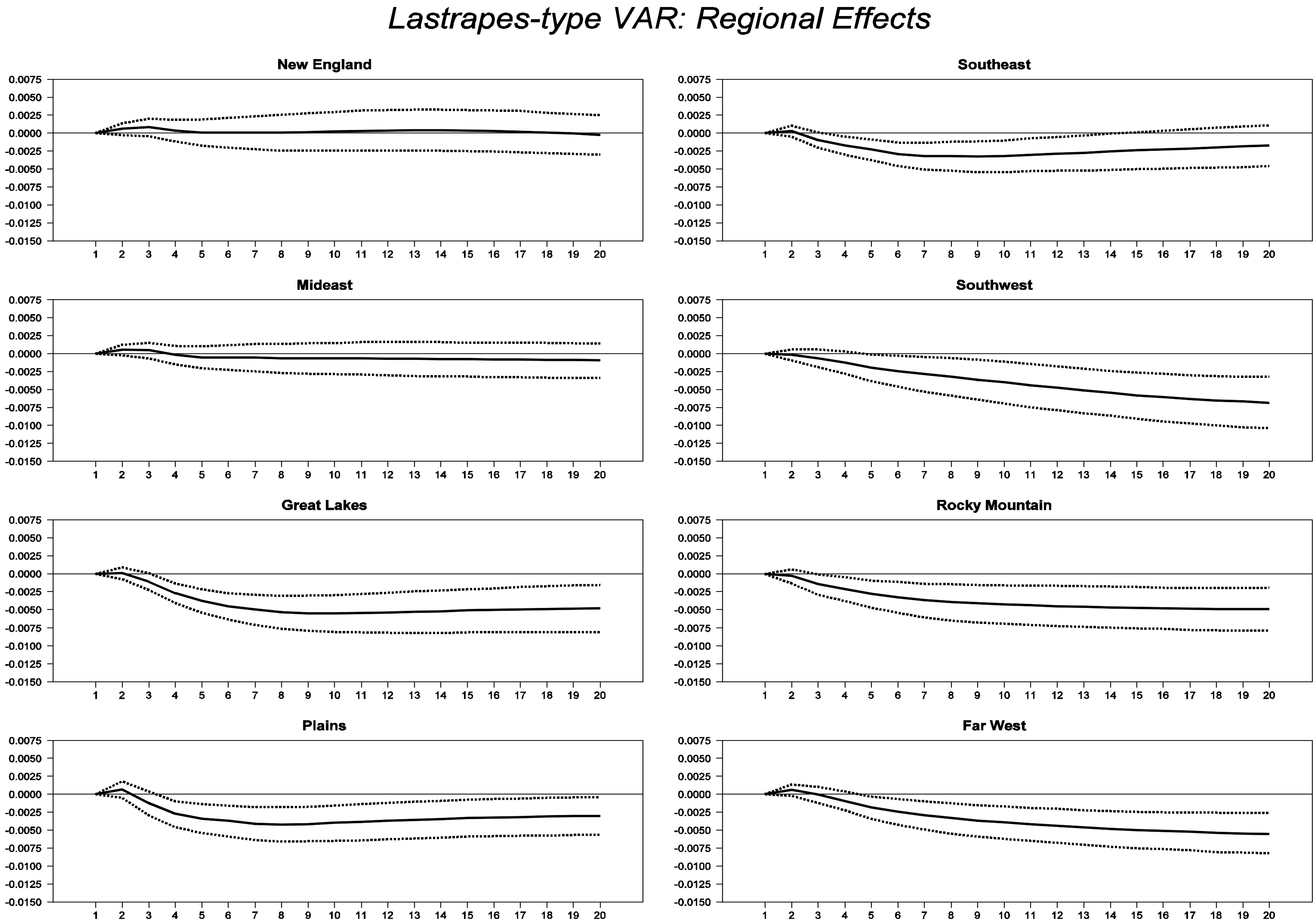


Figure 2.4 — Lastrapes-Type VAR: Regional Effects

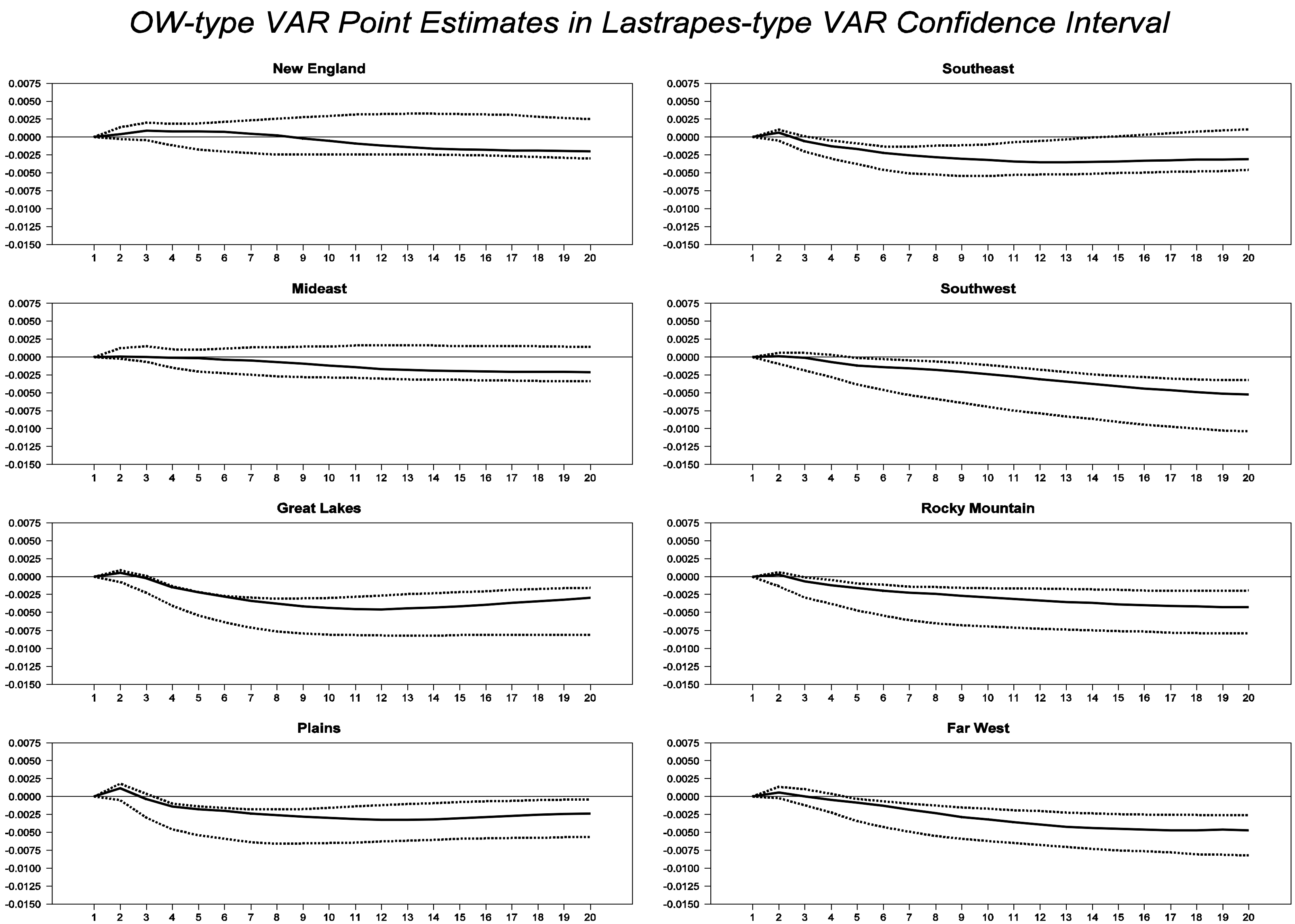


Figure 2.5 — OW-Type VAR Point Estimates in Lastrapes-Type VAR Confidence Interval

The magnitudes of the personal income losses look similar to OW-type VAR model, but Lastrapes-type VAR model has larger declines of PI than OW-type VAR model. The Great Lakes, Plains, and Southeast regions reach their trough around 12 quarters after shock and the Southwest, Rocky Mountain, and Far West regions hit their trough at the end of sample period. Except for the New England and Mideast regions, all other six regions have the difference in the magnitudes of the personal income declines at the troughs. The Great Lakes has the largest decline of PI.

We plot the point estimates of OW-type VAR into Lastrapes-type VAR confidence interval to check the magnitudes of the PI declines. Figure 2.5 shows these results. Except the Great Lakes and Plains regions, the six regions' point estimates of OW-type VAR fit well in the Lastrapes-type VAR's confidence interval. For the Great Lakes and Plains regions, the point estimates hit the upper bound around 4 quarters and return to the inside of confidence interval 7 quarters after shock. Thereafter, they stay inside the confidence interval for the whole sample period. The point estimates of most regions stay closely to the upper bound. It shows the magnitudes of PI loses are larger in the Lastrapes-type VAR model.

The results for the Lastrapes-type restricted VAR are substantially different from the results for the OW-type VAR. With the Lastrapes-type restricted VAR, there are now significant negative effects on the aggregate price level and commodity prices, and, for the six regions affected by monetary policy, the timing, duration and magnitudes of the effects of monetary policy shocks on personal income are different from the OW-type VAR.

2.5.4 Border- Effects Restricted VAR Model

One critique of the pure Lastrapes-type approach is that one region can affect other regions only through the first region's effects on the national economy. The SUR Lastrapes-type

approach allows regional output to depend on its own lagged values as well as on the lagged values of economic activity in adjoining regions while maintaining the same assumptions about the national variables as before.

Figure 2.6 presents the results from the "border-effects" restricted VAR for the national variables. The results are quite similar to those from the Lastrapes-type restricted VAR, although aggregate output returns to its initial level more quickly in the "border-effects" VAR than in the Lastrapes-type VAR.

From Figure 2.7 it is apparent that the regional effects are very similar for both restricted VARs. Compared to the OW-type model, in the Lastrapes-type restricted model, we have long-lived effect of monetary policy shocks on 8 regional and national variables.

Again the New England and Mideast regions do not have significant effects on personal income. However, there are significant effects in all other regions. The effects are very persistent for the Southwest, Rocky Mountain, and Far West regions, but eventually personal income returns to its initial level beyond the 5 year horizon shown.

The magnitudes of the personal income losses look similar to OW-type VAR and Lastrapes-type VAR model, but the border-effects VAR model has larger declines of PI than the OW-type VAR model. Except for the New England and Mideast regions, all other six regions have differences in the magnitudes of the personal income declines at the troughs. The Southwest has the largest decline of PI.

We plot the point estimates of OW-type VAR into the Lastrapes-type VAR and border-effects VAR confidence intervals to check the magnitudes of the PI declines. Figure 2.8 and 2.9 show these results. In the Figure 2.8, all regions' point estimates of OW-type VAR stay well inside the border-effects VAR's confidence interval. The point estimates of most regions stay

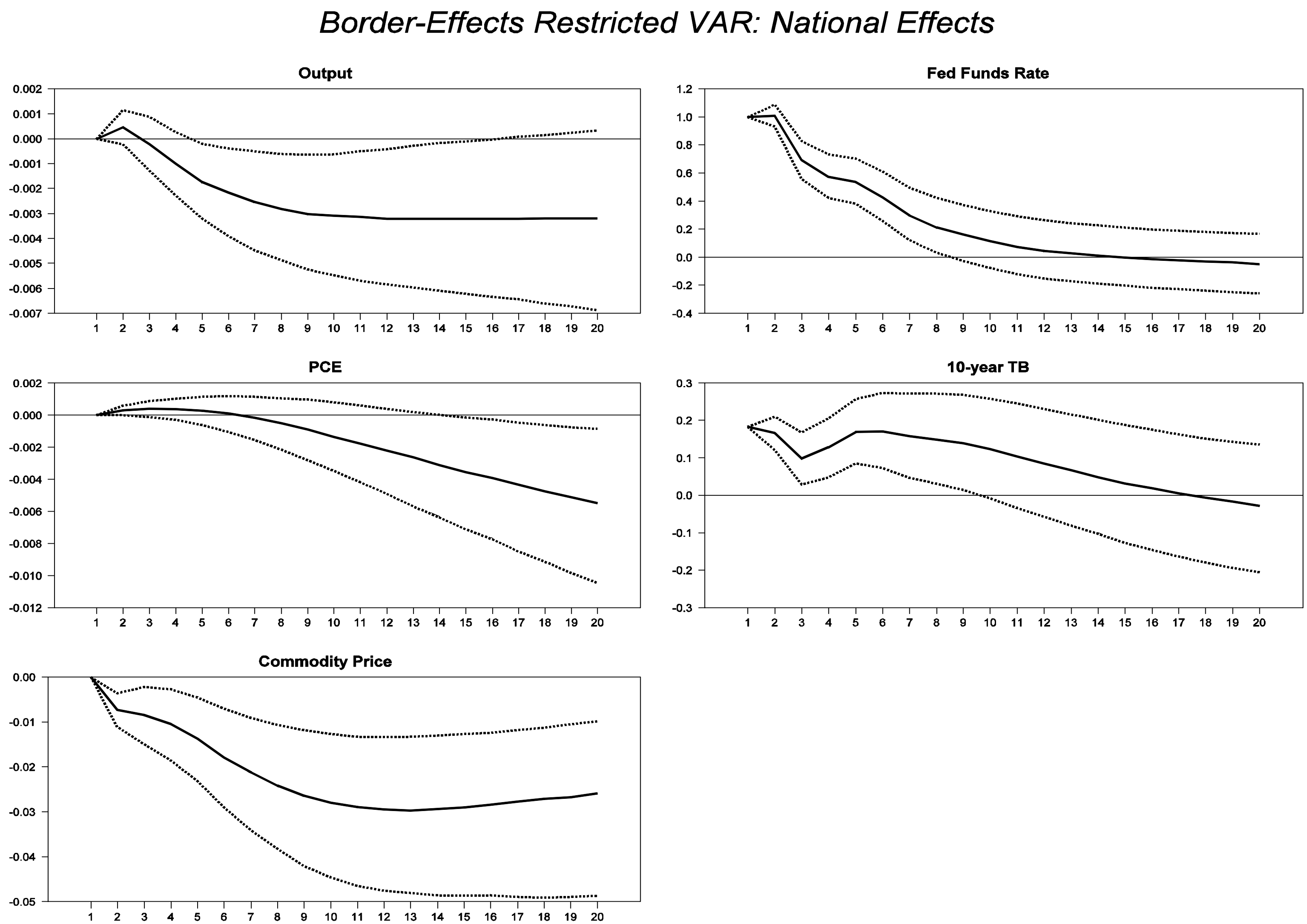


Figure 2.6 — Border-Effects VAR: National Effects

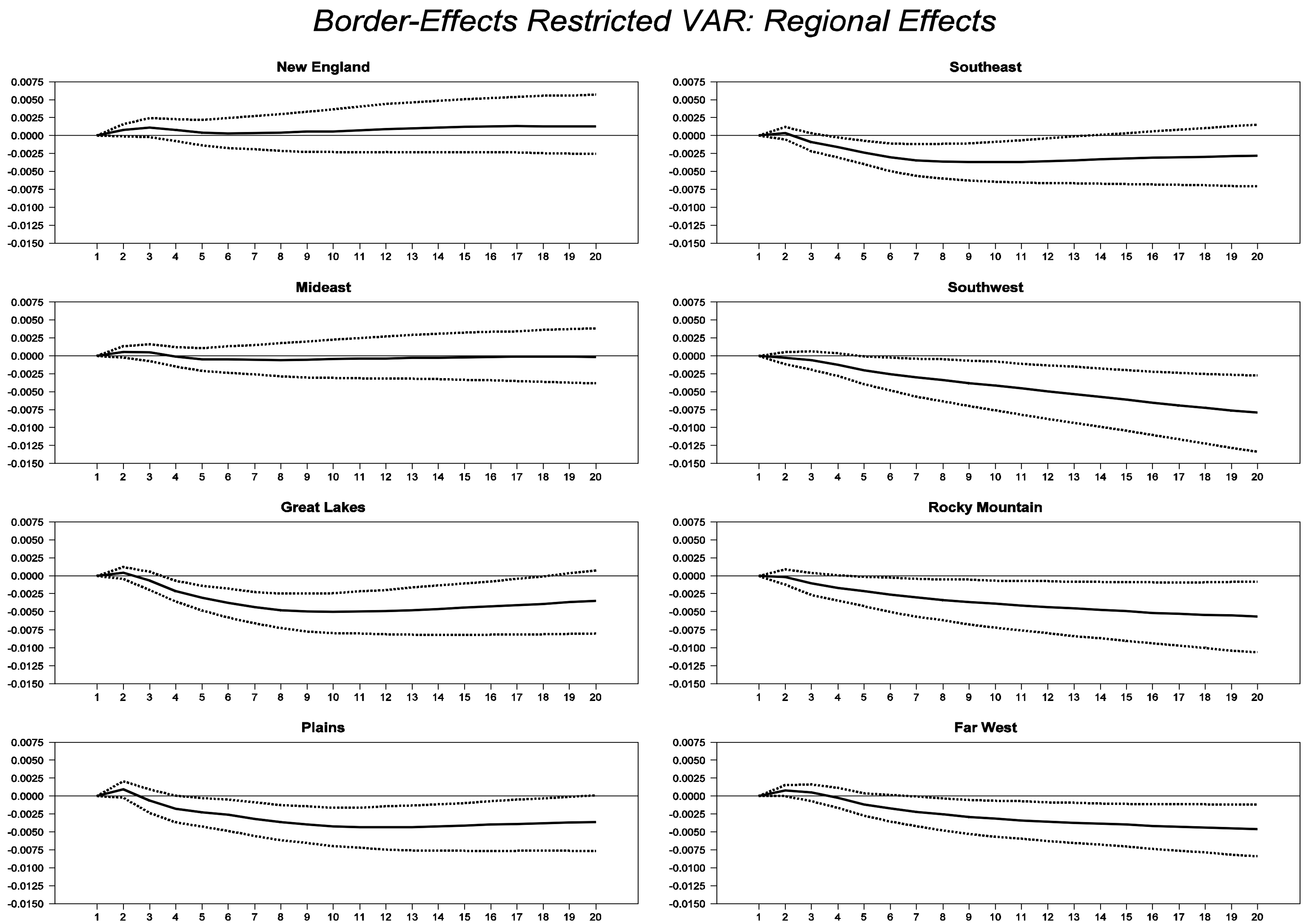


Figure 2.7 — Border-Effects VAR: Regional Effects

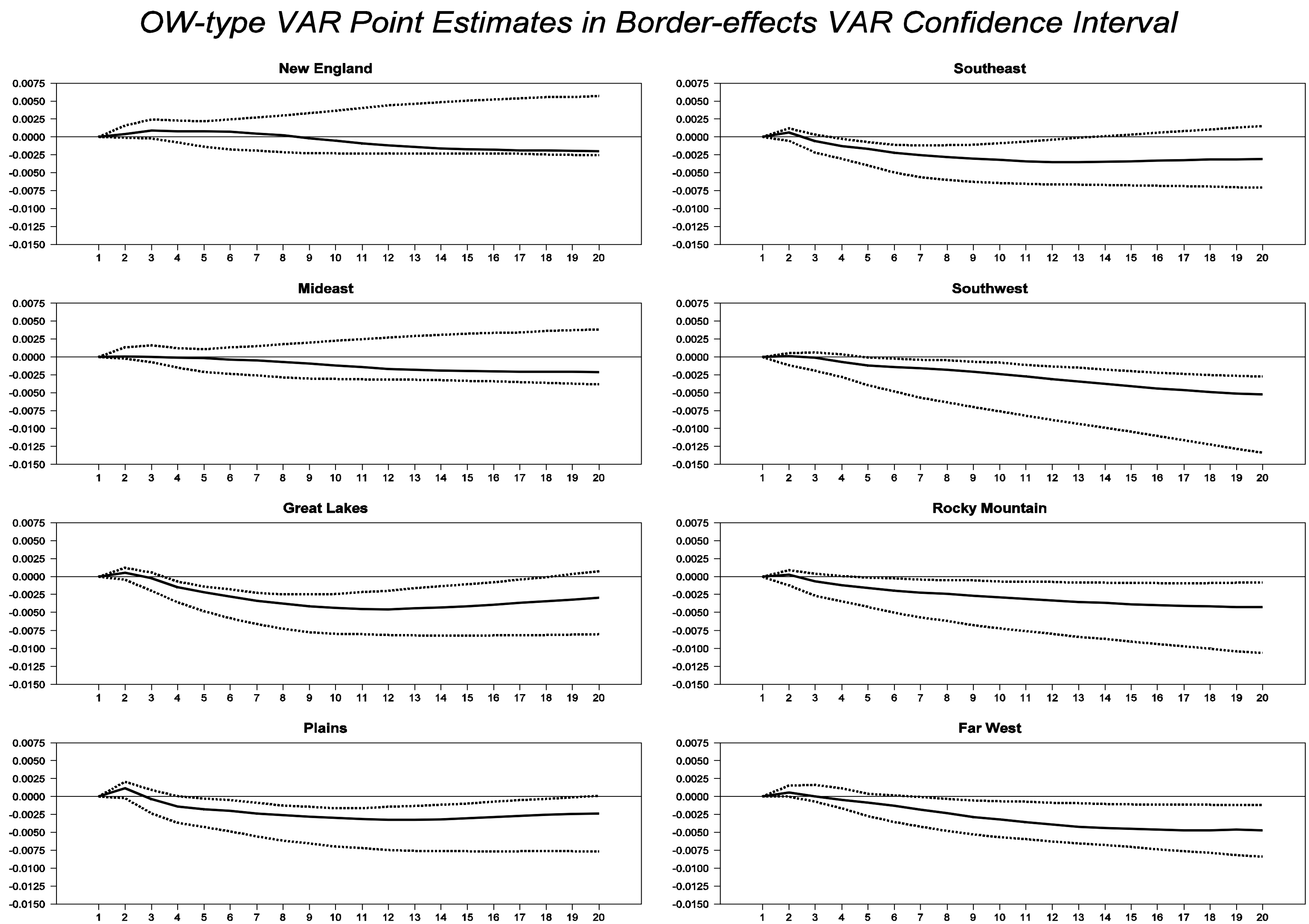


Figure 2.8 — OW-Type VAR Point Estimates in Border-Effects VAR Confidence Interval

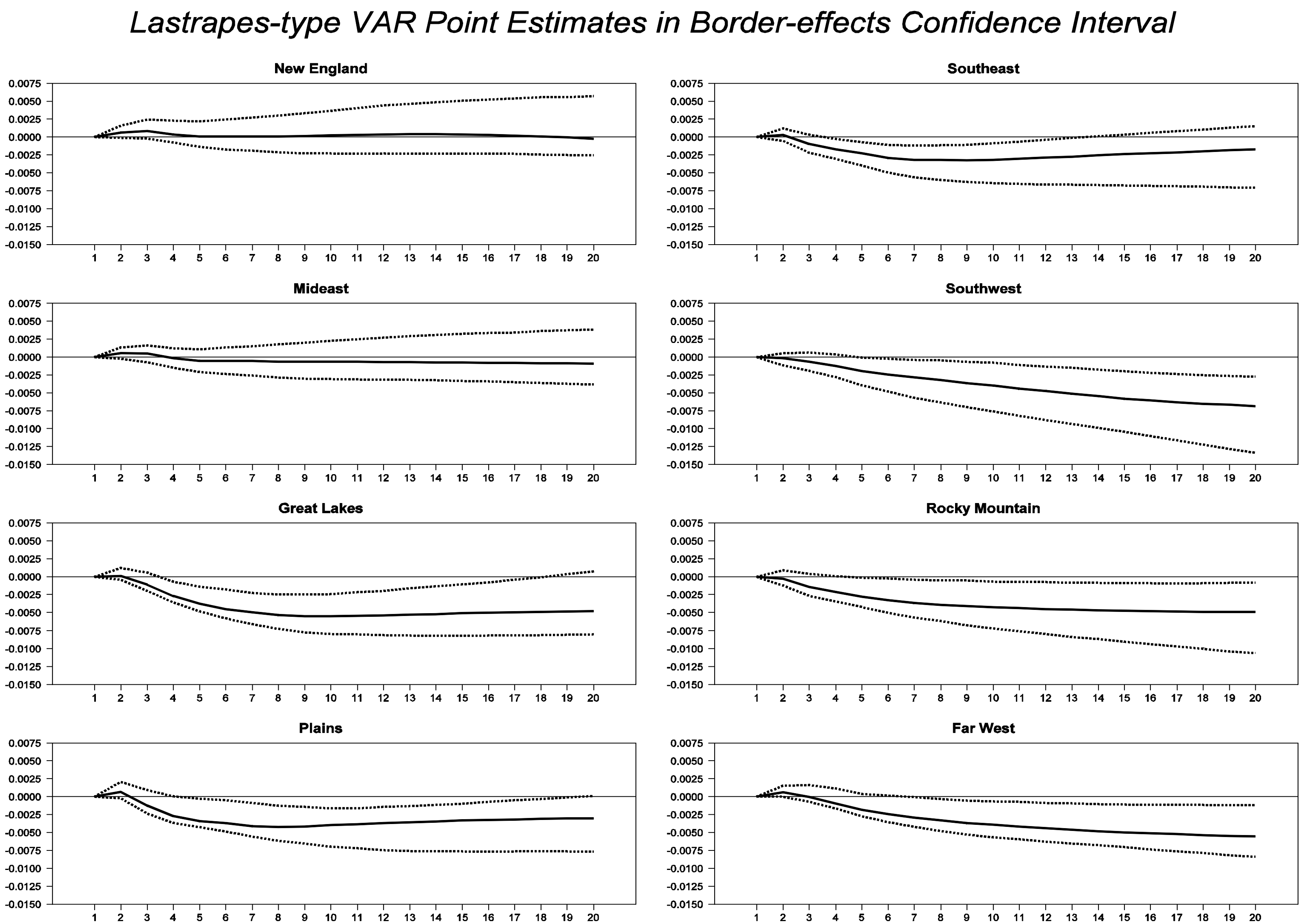


Figure 2.9 — Lastrapes-Type VAR Point Estimates in Border-Effects VAR Confidence Interval

closely to the upper bound in early periods. It shows the magnitudes of PI loses are larger in the border-effects VAR model. Figure 2.9 indicates PI declines of border-effects VAR are quite similar to those from the Lastrapes-type restricted VAR. All regions' estimates of Lastrapes-type VAR fit well inside the border-effects VAR's confidence interval.

The results for the border-effects restricted VAR are substantially different from the results for the OW-type VAR but look similar for the Lastrapes-type VAR. With the border-effects restricted VAR, there are now significant negative effects on the aggregate price level and commodity prices, and, for the six regions affected by monetary policy, the timing, duration and magnitudes of the effects of monetary policy shocks on personal income are different from the OW-type VAR.

2.6 Alternative Definition of Eight BEA Regions in the U.S.

To examine the regional effects of monetary policy, most recent studies have used the eight regions defined by the BEA. Using data from 1943 to 1955 for nearly 700 economic and noneconomic social factors, the BEA grouped states into eight regions based on homogeneity of economic and social factors. Crone (2007) noted that: "The economic factors included the industrial composition of income (e.g., manufacturing, agriculture, trade, and service), the level of per capita income in 1951, and the change in per capita income from 1929 to 1951. The noneconomic factors included, among other things, population density, racial composition, education levels, telephones per 1000 people, and infant deaths per 1000 live births."

This division of the states into the eight BEA regions has not been adjusted since its introduction in the 1950s. However, in Crone (2005)'s article, he argues that for business cycle analysis, states should be grouped into regions based on the similarity of their business cycles. He makes groups of states based on the cyclical components of a new set of coincident indexes

for the 50 states that incorporate changes in payroll employment, unemployment rates, average hours worked in manufacturing, and real wages and salaries. To compare this set of regions to the BEA regions, he groups the 48 contiguous states into eight regions (See Appendix). He uses standard cluster analysis to group the states with similar business cycles. In general, the states in the eight alternative regions are more similar than the states in the original BEA regions based on the business cycle. "For example, most observers would not question that the oil-rich economy of Louisiana, which is the BEA's Southeast region, is much closer to that of Texas and Oklahoma, which are in the BEA's Southwest region" (Crone, 2007). This alternative grouping of states has many similarities with the BEA regions but also some significant differences. The definition of New England and Mideast is the same in both definition of regions, but the regions' remaining six regions' definition is different in Crone. We compute the IRFs of an OW-type VAR, a Lastrapes-type VAR and a border-effects VAR using Crone's definition of regions and compare these IRFs with the results of the same three models estimated with data from the BEA regions.

2.6.1 Owyang-Wall-Type Standard VAR Model

The results from the OW-type VAR using Crone's definitions of regions are presented in Figures 2.10 and 2.11. Figure 2.10 presents the results for the national variables, and Figure 2.11 presents the results for the regional variables. The federal funds rate displays substantial inertia but returns to its initial value approximately after 8 quarters. The 10-year Treasury bond rate rises by a smaller amount than the federal funds rate for an extended period of time, but returns to its initial value after 10 quarters. Both FFR and the 10-year Treasury bond rate come back more quickly to the original level after the shock than in OW model with standard regional definitions. For the aggregate price level, we have initially no significant effect, but it becomes

significant negative after several years. The median effect on the commodity price index is negative but is only very briefly significant.

Figure 2.11 shows the effects for the regional personal income and there are some significantly negative effects at some horizons for all regions except the New England and the Mideast regions. These results are almost the same as in the model using the original definition of regions. The regions with the most extended periods of significant effects are the Great Lakes and the West regions. For the Great Lakes region the effect becomes significant after 4 quarters and remains significant until the 17 quarters after the shock. For the West, the effect becomes significant after 5 quarters and remains significant thereafter for the rest of 5 year horizon reported. The effects are only marginally significant for the Plains, Southeast, Energy Belt, and Mountains/Northern Plains regions. For the Mountains/Northern Plains region, the effect becomes marginally significant 4 quarters after the monetary policy shock and it fluctuates but personal income returns to its initial value 13 quarters after the shock. For the Plains and the Southeast, the effect becomes marginally significant 4 quarters after the monetary policy shock, and personal income returns to its initial value about 14 quarters after the shock. For the Energy Belt, the effect becomes marginally significant with a very long lag of about 15 quarters and personal income returns to its initial value only after 5 years.

We plot the point estimates from the OW model along with confidence intervals from the model using Crone regions. Figure 2.12 presents these results. Even though six regions' definitions are different, all OW point estimates remain well inside the confidence intervals from the model with Crone's definition of regions.

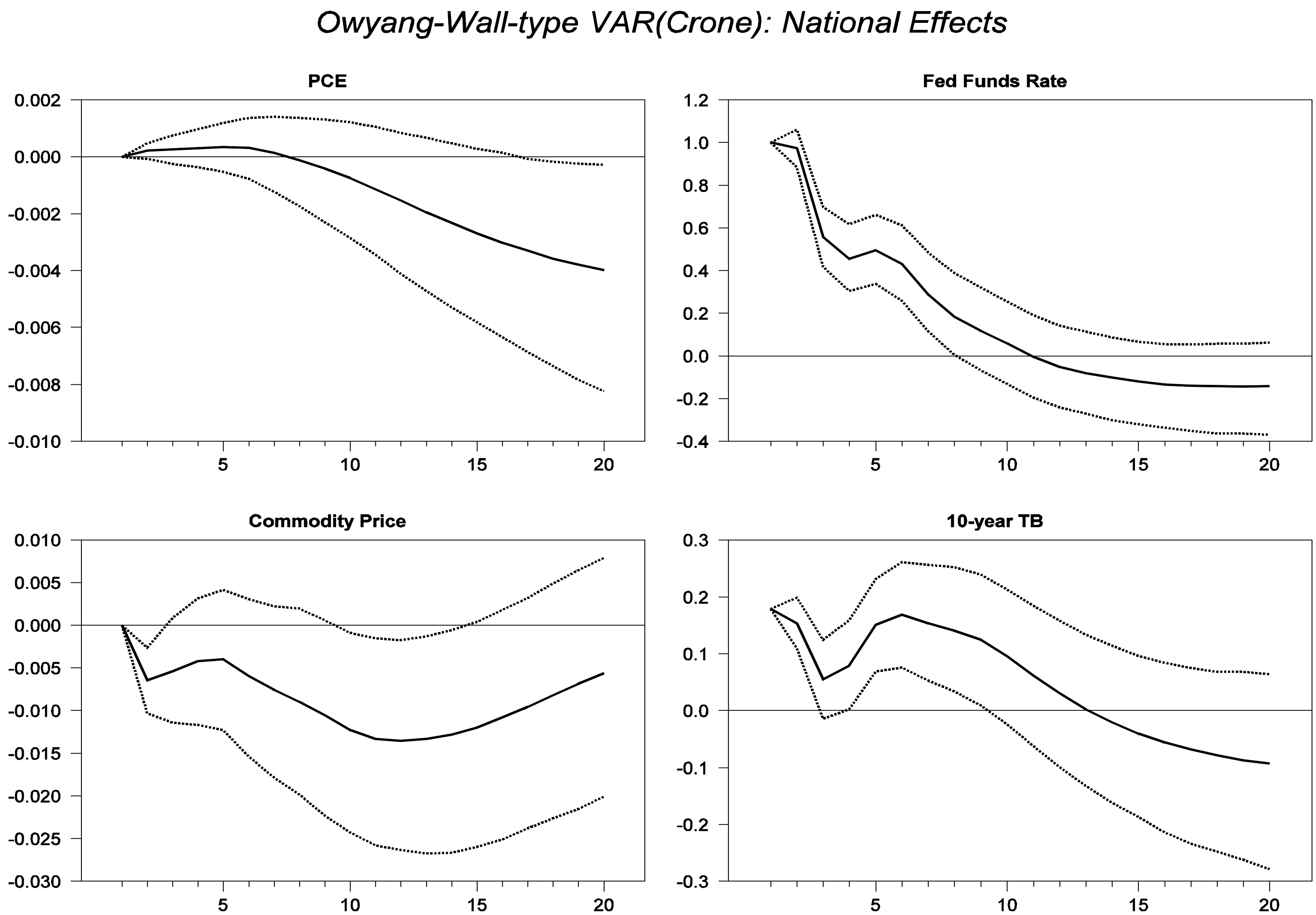


Figure 2.10 — OW-Type (Crone) VAR: National Effects

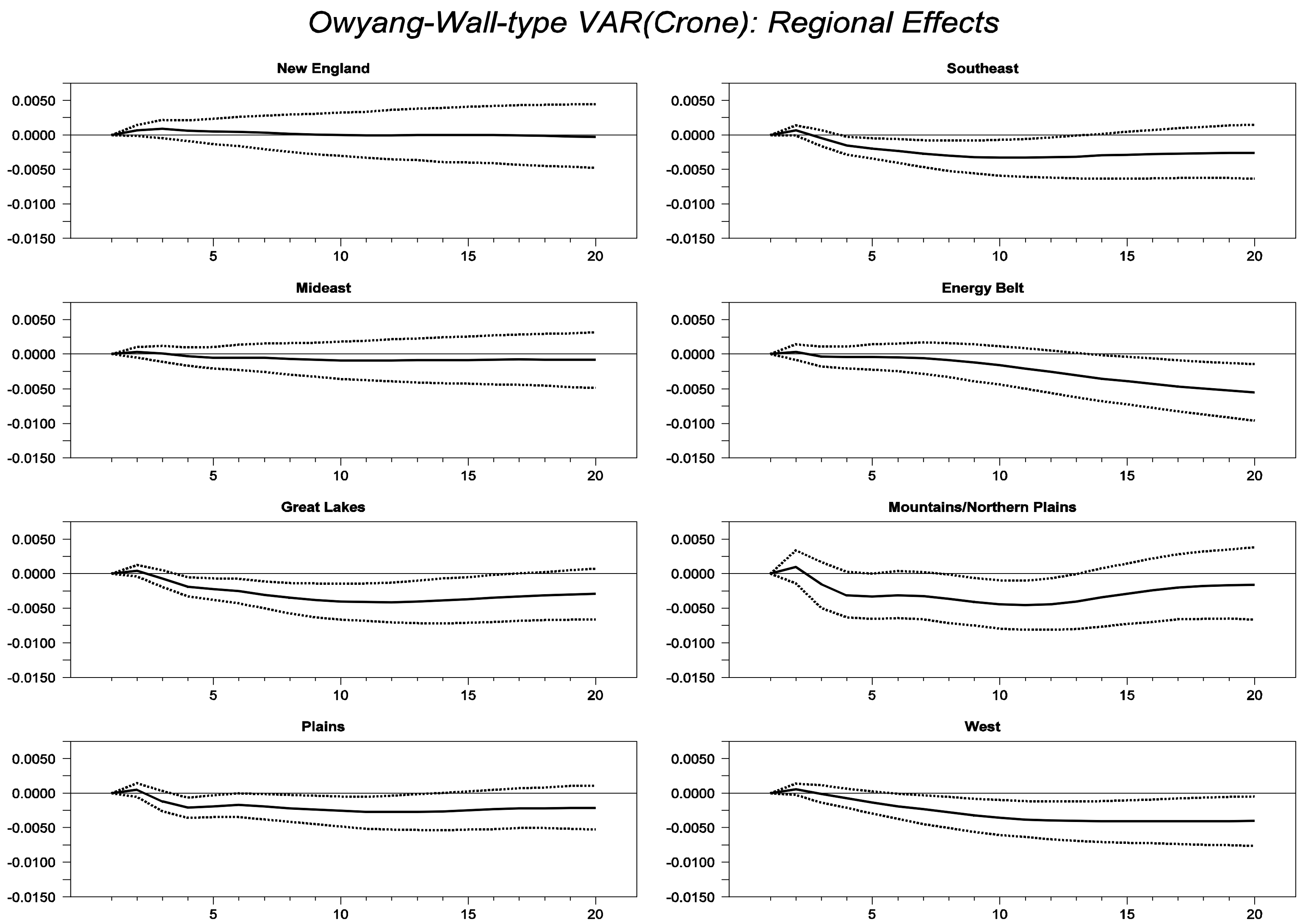


Figure 2.11 — OW-Type (Crone) VAR: Regional Effects

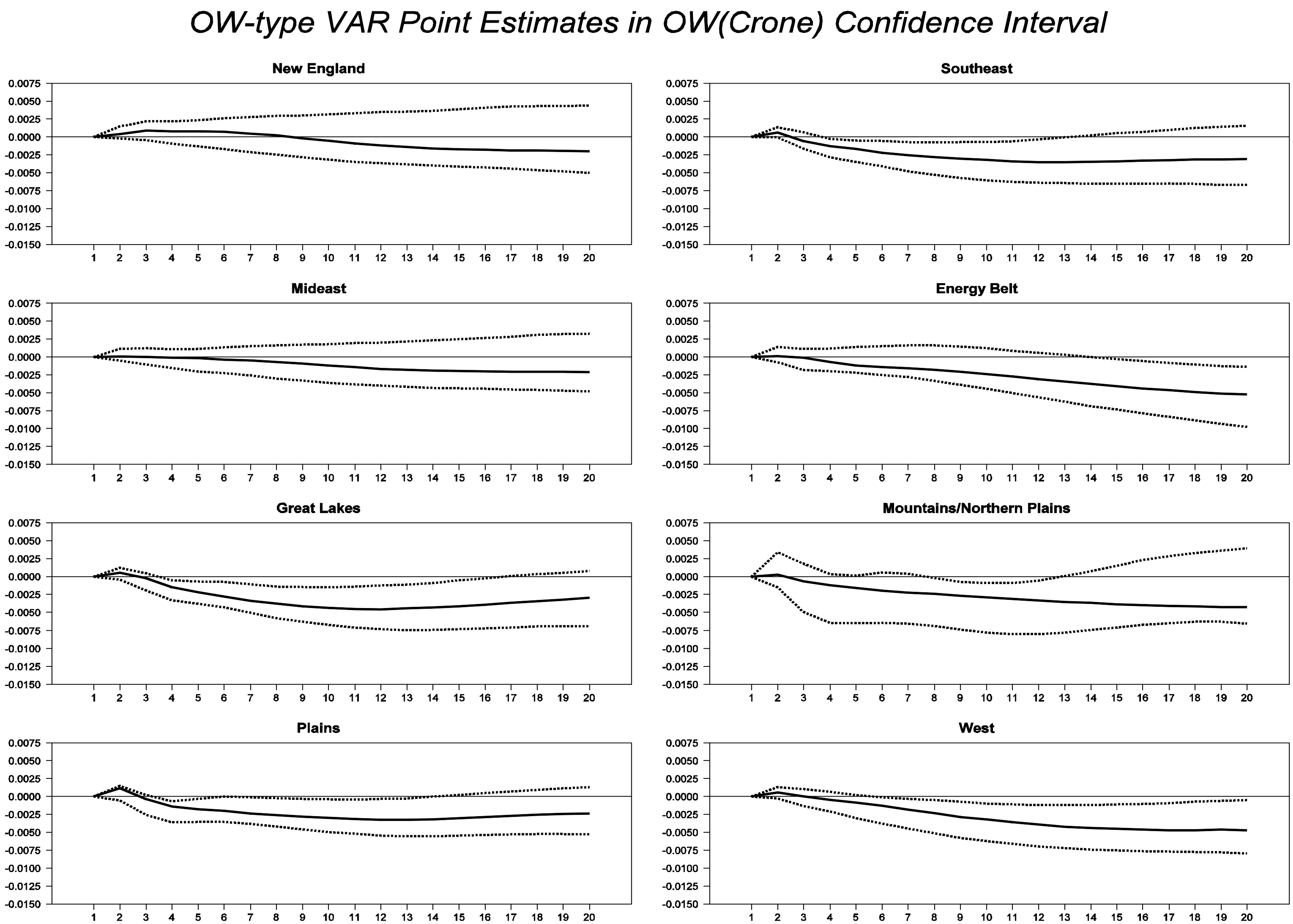


Figure 2.12 — OW-Type VAR Point Estimates in OW-Type VAR (Crone) Confidence Interval

2.6.2 Lastrapes-Type Restricted VAR Model

Figures 2.13 and 2.14 present results from the Lastrapes-type restricted VAR using Crone's definition of regions. The shape and magnitude look similar to the Lastrapes-type VAR results using the BEA regions. However, from Figure 2.13 we see that the persistence in the funds rate after a shock is less than in the Lastrapes-type model using Crone's definition of regions (it returns its initial level after 7 quarters) and the Treasury bond rate returns to its initial value more quickly than in the Lastrapes-type model using Crone's regions definition (it returns its initial level after 9 quarters). There are long-lived significant negative effects on national personal income which returns to its initial level only after 5 years. Commodity prices fall significantly after one quarter, and the effects are very long-lived. Even though we have a smaller price puzzle than the Lastrapes-type model using the BEA regions, there are significant negative effects on the median effect of the aggregate price level after approximately 6 quarters after the shock.

Figure 2.14 presents the regional effects from the Lastrapes-type restricted that uses Crone's regions. Again we see there are no significant effects on personal income in the New England and Mideast regions. However, there are significant effects in all other regions. The effects become significant more quickly than in the Lastrapes-type using the BEA regions. The effects are very persistent for the Great Lakes, Mountains/Northern Plains, Plains, and West regions, but eventually personal income returns to its initial level beyond the 5 year horizon shown. For the Southeast region, the effect becomes marginally significant 3 quarters after the monetary policy shock but personal income returns to its initial value 13 quarters after the shock. For the Energy Belt, the effect becomes marginally significant with a lag of about 3 quarters and personal income returns to its initial value only after 5 years.

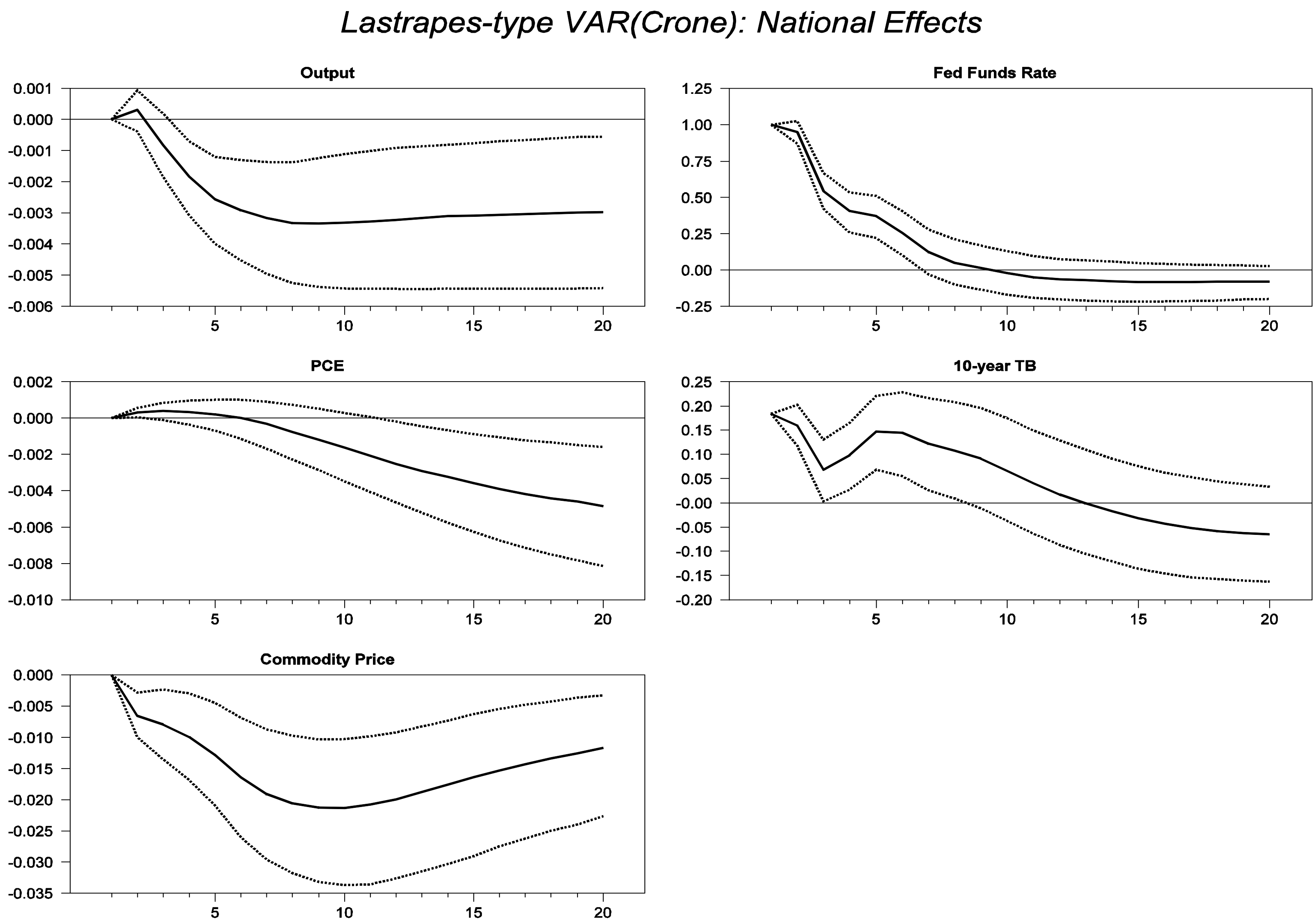


Figure 2.13 — Lastrapes-Type (Crone) VAR: National Effects

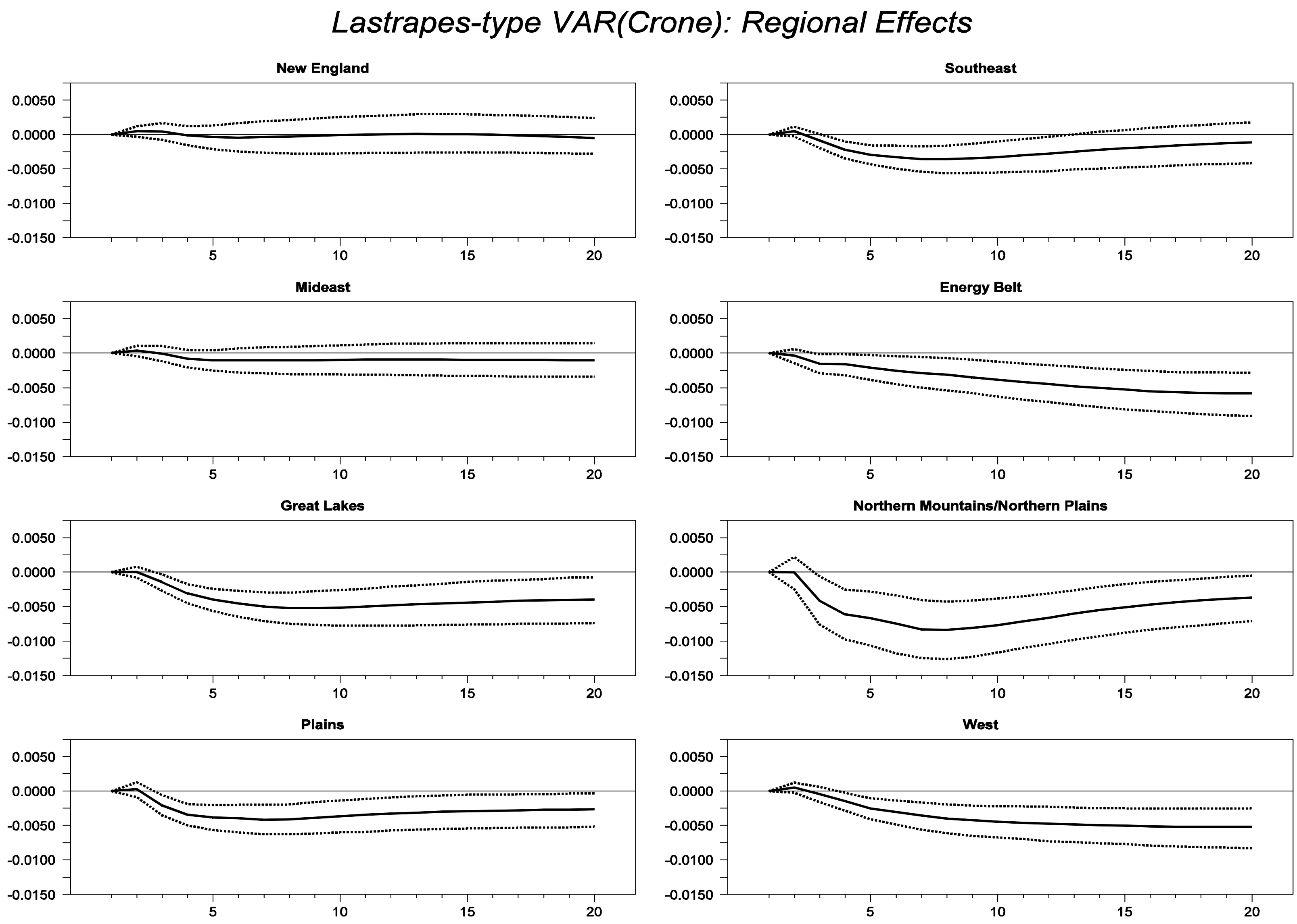


Figure 2.14 — Lastrapes-Type (Crone) VAR: Regional Effects

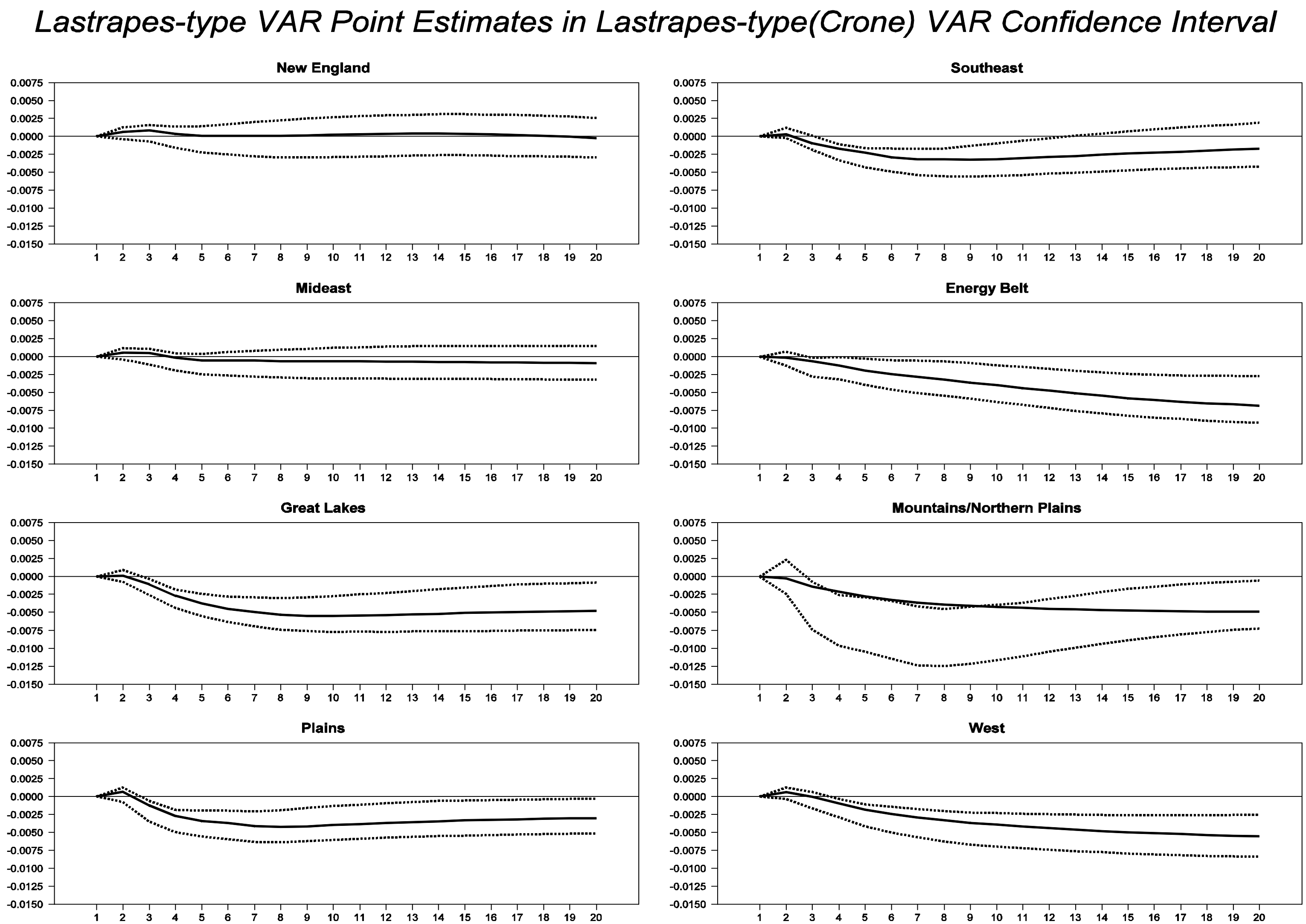


Figure 2.15 — Lastrapes-Type VAR Point Estimates in Lastrapes-Type (Crone) VAR Confidence Interval

We plot the point estimates of Lastrapes-type VAR model with 8 BEA regions definition along with confidence intervals from the Lastrapes-type VAR model with Crone regions. Figure 2.15 presents these results. All point estimates of regions remain well inside the Lastrapes-type VAR model with Crone definition of regions' confidence interval except for the Mountains/Northern Plains region. For the Mountains/Northern Plains region, the point estimates cross the upper bound 4 quarters after the shock and they return into the confidence interval 10 quarters after the shock. Thereafter, they remain in the confidence interval for the whole sample period.

2.6.3 Border- Effects Restricted VAR Model

Figure 2.16 presents the results from the "border-effects" restricted VAR using Crone's regions definition for the national variables. The results are quite similar to those from the border-effects restricted VAR using the BEA regions, although aggregate output returns to its initial level more quickly in the border-effects VAR using Crone's regions definition than in the border-effects VAR using the BEA regions.

From Figure 2.17 it is apparent that the regional effects are very similar for both models. As in the border-effects VAR using the BEA regions model, we have long-lived effect of monetary policy shocks on 8 regional variables in the border-effects restricted VAR using Crone's regions definition. Again we see there are no significant effects on personal income in the New England and Mideast regions. However, there are significant effects in all other regions. The effects are very persistent for the Mountains/Northern Plains, and West regions, but eventually personal income returns to its initial level beyond the 5 year horizon shown. For the Southeast region, the effect becomes marginally significant 3 quarters after the monetary policy shock but personal income returns to its initial value 13 quarters after the shock.

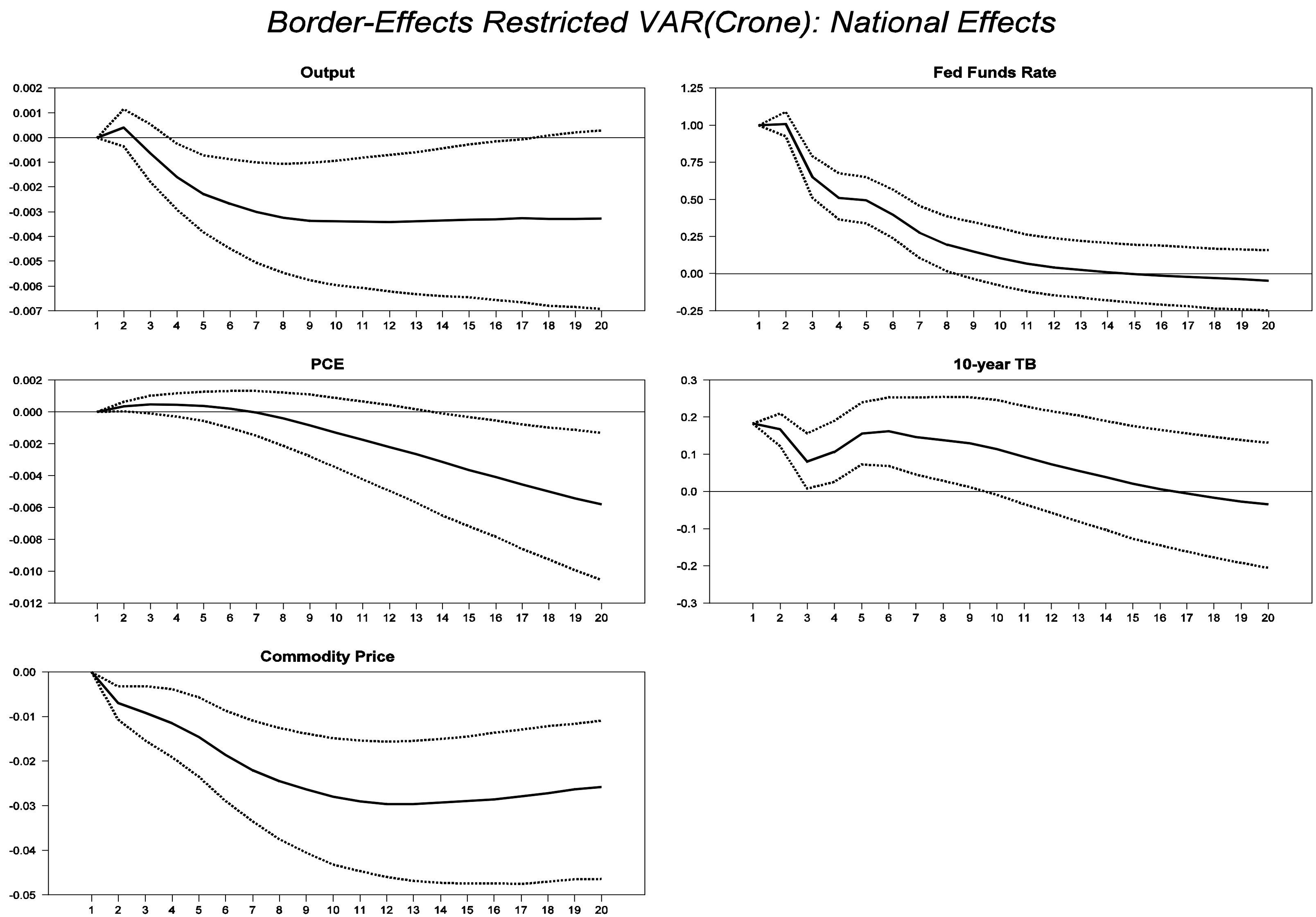


Figure 2.16 — Border-Effects (Crone) VAR: National Effects

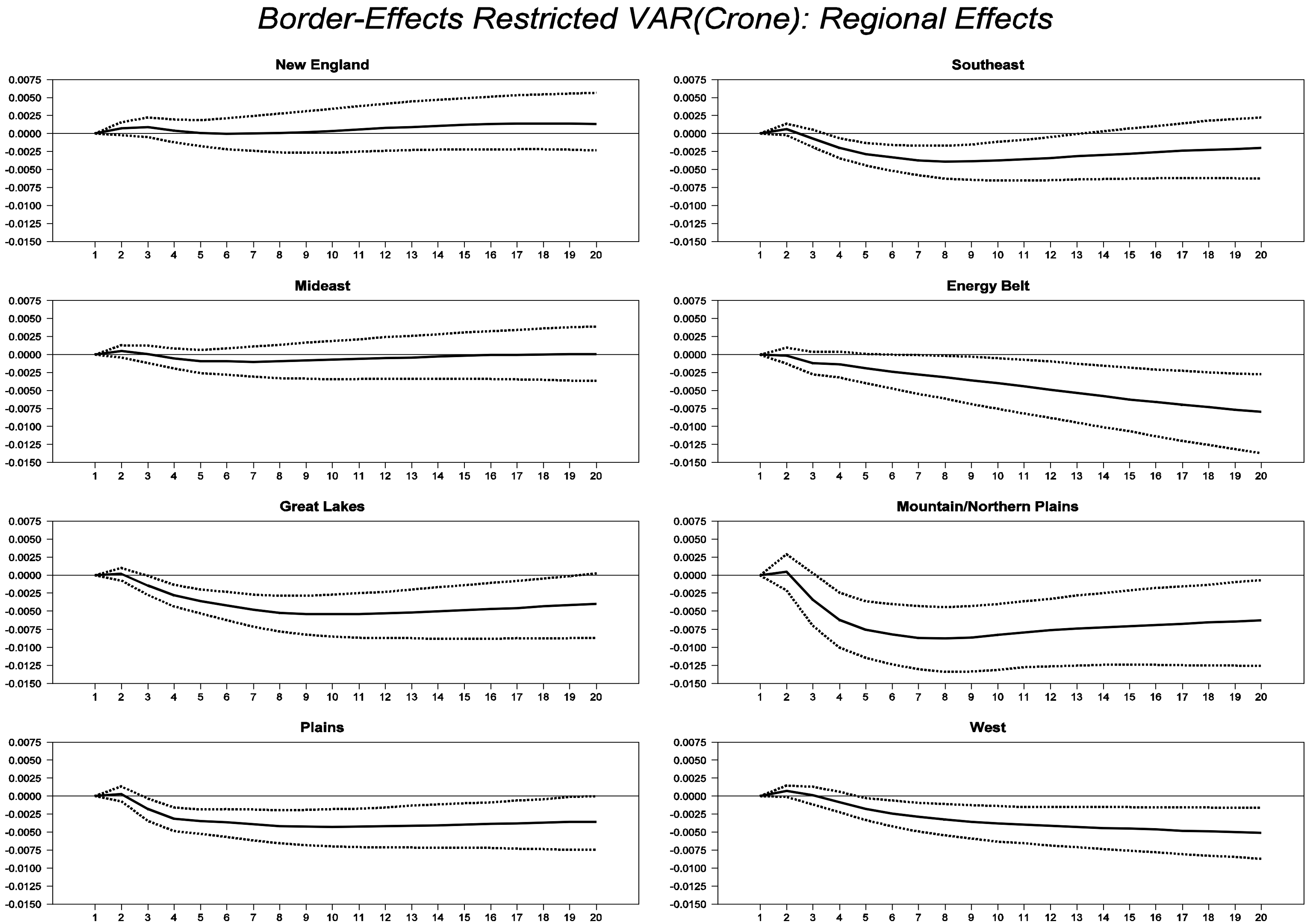


Figure 2.17 — Border-Effects (Crone) VAR: Regional Effects

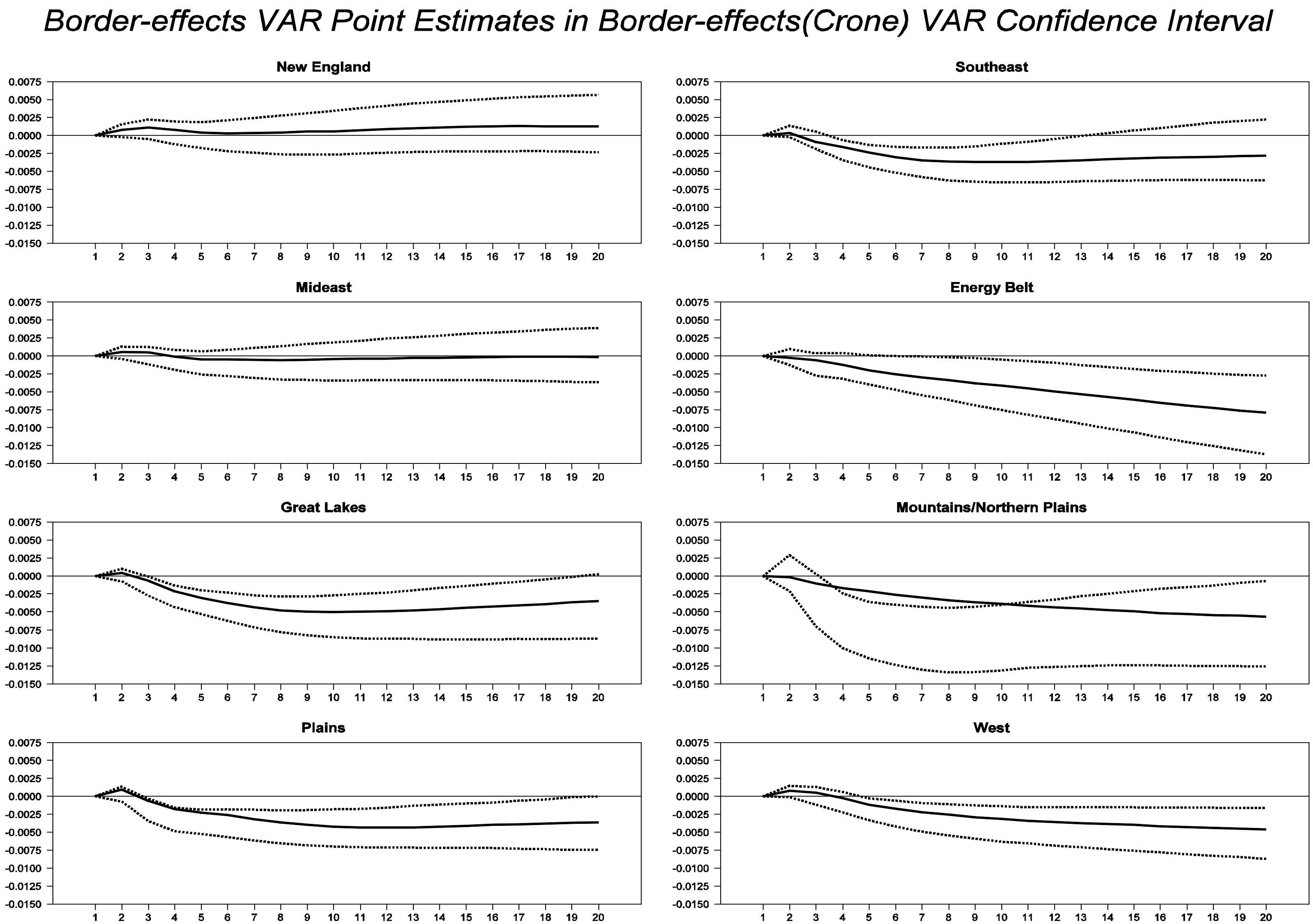


Figure 2.18 — Border-Effects VAR Point Estimates in Border-Effects (Crone) VAR Confidence Interval

For the Energy Belt, the effect becomes marginally significant with a lag of about 5 quarters and personal income returns to its initial value only after 5 years. For the Great Lakes and Plains regions, the effect becomes significant 3 quarters after the monetary policy shock but personal income returns to its initial value 20 quarters after the shock.

We plot the point estimates of IRFs from the border-effects VAR model with 8 BEA regions definition into the confidence intervals from the border-effects VAR model with Crone regions. Figure 2.18 presents these results. All point estimates of regions remain well inside the border-effects VAR model with Crone definition of regions' confidence interval except for the Mountains/Northern Plains region. For the Mountains/Northern Plains region, the point estimates cross over the upper bound 4 quarters after the shock and they return into the confidence interval 10 quarters after the shock. Thereafter, they remain in the confidence interval for the whole sample period.

2.7 Conclusion

This chapter has compared two broad approaches to identifying monetary policy shocks that are used to estimate the regional effects of monetary policy. One approach that has been used in the literature in the past, for example by Owyang and Wall (2005, 2009), assumes that monetary policymakers respond to contemporaneous shocks to personal income in different regions but do not respond directly to shocks to national income. A second general approach assumes that monetary policymakers respond to shocks to national income but do not directly respond to region-specific income shocks. This assumption is based on descriptions of monetary policymaking that indicate that policymakers consider regional information as a guide to what is happening nationally but respond just to developments in the national economy. The second approach is based on a procedure developed by Lastrapes (2005) in a somewhat different

context. Within this second general approach, two restricted VARs are considered. In one it is assumed there is no direct contemporaneous or lagged feedback from one region to another; this allows the restricted VAR to be estimated by ordinary least squares. In the second, it is assumed there are "border-effects" in which there is lagged feedback among contiguous regions. The restricted VAR embodying this assumption is estimated with SUR.

In all, three VAR models—one standard VAR and two restricted VARs—are estimated over a common sample, and monetary policy shocks are identified using a Choleski decomposition that differs across the two types of VARs only in the assumption about how policymakers respond to income shocks, i.e. whether they respond directly only to shocks to national income or whether they respond directly to region-specific income shocks. In the standard VAR in which policy shocks are identified assuming that policymakers respond directly to region-specific policy shocks, personal income from each region is included but national income is not included in the VAR. In the restricted VARs in which policy shocks are identified by assuming that policymakers respond directly to shocks to national personal income and not to region-specific income shocks, national income as well as income from each region is included. The effects of monetary policy shocks on regional economic activity differ across the two broad approaches to identifying policy shocks. Impulse response functions from the standard VAR indicate there are no significant effects in two regions, marginally significant effects in four regions, and significant effects in two regions. Impulse response functions from both restricted VARs suggest no significant effects in the same two regions as the standard VAR, but significant effects in the remaining six regions. For these six regions, the timing and duration of the effects of monetary policy shocks on personal income suggested by the restricted VARs are similar to one another but are different from the OW-type VAR. Thus, the assumptions about how

monetary policymakers respond to shocks to real income seem to matter for estimating the effects of monetary policy on regional economic activity.

The effects on regional personal income by themselves do not support one approach over the other. However, impulse response functions for shocks to monetary policy reveal insignificant effects on aggregate price and commodity prices for the standard VAR but significant negative effects on aggregate price and commodity prices for the restricted VARs. These contrasting results for the aggregate price level and commodity prices weigh in favor of the restricted VAR approach.

Chapter 3. Forty Eight Contiguous States Case
3.1 Introduction

In the previous chapter, it was found that the effects of monetary policy differed across different regions of the U.S. In this chapter, we extend the analysis from 8 BEA regions to the 48 contiguous states. It is important to extend the analysis from the regional level to the state level since different states in the same region may have quite different responses to monetary policy shocks. For example, the mix of industries may differ from one state to another within the region so the effects of monetary policy may be different for one state than for another. Results from previous studies of the state level effects of monetary policy show differences in timing and magnitude for the same state, but use different sample periods, different identification schemes, and different set of variables. This chapter isolates the effects of different identification schemes by using a common sample period and the same set of model variables.

Section 2 describes the prior research on the state effects of monetary policy. Section 3 explains the two statistical models and the set of identifying restrictions we use to measure the dynamic responses to monetary shock. Section 4 describes the data and Section 5 reports the empirical results. This section examines the impulse responses of the national and state variables in the model to a monetary shock. Section 6 is the conclusion.

3.2 Previous Research
3.2.1 Carino and Defina (1999a, 1999b)

Using a structural VAR, Carlino and DeFina (1998) estimate the effects of monetary policy on real personal income in each of the eight BEA U.S. regions. In Carlino and DeFina (1999a, 1999b), they extend their analysis of the effects of monetary policy to the state level and use a quarterly structural vector autoregression (SVAR) estimated over the period 1958:1 to

1992:4 to examine the effects of changes in monetary policy on real personal income growth in each of the 48 contiguous states

The variables in their VAR include real personal income growth for the state under consideration, the real personal income growth for the remainder of the BEA region that contains the state being considered, the other seven major BEA regions' real personal income growth, three macroeconomic variables: the core CPI, the BEA index of leading indicators, the producer price index (PPI), and FFR. Three macroeconomic variables are used to control for macroeconomic effects on state economies and Fed policy decisions; the change in core CPI captures trends in the aggregate price level, the change in the index of leading indicators is a way to summarize a variety of macroeconomic variables, and PPI is used to account for energy price shocks. FFR is a measure monetary policy.

Carlino and DeFina use three sets of restrictions to identify monetary policy shocks. First, they assume a state-specific shock affects contemporaneously only the state of origin with no contemporaneous effect on other states. That is, a shock to a state's real PI growth affects other states' growth only after one-period lag. Second, Fed policies are assumed to affect personal income growth only with a lag and shocks to core inflation, the leading indicators, and the relative energy price are assumed have no contemporaneous effect on state personal income growth. Third, state income growth and monetary policy actions are assumed not to have contemporaneous effects on core inflation, the leading indicators, and relative energy prices.

From the estimated SVARs, they compute cumulative IRFs for personal income of 48 contiguous states from a one-percentage-point increase in FFR. They group the state responses by eight BEA regions and include the weighted average state responses as a benchmark. Then they show the state responses' difference of monetary policy effect within and between regions.

Carlino and DeFina find that, after a small initial rise, the level of real personal income declines substantially, reaching its maximum response approximately two years (eight quarters) after a one-percentage-point increase in the funds rate. While most of the 48 contiguous states responses follow this general pattern, the magnitude of the decline in PI varies across states. The eight-quarter cumulative response of real PI falls by 1.16 percent nationally. Michigan is the largest response among states: real PI falls 2.7 percent after a one-percentage-point increase in FFR. Four states (Arizona, Indiana, New Hampshire, and Oregon) respond more than one and a half times as much as the nation. On the contrary, four states (Louisiana, Oklahoma, Texas, and Wyoming) respond less than half as much as the nation. Finally, the smallest response among states is Oklahoma in which falls real PI by 0.07 percent after a one-percentage-point increase in FFR.

3.2.2 Beckworth (2010)

Beckworth uses states monthly coincident indicators as a measure of state's real economic activity. The Philadelphia Federal Reserve bank constructs a coincident indicator that summarizes each state's real economic conditions. To borrow the Philadelphia Federal Reserve bank website's phrase, "The coincident indexes combine four state-level indicators to summarize current economic conditions in a single statistic. The four state-level variables in each coincident index are nonfarm payroll employment, average hours worked in manufacturing, the unemployment rate, and wage and salary disbursements deflated by the consumer price index (U.S. city average). The trend for each state's index is set to the trend of its gross domestic product (GDP), so long-term growth in the state's index matches long-term growth in its GDP." Stock and Watson (1989) developed the basic model for constructing a coincident index for the U.S. Crone and Clayton-Matthews (2005) adapted the basic model for the states.

Beckworth follows Lastrapes (2005, 2006)'s method to estimate a large VAR that has partitioned the set of endogenous variables. In the first block are four macroeconomic variables that include the monthly coincident indicator for the U.S., the CPI price index, the commodity price index, and FFR. In the second block are state-level variables that include 48 states' monthly coincident indicator and a border economy measure. His estimation period is 1983:1 to 2008:3.

Beckworth uses an identification scheme that assumes a systematic monetary policy response only to national variables rather than assuming the Fed directly responded contemporaneously to movements in state variables. Further it is assumed that state variables cannot influence the national variables but state variables can be affected by the national economy variables.

To able to estimate a large 52 variable VAR that has both macroeconomic and state-level variables, Beckworth imposes two sets of over-identifying restrictions on the VAR model. First, a state-specific shock is assumed to affect~~s~~ only the state of origin but not another state if they are not contiguous. If they are contiguous, a state-specific shock affects the contiguous state. This reflects the assumption that there are no contemporaneous direct effects of one state on another unless they are adjoined. Second, it is assumed that the state-level variables do not have a direct effect on the macro variables.

Using these restrictions, Beckworth uses a two-step procedure to estimate the large VAR. First, he estimates a standard VAR for the national variables block. Second, the state variable equations are estimated individually by SUR since a state-level border is included. Beckworth calculates cumulative IRFs for each state's coincident indicator for a positive one standard deviation monetary policy shock to the FFR.

After a positive one unit FFR shock, most states' economic decline happen by 24 months and at that time U.S.'s decline is 0.25 percent. Beckworth finds there are some different patterns to the shock in which states' standard error bands fall outside the U.S. IRF; 12 states do better than the U.S., so coincident indicators decline less than the U.S.'s after the shock. Eight states do worse than the U.S., so their coincident indicators decrease more than that of the U.S. average after the shock, and the rest of the states' response are similar to the U.S. average.

3.3 Empirical Framework

In this section we describe two Restricted VAR models estimated (Lastrapes-type Restricted VAR and Border-effects Restricted VAR) and the identification of monetary policy shocks for VARs. We assume policy makers respond only to contemporaneous and lagged movements in national variables but policy actions affect both national and regional variables. We consider a 53-variable VAR which has partitioned into two blocks; the first block includes 5 macro variables and second block includes 48 state-level variables. In our model, it is possible to use state-level data to estimate 48 different responses to a monetary policy shock. Unfortunately, the estimation of a 53-variable model with the OW-type VAR identification is not feasible due to a degrees of freedom problem. There are 191 quarterly observations over the sample period (1960: I to 2007: III) with 53 explanatory variables. With the three lags, we do not have enough data to estimate an OW-type VAR. Therefore, we only use the two restricted VAR approaches.

In these two approaches, we have partitioned our model variable into two blocks. The first block is a macro variable that includes aggregate real personal income, the price level (PCE), a commodity price index (COP), the federal funds rate (FFR), and a long-term bond rate (TB). The ordering of the macro variables within this block is national output (aggregate real personal income), price level (PCE), commodity price (COP), federal funds rate (FFR), and 10-year

Treasury Bill (TB). The second block is a state-level block that includes real personal income from the 48 contiguous states. Additionally, lags of the oil shock dummy discussed in the previous chapter are included as exogenous variables in each equation of the model along with an intercept term. The monetary policy variable is FFR, and a structural monetary policy shock is identified using a Choleski decomposition using the ordering just described. The first block (national block) is ordered before the second block (state block). This ordering assumes that monetary policymakers respond contemporaneously to shocks to the national personal income variable, the aggregate price level, and the commodity price index in setting FFR, but policy actions affect these variables only with a lag. We also order commodity prices before the funds rate in order to allow a contemporaneous response by policymakers to shocks to commodity prices. We further assume that monetary policy actions affect the long-term bond rate within the period, but that policymakers respond to movements in the long-term bond rate only with a lag. We assume that within the state block a shock to personal income in one state has no contemporaneous effect on personal income in other states. We will examine further Lastrapes-type and Border-effects restricted VARs in the next section.

3.3.1 Lastrapes-Type Restricted VAR Model

Let $y_t = \begin{pmatrix} z_t \\ x_t \end{pmatrix}$ be a (53×1) vector stochastic process. We have partitioned our endogenous variable, y_t into two blocks. z_t is a (5×1) vector of macroeconomic variables that includes the aggregate real personal income, the price level, the commodity price index, the federal funds rate, and Treasury bill rate and is our first block. x_t is a (48×1) vector of the state economy variables that includes a real economy activity measure for each state economy (48

states personal income) and is our second block. Assume that this process is generated by the linear dynamic model:

$$A_0 y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t$$

$$= B_1 y_{t-1} + \ldots + B_p y_{t-p} + \varepsilon_t \,,$$

where $u_t = \begin{pmatrix} u_{1t} \\ u_{2t} \end{pmatrix}$ is a white noise vector process normalized so that $E u_t u_t' = \Omega$, $E\varepsilon_t \varepsilon_t' = \Sigma$,

$B_i = A_0^{-1} A_i$ and $A_i, i = 0, \ldots, p$, is a (53×53) vector matrix. Thus, $y_t = [z_t \,, x_t]'$ and the A_0 matrix in the structural model can be written as: $\begin{bmatrix} A_{01z} & A_{01x} \\ A_{02z} & A_{02x} \end{bmatrix}$.

From Lastrapes (2005, 2006) and as in the chapter 2, we consider two sets of over-identifying restrictions on the VAR: First, the assumption that the regional economic variables cannot affect the macroeconomic variables sets the (1, 2) element of the A_0 sub matrix ($A_{01x} = 5 \times 48$) to be zero. Second, the assumption that the regional-specific shock affects contemporaneously only the region of origin sets the (2, 2) element of the A_0 sub matrix ($A_{02x} = 48 \times 48$) to be diagonal. As shown in Lastrapes (2005), using these restrictions, equation-by-equation OLS estimation is efficient. Therefore, we use OLS to estimate the Lastrapes-type VAR.

Let us examine our structural model in more detail. As shown in chapter 2, the (1, 1) element of the A_0 sub matrix, A_{01z} is a (5 × 5) matrix of national variables with 1's on the diagonal, non-zero coefficients below the diagonal, and 0's above the diagonal.

The (1, 1) element of the $A_0 = A_{01z} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{021z} & 1 & 0 & 0 & 0 \\ a_{031z} & a_{032z} & 1 & 0 & 0 \\ a_{041z} & a_{042z} & a_{043z} & 1 & 0 \\ a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 \end{bmatrix}$

This matrix represents a recursive causal chain and the ordering implies output, the price level, and commodity prices have contemporaneous effects on the funds rate, but the funds rate has no contemporaneous effects on output, the price level, and commodity prices. However, the funds rate has a contemporaneous effect on the long-term bond rate.

Due to the first restriction, the (1, 2) element of the A_0 matrix, A_{01x} becomes a (5 × 48) null matrix. It reflects the assumption that the state variables don't have a direct effect on the national variables.

The (1, 2) element of the $A_0 = A_{01x} = \begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \end{bmatrix}$

The (2, 1) element of the A_0 matrix, A_{02z} is a (48 × 5) matrix with coefficients that are all allowed to be non-zero. These coefficients represent the contemporaneous effects of the national variables on the state variables.

$$\text{The (2, 1) element of the } A_0 = A_{02z} = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{0521z} & a_{0522z} & a_{0523z} & a_{0524z} & a_{0525z} \\ a_{0531z} & a_{0532z} & a_{0533z} & a_{0534z} & a_{0535} \end{bmatrix}$$

The (2, 2) element of the A_0 matrix, A_{02x} is a (48 × 48) diagonal matrix with 1's on the diagonal. This reflects the assumption that there are no contemporaneous direct effects of one state on another and it is the second restriction.

$$\text{The (2, 2) element of the } A_0 = A_{02x} = \begin{bmatrix} 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 \\ \vdots & 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & 0 & \ddots & 0 & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & 0 & \ddots & 0 & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & 0 & \ddots & 0 & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & 0 & \ddots & 0 & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & 0 & 1 & 0 & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 & 0 \\ 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 \end{bmatrix} 0$$

The A_1 matrix can be written as $\begin{bmatrix} A_{11z} & A_{11x} \\ A_{12z} & A_{12x} \end{bmatrix}$. The (1, 1) element of the A_1 matrix, A_{11z} is a (5 × 5) matrix of coefficients of the effects of the national variables lagged one period on themselves. All these coefficients are allowed to be non-zero.

The (1, 1) element of the $A_1 = A_{11z} = \begin{bmatrix} a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} \\ a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} \\ a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} \\ a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} \\ a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} \end{bmatrix}$

The (1, 2) element of the A_1 matrix, A_{11x} is a (5 × 48) null matrix, reflecting the assumption that the state variables do not have a direct effect—contemporaneous or lagged—on the national variables.

The (1, 2) element of the $A_1 = A_{11x} = \begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \end{bmatrix}$

The (2, 1) element of the A_1, A_{12z} is a (48 × 5) matrix of coefficients that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the state variables.

The (2, 1) element of the $A_1 = A_{12z} = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{0521z} & a_{0522z} & a_{0523z} & a_{0524z} & a_{0525z} \\ a_{0531z} & a_{0532z} & a_{0533z} & a_{0534z} & a_{0535} \end{bmatrix}$

The (2, 2) element of the A_1, A_{12x} is a (48 × 48) diagonal matrix with non-zero coefficients on the diagonal.

$$A_{12x} = \begin{bmatrix} a_{166x} & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & a_{177x} & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 \\ \vdots & 0 & a_{188x} & 0 & \cdots & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & 0 & \ddots & 0 & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & 0 & \ddots & 0 & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & 0 & \ddots & 0 & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & 0 & \ddots & 0 & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & 0 & a_{15151x} & 0 & \vdots \\ 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0 & 0 & a_{15252x} & 0 \\ 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & a_{15353x} \end{bmatrix}$$

This reflects the assumption that there are no lagged direct effects of one state on another, and the lagged effects of one state on itself are captured in the diagonal coefficients. The other A_i matrices are defined in a same manner.

By the same reasoning, the reduced form of B_1 matrix in the restricted VAR can be written as $\begin{bmatrix} B_{11z} & B_{11x} \\ B_{12z} & A_{12x} \end{bmatrix}$. The (1, 1) element of the B_1 matrix, B_{11z} is a (5 × 5) matrix of reduced form coefficients of the effects of the national variables lagged one period on themselves. As in the case of the structural coefficient matrices, there are no lagged direct effects of the state variables on the national variables so the (1, 2) element of the B_1 matrix, B_{11x} is a (5 × 48) null matrix. The (2, 1) element of the B_1 matrix, B_{12z} is an (48 × 5) matrix of reduced form coefficients that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the state variables. The (2, 2) element of the B_1, B_{12x} is an (48 × 48) diagonal matrix with non-zero reduced form coefficients on the diagonal that capture the one period lagged effect of a state variable on itself. The other B_i matrices are defined in a same manner.

The restricted VAR is estimated, and a Choleski decomposition is applied to the restricted VAR's estimated variance-covariance matrix with the ordering described above—national block first and state block next. Placing the state block after the national block means the state variables will have no contemporaneous effects on the national variables, as specified in the A_0 matrix described above. The national block in the A_0 matrix above is recursive and the ordering listed above reflects the assumption that monetary policy responds contemporaneously to shocks to national output, the aggregate price level, and commodity prices but not to contemporaneous shocks to the long-term bond rate. The ordering further implies that monetary policy shocks affect the long-term bond rate contemporaneously but affect national output, the aggregate price level, and commodity prices only with a lag. For the Restricted VAR, the vector of variables in the Choleski decomposition ordering is

$$\begin{aligned} y_t = [&Y_t^{US}, PCE_t, COP_t, FFR_t, TB_{t,} Y_t^{AL}, Y_t^{AZ}, Y_t^{AR}, Y_t^{CA}, Y_t^{CO}, Y_t^{CT}, Y_t^{DE}, Y_t^{FL}, Y_t^{GA}, Y_t^{ID}, Y_t^{IL}, Y_t^{IN}, Y_t^{IA}, \\ &Y_t^{KS}, Y_t^{KY}, Y_t^{LA}, Y_t^{ME}, Y_t^{MD}, Y_t^{MA}, Y_t^{MI}, Y_t^{MN}, Y_t^{MS}, Y_t^{MO}, Y_t^{MT}, Y_t^{NE}, Y_t^{NV}, Y_t^{NH}, Y_t^{NJ}, Y_t^{NM}, Y_t^{NY}, \\ &Y_t^{NC}, Y_t^{ND}, Y_t^{OH}, Y_t^{OK}, Y_t^{OR}, Y_t^{PA}, Y_t^{RI}, Y_t^{SC}, Y_t^{SD}, Y_t^{TN}, Y_t^{TX}, Y_t^{UT}, Y_t^{VT}, Y_t^{VA}, Y_t^{WA}, Y_t^{WV}, Y_t^{WI}, Y_t^{WY}]' \end{aligned}$$

3.3.2 Border-Effects Restricted VAR Model

One concern with the Lastrapes-type approach just described is that one state can affect other states only directly through the first state's effects on the national economy. One might expect that economic activity in, for example, New York might have effects on adjoining states like New Jersey, Pennsylvania, Massachusetts, Connecticut, and New Hampshire directly as well as through effects on national variables. A second Lastrapes-type approach allows state output to depend on its own lagged values as well as on the lagged values of economic activity in adjoining states while maintaining the same assumptions about the national variables as before.

For the restricted VAR model with border effects, the A_0^B matrix in the structural model can be written as: $\begin{bmatrix} A_{01z}^B & A_{01x}^B \\ A_{02z}^B & A_{02x}^B \end{bmatrix}$. The A_0^B matrix is the same as for the A_0 matrix in the first restricted VAR model.

The (1, 1) element of the A_0^B matrix, A_{01z}^B is a (5 × 5) matrix of national variables with 1's on the diagonal, non-zero coefficients below the diagonal, and 0's above the diagonal. The (1, 2) element of the A_0^B matrix, A_{01x}^B is a (5 × 48) null matrix. The (2, 1) element of the A_0^B matrix, A_{02z}^B is a (48 × 5) matrix of coefficients that are all allowed to be non-zero. The (2, 2) element of the A_0^B matrix, A_{02x}^B is a (48 × 48) diagonal matrix with 1's on the diagonal.

The (1, 1) element of the $A_0^B = A_{01z}^B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{021z} & 1 & 0 & 0 & 0 \\ a_{031z} & a_{032z} & 1 & 0 & 0 \\ a_{041z} & a_{042z} & a_{043z} & 1 & 0 \\ a_{051z} & a_{052z} & a_{053z} & a_{054z} & 1 \end{bmatrix}$

The (1, 2) element of the $A_0^B = A_{01x}^B = \begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \end{bmatrix}$

The (2, 1) element of the $A_0^B = A_{02z}^B = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{0521z} & a_{0522z} & a_{0523z} & a_{0524z} & a_{0525z} \\ a_{0531z} & a_{0532z} & a_{0533z} & a_{0534z} & a_{0535} \end{bmatrix}$

The (2, 2) element of the $A_0^B = A_{02x}^B = \begin{bmatrix} 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 \\ \vdots & 0 & 1 & 0 & \cdots & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & 0 & \ddots & 0 & \cdots & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & 0 & \ddots & 0 & \cdots & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & 0 & \ddots & 0 & \cdots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & 0 & \ddots & 0 & \vdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & 0 & 1 & 0 & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 & 0 \\ 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 1 \end{bmatrix} 0$

The A_1^B matrix can be written as $\begin{bmatrix} A_{11z}^B & A_{11x}^B \\ A_{12z}^B & A_{12x}^B \end{bmatrix}$. For the A_1^B matrix, the A_{11z}^B, A_{11x}^B, and A_{12z}^B sub-matrices are the same as for the first restricted VAR.

The (1, 1) element of the A_1^B matrix, A_{11z}^B is a (5 × 5) matrix of coefficients of the effects of the national variables lagged one period on themselves. All these coefficients are allowed to be non-zero. The (1, 2) element of the A_1^B matrix, A_{11x}^B is a (5 × 48) null matrix, reflecting the assumption that the state variables do not have a direct effect—contemporaneous or lagged—on the national variables. The (2, 1) element of the A_1^B matrix, A_{12z}^B is a (48 × 5) matrix of

coefficients that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the state variables.

$$\text{The (1, 1) element of the } A_1^B = A_{11z}^B = \begin{bmatrix} a_{111z} & a_{112z} & a_{113z} & a_{114z} & a_{115z} \\ a_{121z} & a_{122z} & a_{123z} & a_{124z} & a_{125z} \\ a_{131z} & a_{132z} & a_{133z} & a_{134z} & a_{135z} \\ a_{141z} & a_{142z} & a_{143z} & a_{144z} & a_{145z} \\ a_{151z} & a_{152z} & a_{153z} & a_{154z} & a_{155z} \end{bmatrix}$$

$$\text{The (1, 2) element of the } A_1^B = A_{11x}^B = \begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \end{bmatrix}$$

$$\text{The (2, 1) element of the } A_1^B = A_{12z}^B = \begin{bmatrix} a_{061z} & a_{062z} & a_{063z} & a_{064z} & a_{065z} \\ a_{071z} & a_{072z} & a_{073z} & a_{074z} & a_{075z} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{0521z} & a_{0522z} & a_{0523z} & a_{0524z} & a_{0525z} \\ a_{0531z} & a_{0532z} & a_{0533z} & a_{0534z} & a_{0535} \end{bmatrix}$$

However, the (2, 2) element of the A_1^B matrix, A_{12x}^B is different. It is no longer simply a diagonal matrix with the own lag coefficients on the diagonal because the coefficients on the lag of the state personal income of contiguous states are now included in this matrix. For example, for the equation for the New York, its lag coefficient as well as the coefficients for the lag on income of the states that are contiguous to New York is included in the A_{12x}^B matrix. For this reason, the state variables equations do not have the same number of right-hand side variables.

In this case, we cannot estimate efficiently using the equation-by-equation OLS. Therefore, we use SUR to estimate the effects of monetary policy. The other A_i^B matrices are defined in an analogous manner.

By the same token, the reduced form of B_1^B matrix in the restricted VAR can be written as $\begin{bmatrix} B_{11z}^B & B_{11x}^B \\ B_{12z}^B & B_{12x}^B \end{bmatrix}$. The (1, 1) element of the B_1^B matrix, B_{11z}^B is a (5 × 5) matrix of reduced form coefficients of the effects of the national variables lagged one period on themselves. As in the case of the structural coefficient matrices, there are no lagged direct effects of the state variables on the national variables so the (1, 2) element of the B_1^B matrix, B_{11x}^B is a (5 × 48) null matrix. The (2, 1) element of the B_1^B matrix, B_{12z}^B is a (48 × 5) matrix of reduced form coefficients that are all allowed to be non-zero and represent the one-period lagged effects of the national variables on the state variables. The (2, 2) element of the B_1^B, B_{12x}^B is a (48 × 48) diagonal matrix with non-zero reduced form coefficients on the diagonal that capture the one period lagged effect of a state variable on itself. The other B_i^B matrices are defined in an analogous manner.

3.4 Data

The restricted VARs are estimated using quarterly data for the period 1960: I-2007: III. Again, all lags in the VARs were 3 quarters, although the results were not sensitive to lags of 2, 4, and 5 quarters. Data for quarterly US (Y^{US}) and state personal income and the quarterly personal consumption expenditures deflator (PCE) comes for Bureau of Economic Analysis web site. Real state personal income is calculated by deflating by PCE quarterly data on nominal state personal income for each state. The PCE deflator was used in the VARs since the Federal Reserve focuses on this index in evaluating price stability. We also used the PCE for

measuring the price level. Data for the Federal Funds Rate (FFR) and the 10-year Treasury bond rate (TB) comes from Board of Governors of the Federal Reserve web site, and the quarterly average of the monthly CRB spot index (*COP*) comes from the Commodity Research Bureau web site. FFR, COP and the 10-year Treasury-bill rate are monthly, so we used the arithmetic average to convert these variables to quarterly data. For the restricted VARs, the vector of variables in the Choleski decomposition ordering is

$$
\begin{aligned}
y_t = [&Y_t^{US}, PCE_t, COP_t, FFR_t, TB_t, Y_t^{AL}, Y_t^{AZ}, Y_t^{AR}, Y_t^{CA}, Y_t^{CO}, Y_t^{CT}, Y_t^{DE}, Y_t^{FL}, Y_t^{GA}, Y_t^{ID}, Y_t^{IL}, Y_t^{IN}, Y_t^{IA}, \\
&Y_t^{KS}, Y_t^{KY}, Y_t^{LA}, Y_t^{ME}, Y_t^{MD}, Y_t^{MA}, Y_t^{MI}, Y_t^{MN}, Y_t^{MS}, Y_t^{MO}, Y_t^{MT}, Y_t^{NE}, Y_t^{NV}, Y_t^{NH}, Y_t^{NJ}, Y_t^{NM}, Y_t^{NY}, \\
&Y_t^{NC}, Y_t^{ND}, Y_t^{OH}, Y_t^{OK}, Y_t^{OR}, Y_t^{PA}, Y_t^{RI}, Y_t^{SC}, Y_t^{SD}, Y_t^{TN}, Y_t^{TX}, Y_t^{UT}, Y_t^{VT}, Y_t^{VA}, Y_t^{WA}, Y_t^{WV}, Y_t^{WI}, Y_t^{WY}]'
\end{aligned}
$$

3.5 The Empirical Results

In our model, the Impulse Response Functions (IRFs) for a one unit shock to the federal funds rate are computed for each model and are presented in the figures. As mentioned in chapter 2, in each figure, the solid line is the median estimate from the simulation, and the dotted lines are the upper and lower bounds which represent the 84th and 16th percentiles, respectively. Thus, as is common in the literature, approximate one-standard deviation confidence bands are plotted. The confidence bands are derived from Monte Carlo simulations with 2500 draws. The figures report the estimated IRFs for a positive one unit shock to the federal funds rate for the macro variables and 48 contiguous states real personal income. The effects of monetary policy on state output are compared for the two Restricted VARs. As in the chapter 2, the patterns of effects are often similar: a U-shaped output response, decrease in the price level even though we have a price puzzle, and a temporary rise in the interest rate. Significant differences in the magnitude of the effects, however, are found even though the general pattern of effects is similar across the two approaches.

3.5.1 Lastrapes-Type Restricted VAR

We group the states' responses (IRFs) by eight BEA regions and show the different monetary policy effect on each state's economy.

Figure 3.1 presents the national effects from the Lastrapes-type restricted VAR (state) model. Comparing Figure 3.1 (the Lastrapes-type restricted VAR (state) model) and Figure 2.3 (the Lastrapes-type restricted VAR (region) model), we find that in the Lastrapes-type restricted VAR (state) model, the funds rate's persistence after a shock is less than in the Lastrapes-type restricted VAR (region) model and the Treasury bond rate returns to its initial value more quickly than in the Lastrapes-type restricted VAR (region) model. There are long-lived significant negative effects on national personal income which returns to its initial level only after 5 years. Commodity prices fall significantly after one quarter, and the effects are very long-lived. Even though we have a smaller price puzzle than the Lastrapes-type restricted VAR (region) model, there are significant negative effects on the aggregate price level after six quarters.

Figures 3.2.1 through 3.2.8 presents the state effects from the Lastrapes-type restricted VAR (state) model. From Figure 2.4 (the Lastrapes-type restricted VAR (region) model), we see there is no significant effect on personal income in the New England region. From Figure 3.2.1 (the state level), we see a very brief transitory significant negative effect on state personal income in New Hampshire. The rest of the five states (Connecticut, Maine, Massachusetts, Rhode Island, and Vermont) have no significant effects on state income.

In the Lastrapes-type restricted VAR (region) model (Figure 2.4), the Mideast region has no significant effects of monetary policy. However, there is a significant effect in Pennsylvania and a weakly significant effect in Delaware. Maryland, New Jersey, and New York do not have

a significant effect at the state level in the Lastrapes-type restricted VAR (state) model (see Figure 3.2.2). Even though with regional data there is not a significant effect of monetary policy in the Mideast region, state level data shows a significant response of two states in the Mideast region.

In the Lastrapes-type restricted VAR (region) model (in the Figure 2.4), the effects of monetary policy are very persistent for the Great Lakes, Plains, Southwest, Rocky Mountain, and Far West regions. Eventually, personal income returns to its initial level beyond the 5 year horizon shown.

From Figures 3.2.3 through 3.2.8, we also find that most states in the Great Lakes, Plains, Southeast, Rocky Mountains, and Far West regions have a persistent and significant negative effect on the state income. However, each state has a little different timing and duration of the effect.

From Figure 3.2.3, all states (Illinois, Indiana, Michigan, Ohio, and Wisconsin) in the Great Lakes regions have a significant negative effect of monetary policy shocks on state personal income and the effects are persistent. This result is the same as in Carlino and DeFina (1999a) that monetary policy shocks' impact on states in the Great Lakes region has a significant negative effect on state PI and states in the Great Lakes region are the most affected by the monetary policy shocks.

In Figure 3.2.4, the states (Iowa, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota) in the Plains regions have a significant negative effect of monetary policy shocks on state personal income and the effects are long-lived, except for Kansas, which has only a weakly significant effect.

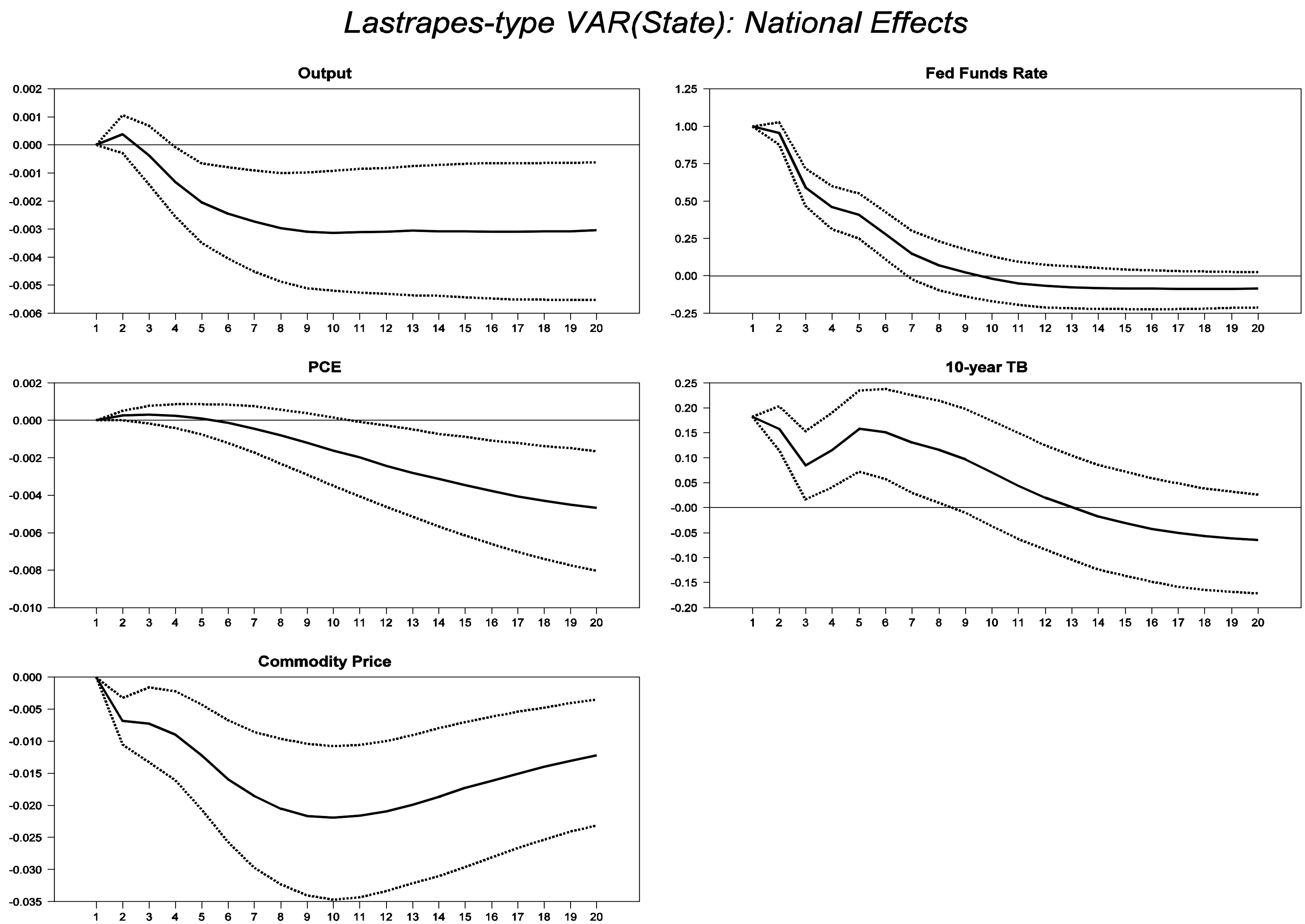


Figure 3.1 — Lastrapes-Type VAR (State): National Effects

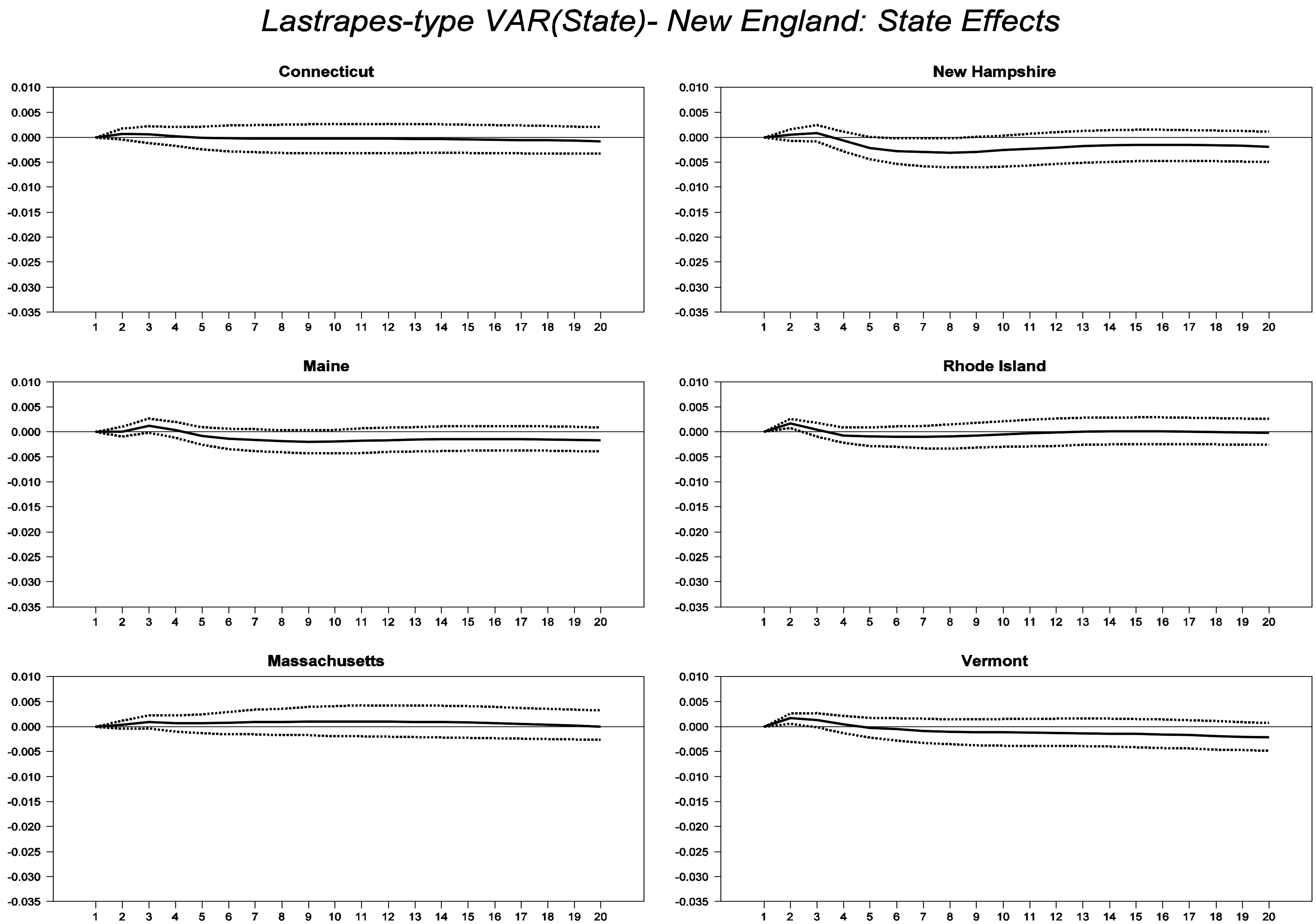


Figure 3.2.1 — Lastrapes-Type VAR (State) – New England: State Effects

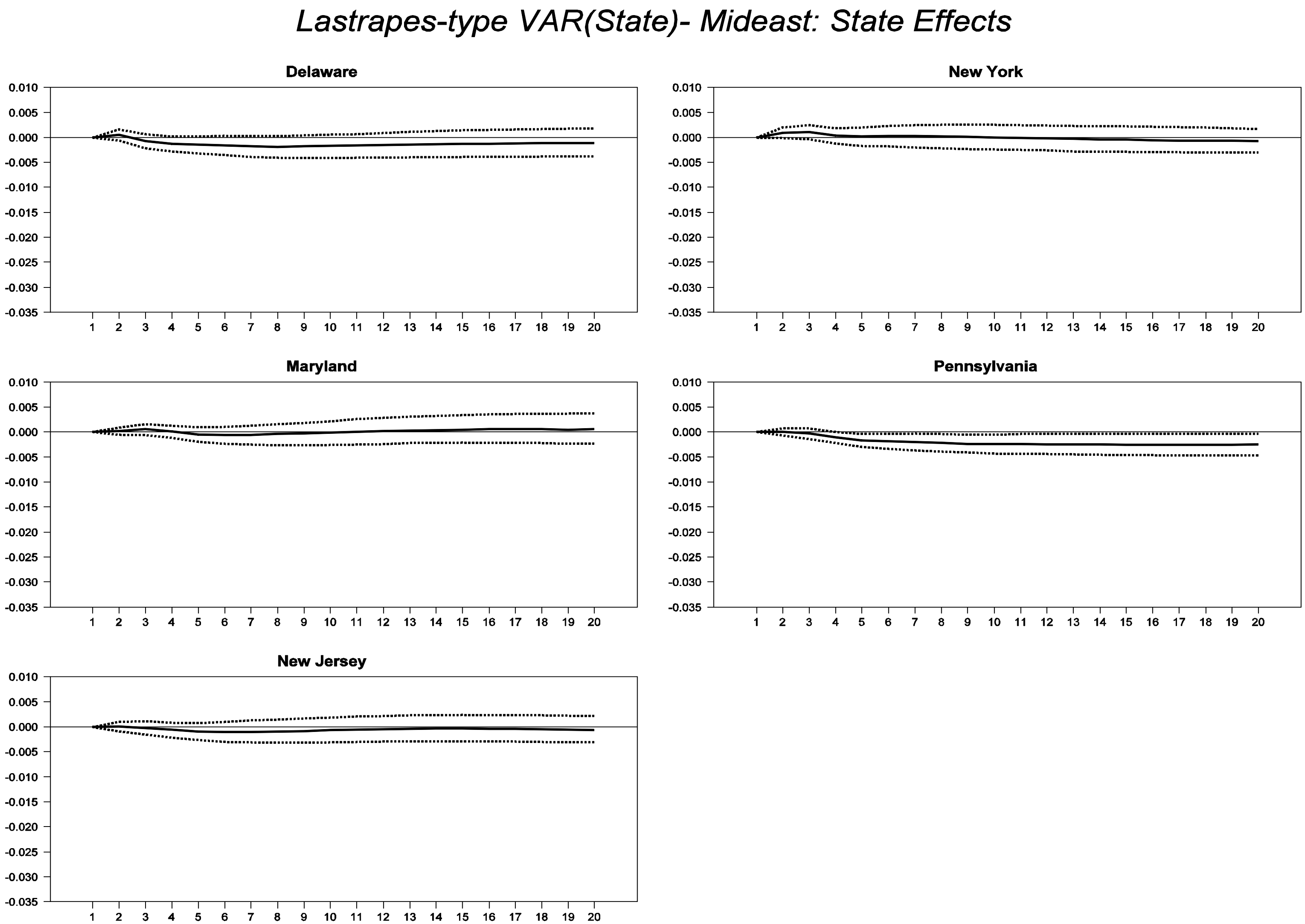


Figure 3.2.2 — Lastrapes-Type VAR (State) – Mideast: State Effects

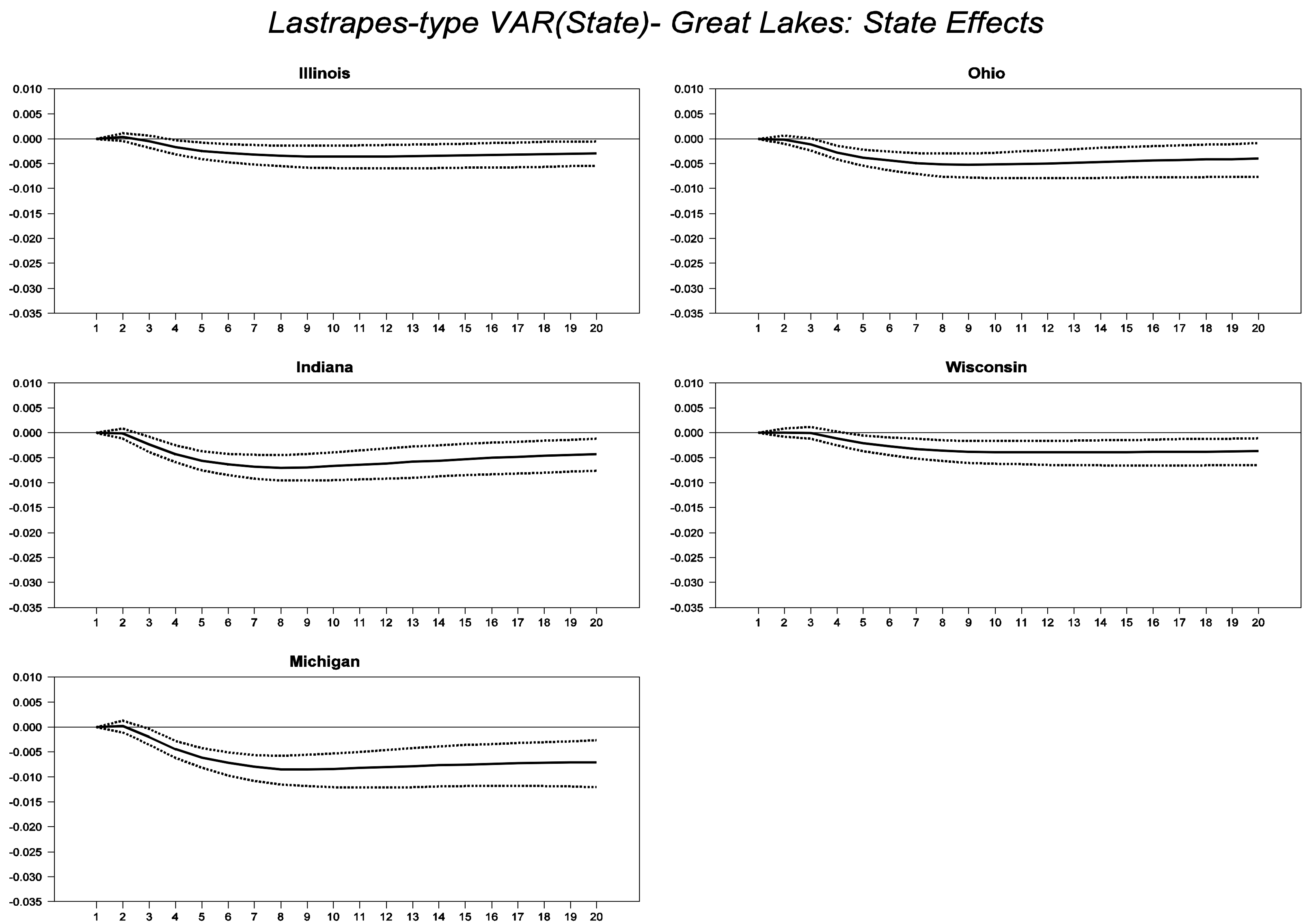


Figure 3.2.3 — Lastrapes-Type VAR (State) – Great Lakes: State Effects

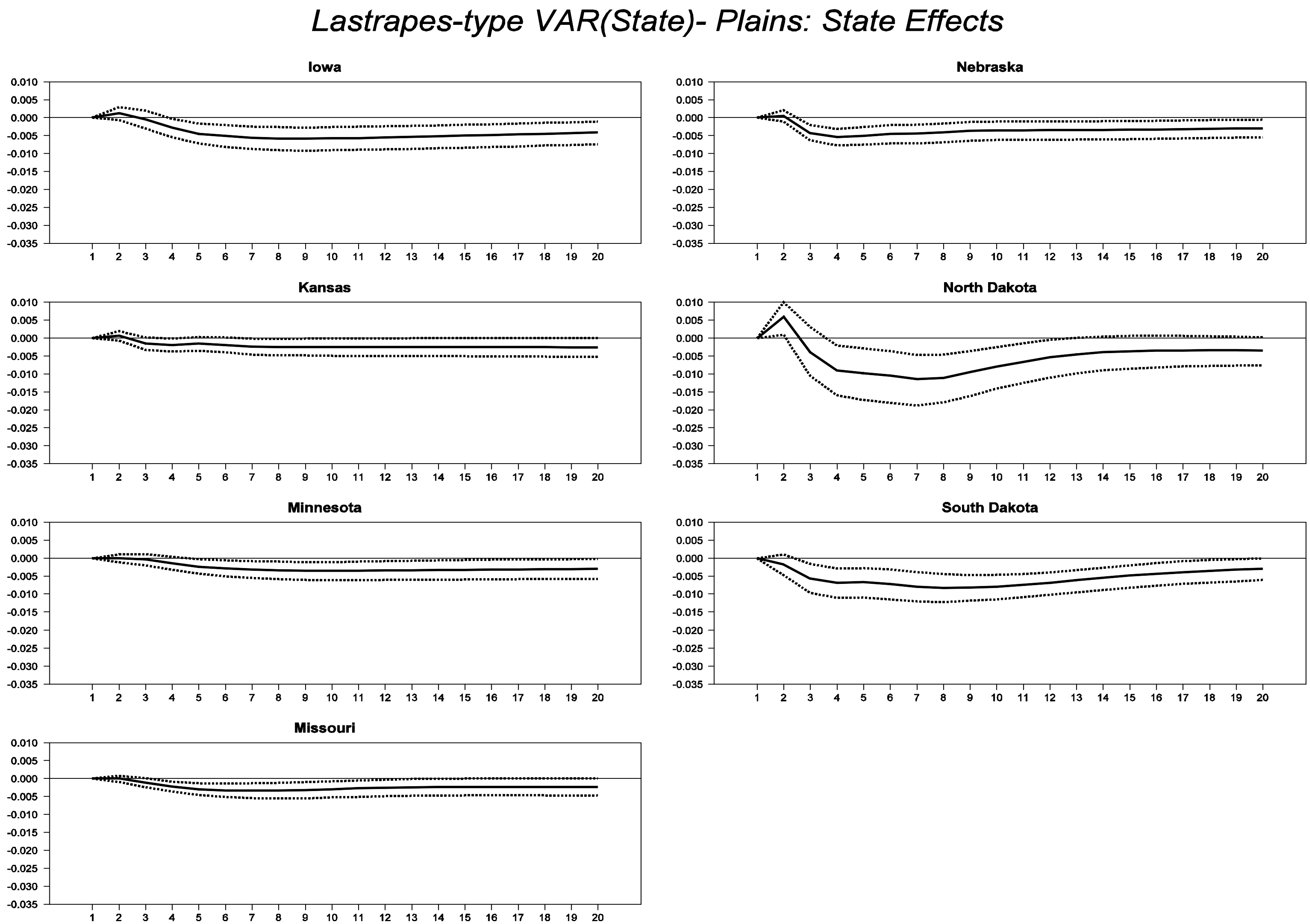


Figure 3.2.4 — Lastrapes-Type VAR (State) – Plains: State Effects

From Figure 3.2.5, we find that ten of the twelve states in the Southeast region show a significant and persistent effect of monetary policy on state personal income. Virginia shows only a brief weakly significant effect. Louisiana has a transitory large significant effect after two quarters but the effect quickly becomes insignificant. Five states' effects (Alabama, Arkansas, Kentucky, Mississippi, and West Virginia) are very persistent but eventually personal state income returns to its initial level beyond the 5 year horizon shown. For the Florida and Georgia, the effect becomes marginally significant 4 quarters after the monetary policy shock, but state personal income returns to its initial value 12 quarters after the shock. The effect becomes marginally significant 3 quarters after the monetary policy shock, but state personal income returns to its initial value 15 quarters after the shock in the North Carolina, South Carolina, and Tennessee. Comparing the regional level responses, states' responses in the Southeast region show much variation to monetary policy shocks.

In Figure 3.2.6, three (Arizona, New Mexico, and Texas) of the four states in the Southwest region have long-lived significant negative effects on state personal income which returns to its initial level after 5 years. Oklahoma has a significant negative effect only after 12 quarters.

Four states (Idaho, Montana, Utah, and Wyoming) in the Rocky Mountains region (in Figure 3.2.7) have a long-lived and significant negative effect of monetary policy on the state personal income. Colorado shows only a brief weakly significant effect.

From Figure 3.2.8, we find all four states (California, Nevada, Oregon, and Washington) have a significant effect of monetary policy on state income. Nevada's income returns the original level around 20 quarters after the shock and the rest of the states' income return to normal after 20 quarters.

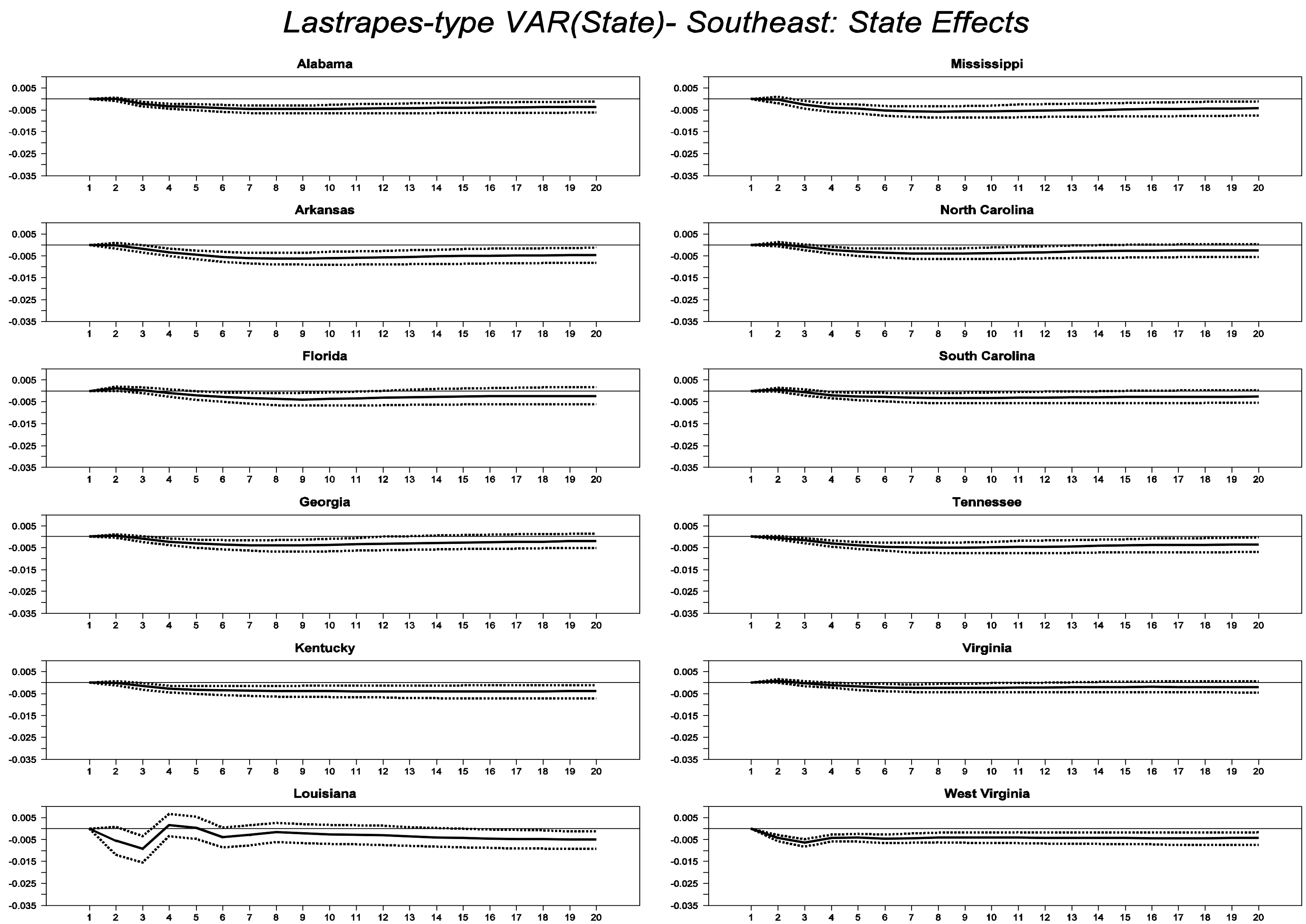


Figure 3.2.5 — Lastrapes-Type VAR (State) – Southeast: State Effects

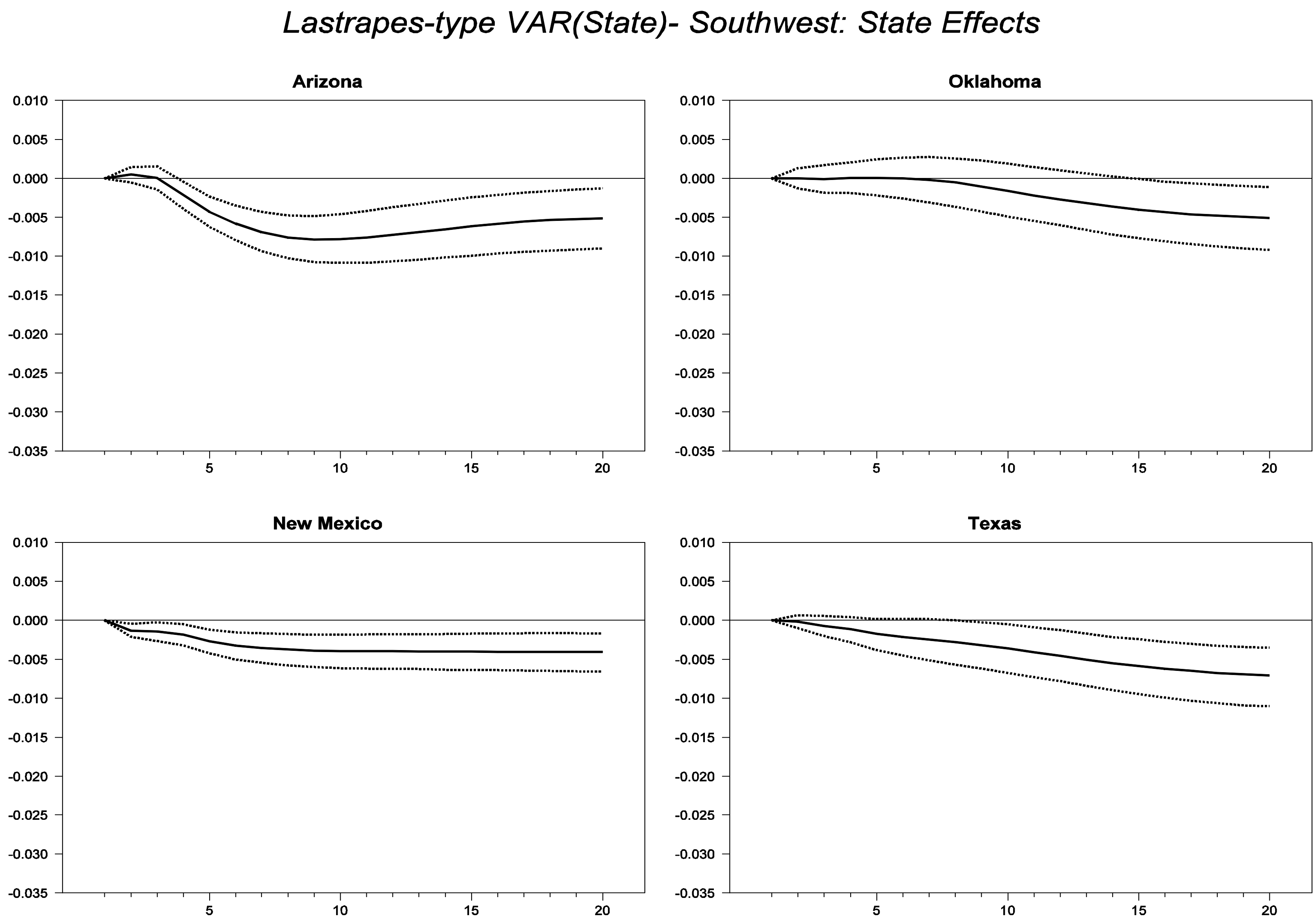


Figure 3.2.6 — Lastrapes-Type VAR (State) – Southwest: State Effects

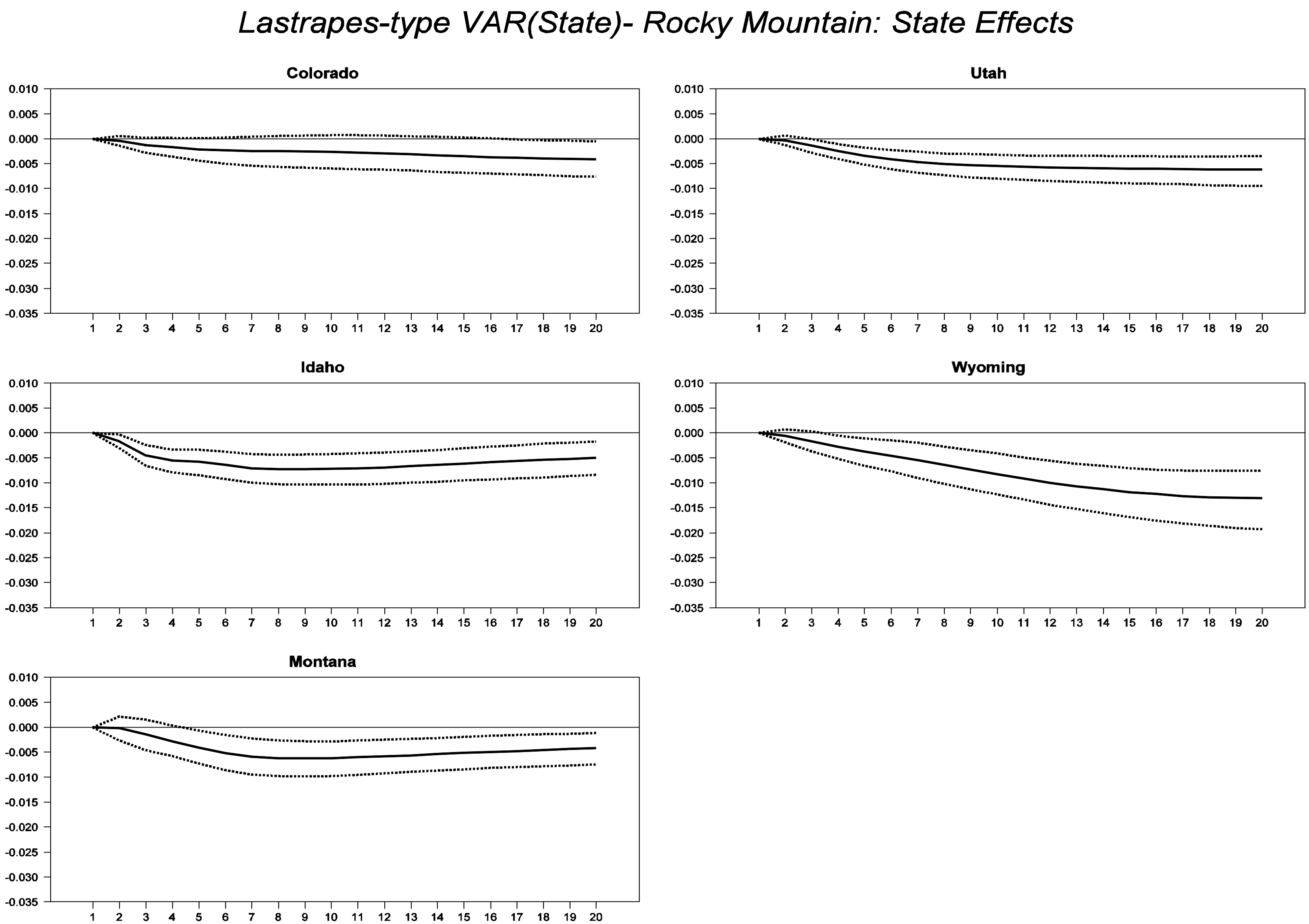


Figure 3.2.7 — Lastrapes-Type VAR (State) – Rocky Mountain: State Effects

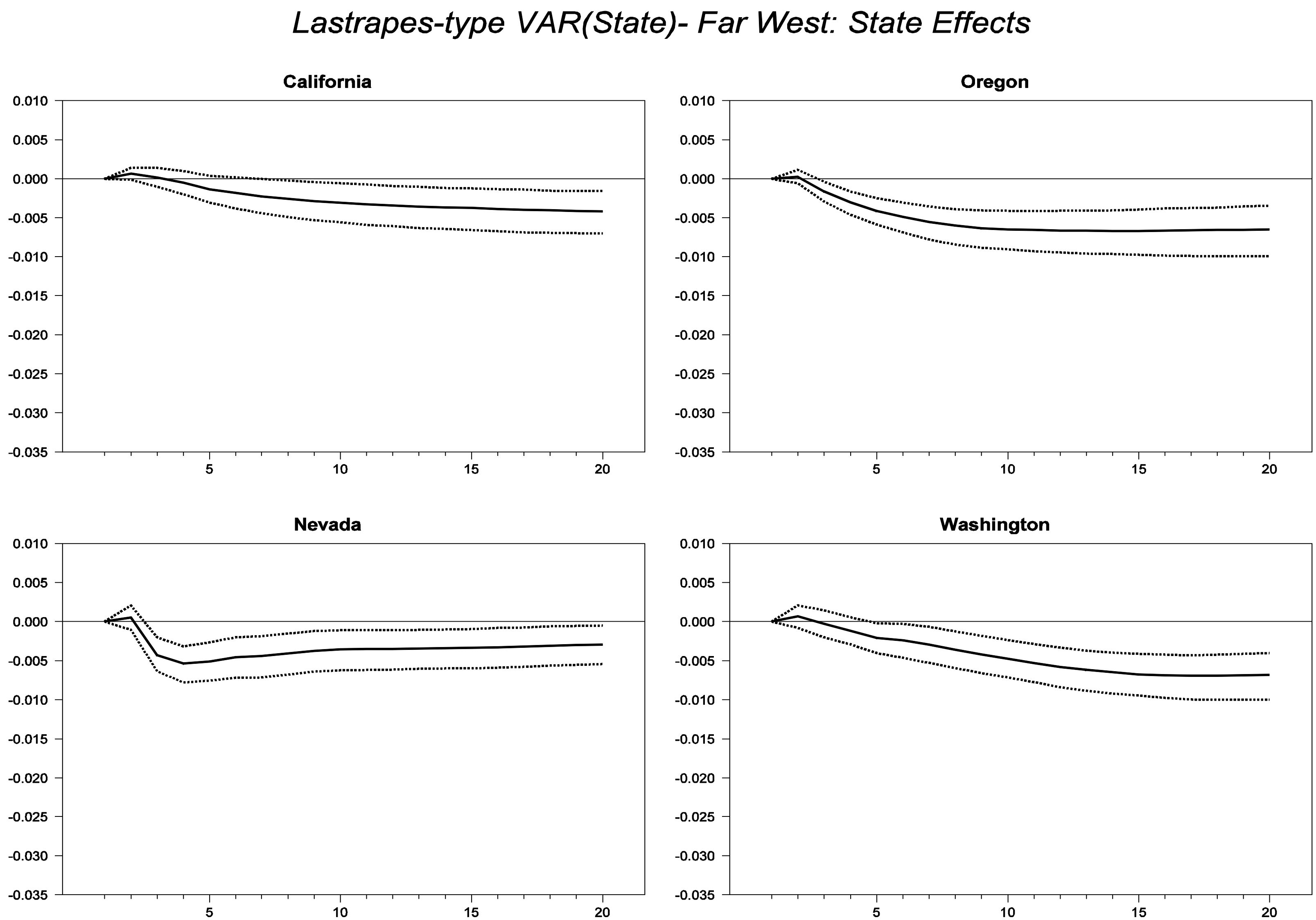


Figure 3.2.8 — Lastrapes-Type VAR (State) – Far West: State Effects

Overall, we find that different states in the same region often have quite different responses to monetary policy shocks in the Lastrapes-type (state) VAR model.

3.5.2 Border- Effects Restricted VAR Model

As mentioned in chapter 2, the pure Lastrapes-type approach allows one state to affect other states only through the first state's effects on the national economy. The SUR Lastrapes-type VAR allows state output to depend on its own lagged values as well as on the lagged values of economic activity in the contiguous states while maintaining the same assumptions about the national variables as before.

Figure 3.3 presents the results from the border-effects restricted VAR (state) for the national variables. Figures 3.4.1 through 3.4.8 show the results for the state variables and it is apparent that the state effects are very similar for both restricted VARs.

Comparing Figure 3.3 (the border-effects restricted VAR (state) model) and Figure 2.6 (the border-effects restricted VAR (region) model: national effects), the SUR Lastrapes-type VAR's results are quite similar to those from the border-effects restricted (region) VAR, although aggregate output returns to its initial level quicker in the "border-effects" VAR (state) than in the border-effects VAR (region). We also find that in the border-effects restricted VAR (state) model, the funds rate's persistence after a shock is less than in the border-effects restricted VAR (region) model and the Treasury bond rate returns to its initial value more quickly than in the border-effects restricted VAR (region) model. There is no significant negative effect on national personal income. Commodity prices fall significantly after one quarter, and the effects are very long-lived. Even though we have a smaller price puzzle than the border-effects restricted VAR (region) model, there are significant negative effects on the aggregate price level after six quarters.

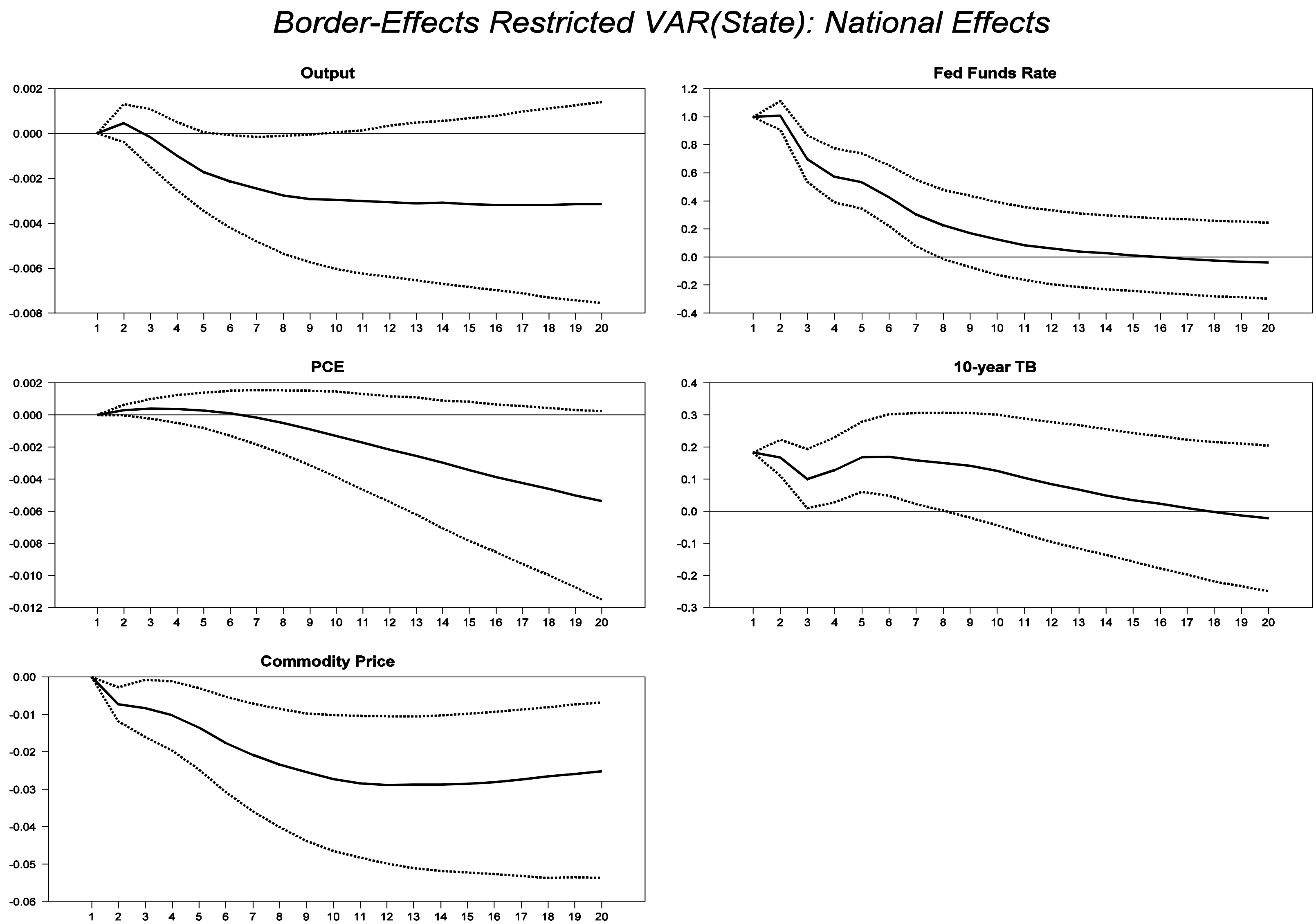


Figure 3.3 — Border-Effects VAR (State): National Effects

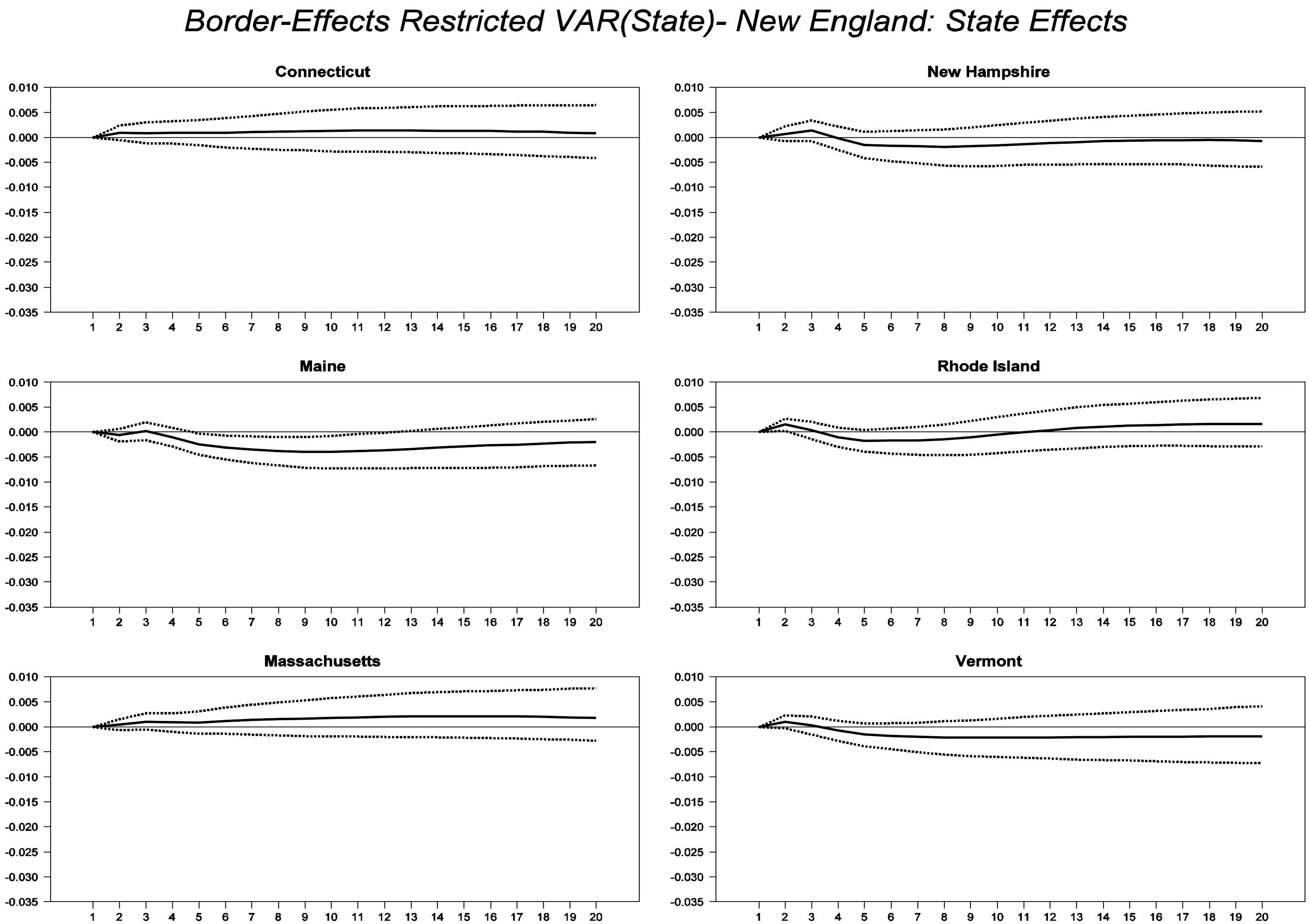


Figure 3.4.1 — Border-Effects VAR (State) – New England: State Effects

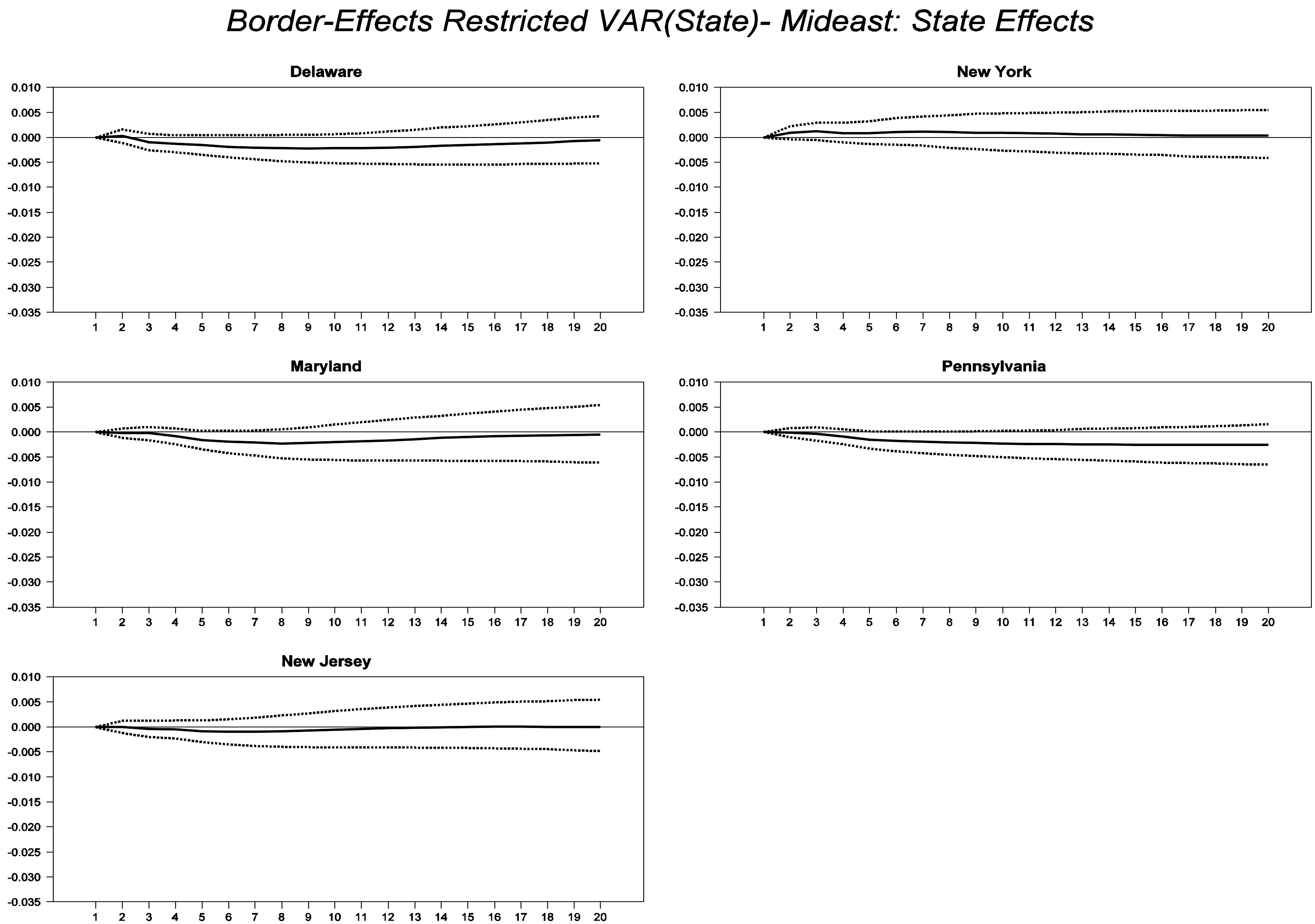


Figure 3.4.2 — Border-Effects VAR (State) – Mideast: State Effects

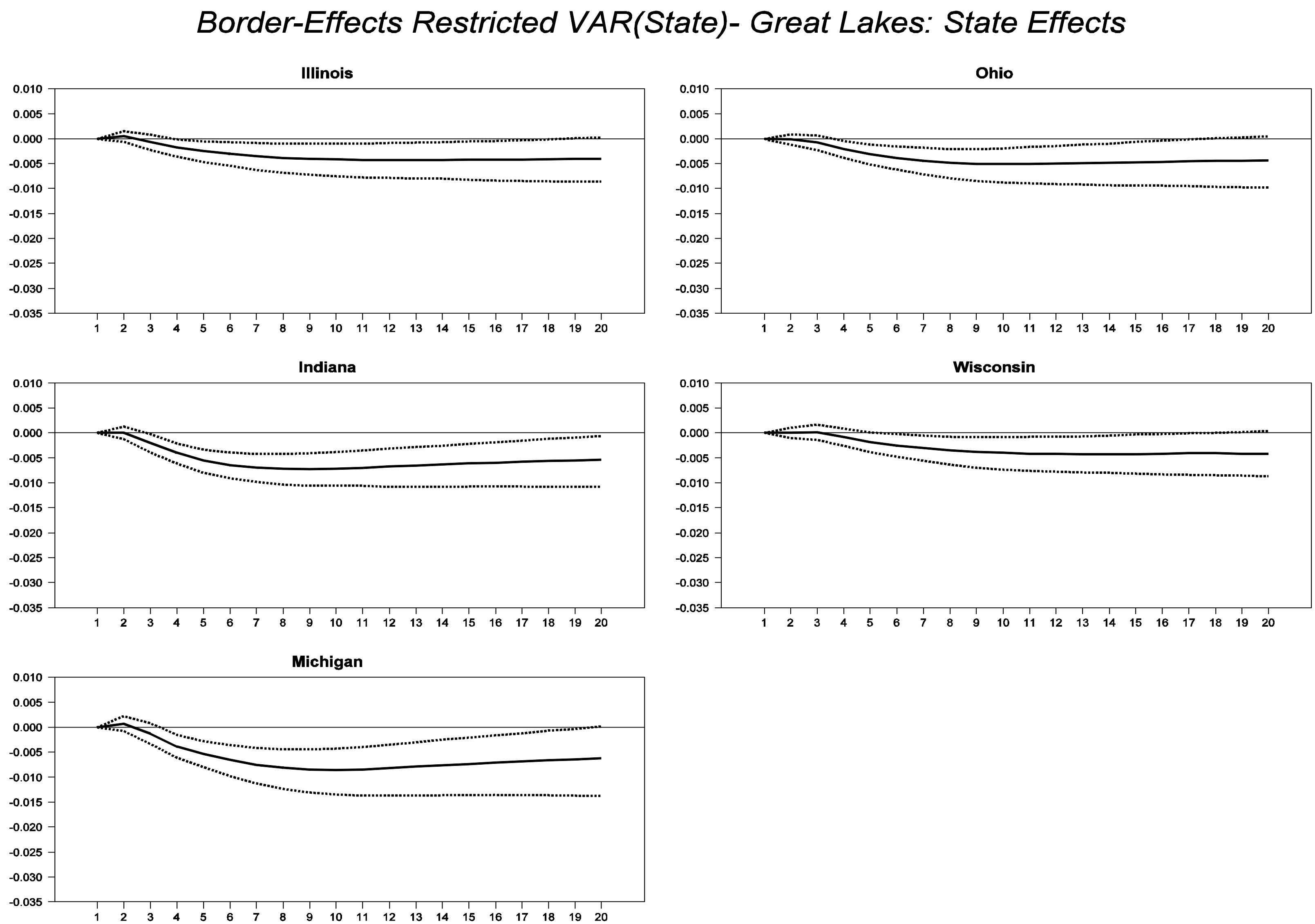


Figure 3.4.3 — Border-Effects VAR (State) – Great Lakes: State Effects

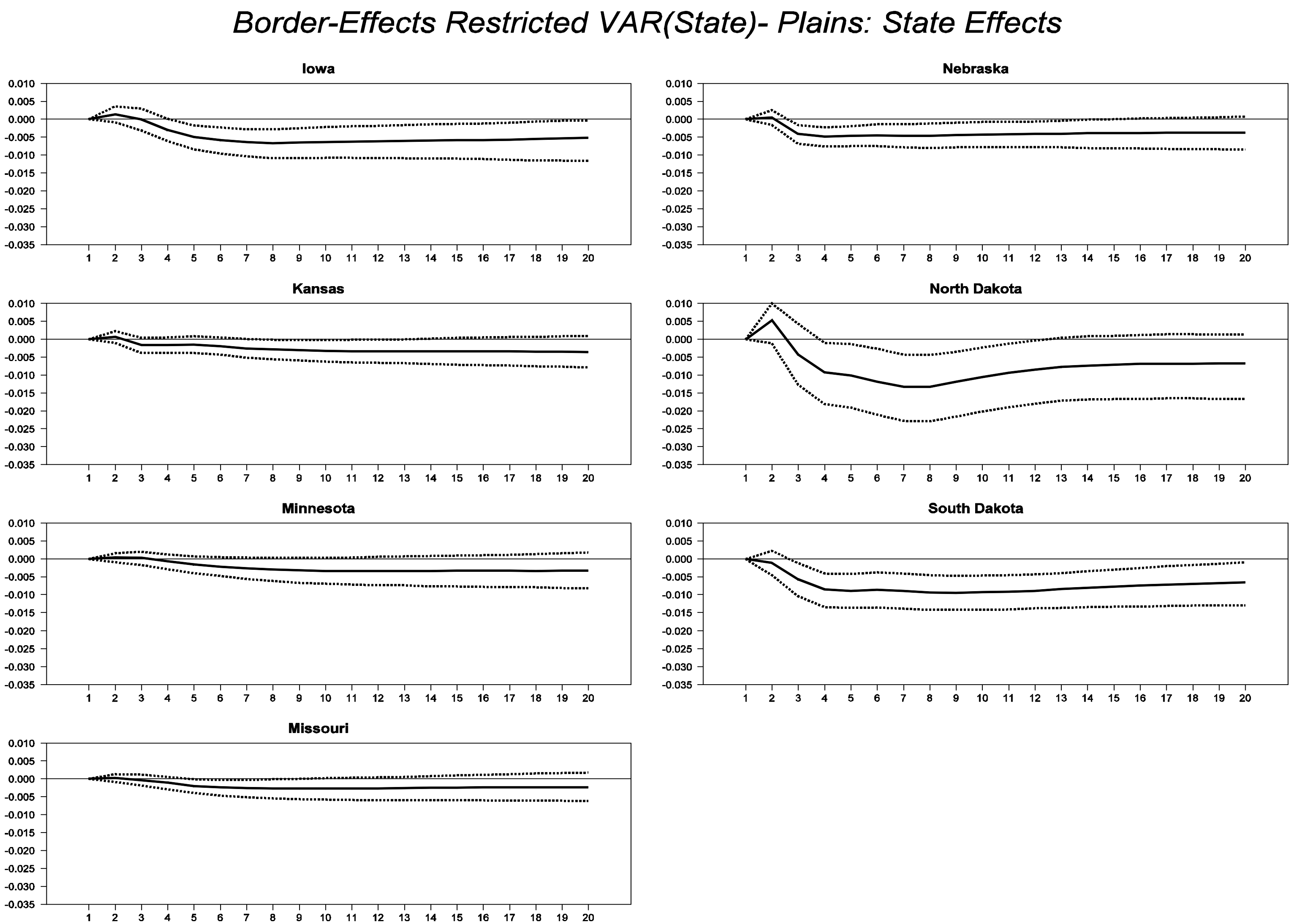


Figure 3.4.4 — Border-Effects VAR (State) – Plains: State Effects

Figures 3.4.1 through 3.4.8 presents the state effects from the border-effects restricted VAR (state) approach. From Figure 2.7 (the border-effects restricted VAR (region) model: regional effects), we see there is no significant effect on personal income in the New England region. However, from Figure 3.4.1 (the border-effects restricted VAR (state) model), Maine has a weakly significant effect on state personal income. The remaining five states (Connecticut, Massachusetts, New Hampshire, Rhode Island, and Vermont) have no significant effects on state income.

In the border-effects restricted VAR (region) model (Figure 2.7), the Mideast region has no significant negative effects of monetary policy. However, in the SUR Lastrapes-type VAR (state) model (Figure 3.4.2), weakly significant effects are found in Pennsylvania and Maryland, and the remaining three states (Delaware, New Jersey, and New York) do not have significant effects of monetary policy on state personal income.

From Figure 2.7 (the border-effects restricted VAR (region) model), the effects of monetary policy are very persistent for the Southwest, Rocky Mountain, and Far West regions and eventually personal income returns to its initial level beyond the 5 year horizon shown. For the Great Lakes, plains, and Southeast regions, the effects are marginally significant 4 quarters after the shocks but they return their original level around 16 quarters after the shocks.

Figure 3.4.3 shows that all states (Illinois, Indiana, Michigan, Ohio, and Wisconsin) in the Great Lakes regions have a significant negative effect of monetary policy shocks on state personal income and the effects are persistent.

From Figure 3.4.4, the border-effects VAR (state) model shows that four of the seven states (Iowa, Nebraska, North Dakota, and South Dakota) in the Plains region have a significant

negative effect on the state income and Kansas, Minnesota, and Missouri have weakly significant effects.

In the border-effects VAR (state) model (Figure 3.4.5), Louisiana has no significant effects on state income level and four states (Florida, Georgia, North Carolina, and South Carolina) in the Southeast region have a weakly significant effect. The rest of the seven states have a significant negative effect on state personal income.

In Figure 2.7 (the border-effects restricted VAR (region) model), the Southwest region has persistent and significant negative effects on PI in the regional level. However, in Figure 3.4.6, only one of the four states (New Mexico) shows similar response in the border-effects (state) VAR model, Arizona is considerably more responsive than in the border-effects (region) VAR model, Texas's effects are weakly significant after 12 quarters, and Oklahoma has no significant effect on state PI to monetary policy shocks in the border-effects (state) VAR model.

In the border-effects VAR (state) model (Figure 3.4.7), Colorado does not have a significant effect, but the remaining four states (Idaho, Montana, Utah, and Wyoming) in the Rocky Mountains region have a long-lived and significant negative effect of monetary policy on state personal income.

Based on Figure 3.4.8 (the border-effects restricted VAR (state) model), California has an insignificant effect, but the remaining three states (Nevada, Oregon, and Washington) in the Far West region have a long-lived and significant negative effect on the state personal income.

We compared the effects of monetary policy on state PI for the two Restricted VARs and found the patterns of effects are often similar across the two approaches. However, in general, there is much less variation in regional responses to monetary policy shocks than in state responses.

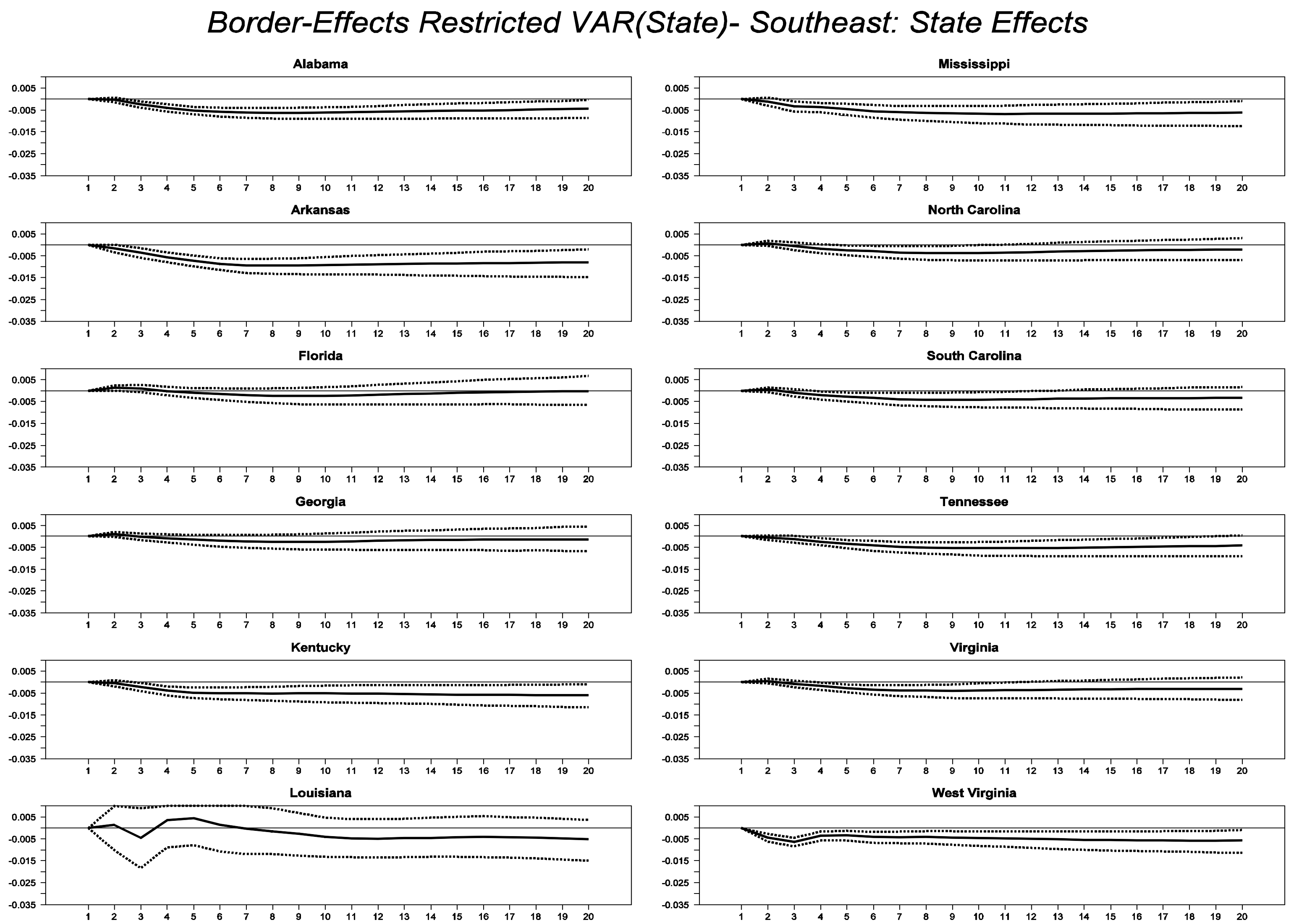


Figure 3.4.5 — Border-Effects VAR (State) – Southeast: State Effects

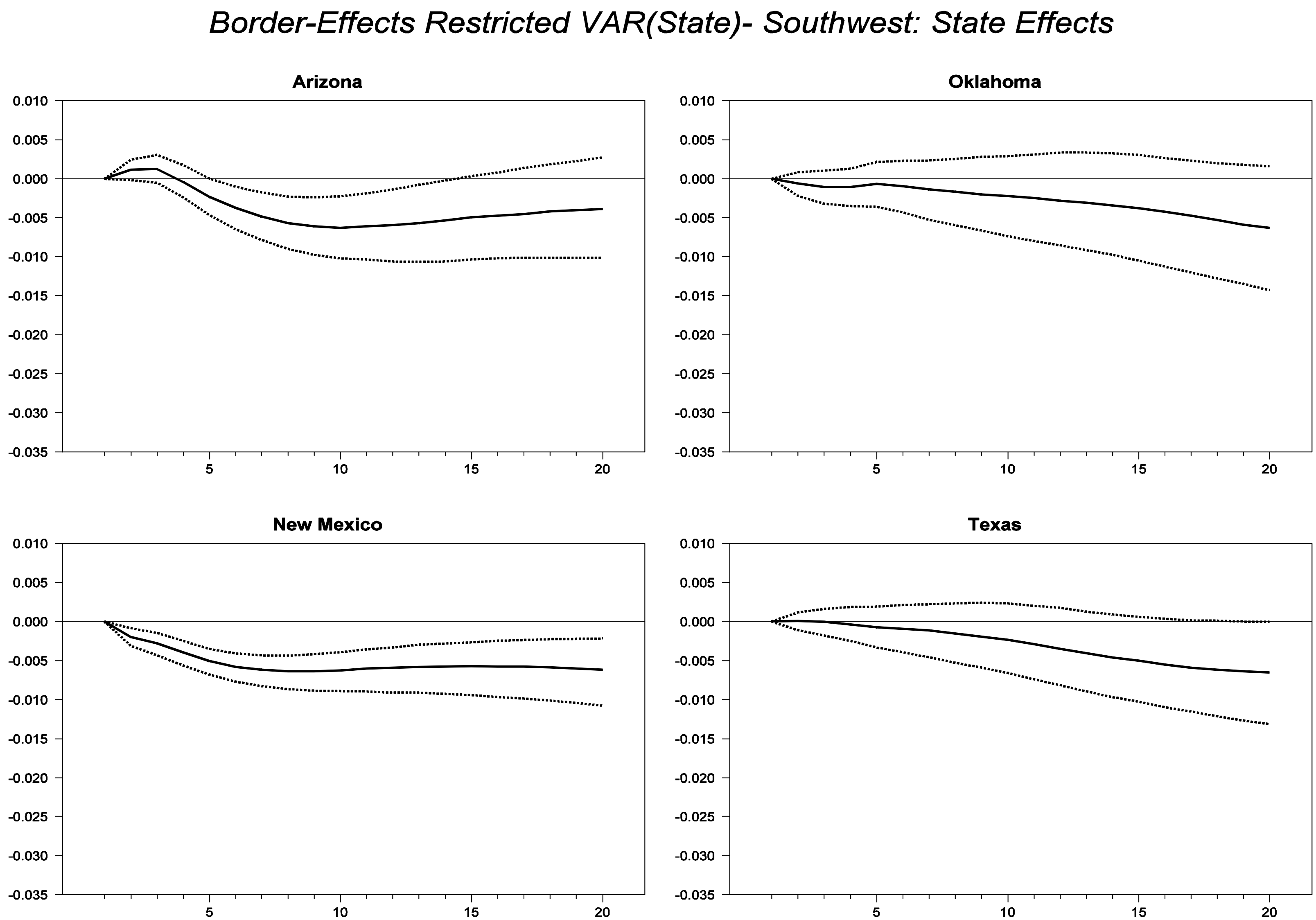


Figure 3.4.6 — Border-Effects VAR (State) – Southwest: State Effects

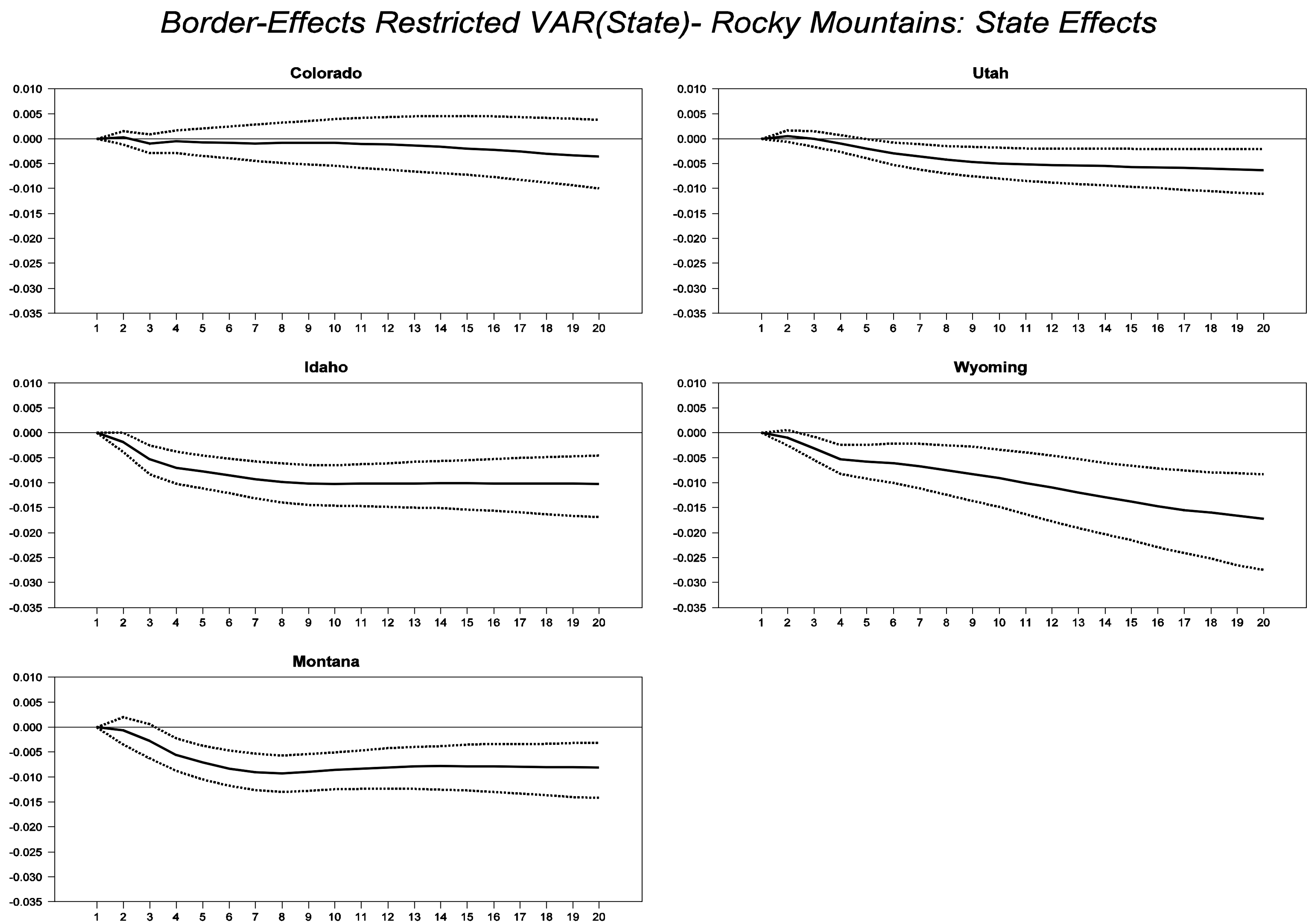


Figure 3.4.7 — Border-Effects VAR (State) – Rocky Mountain: State Effects

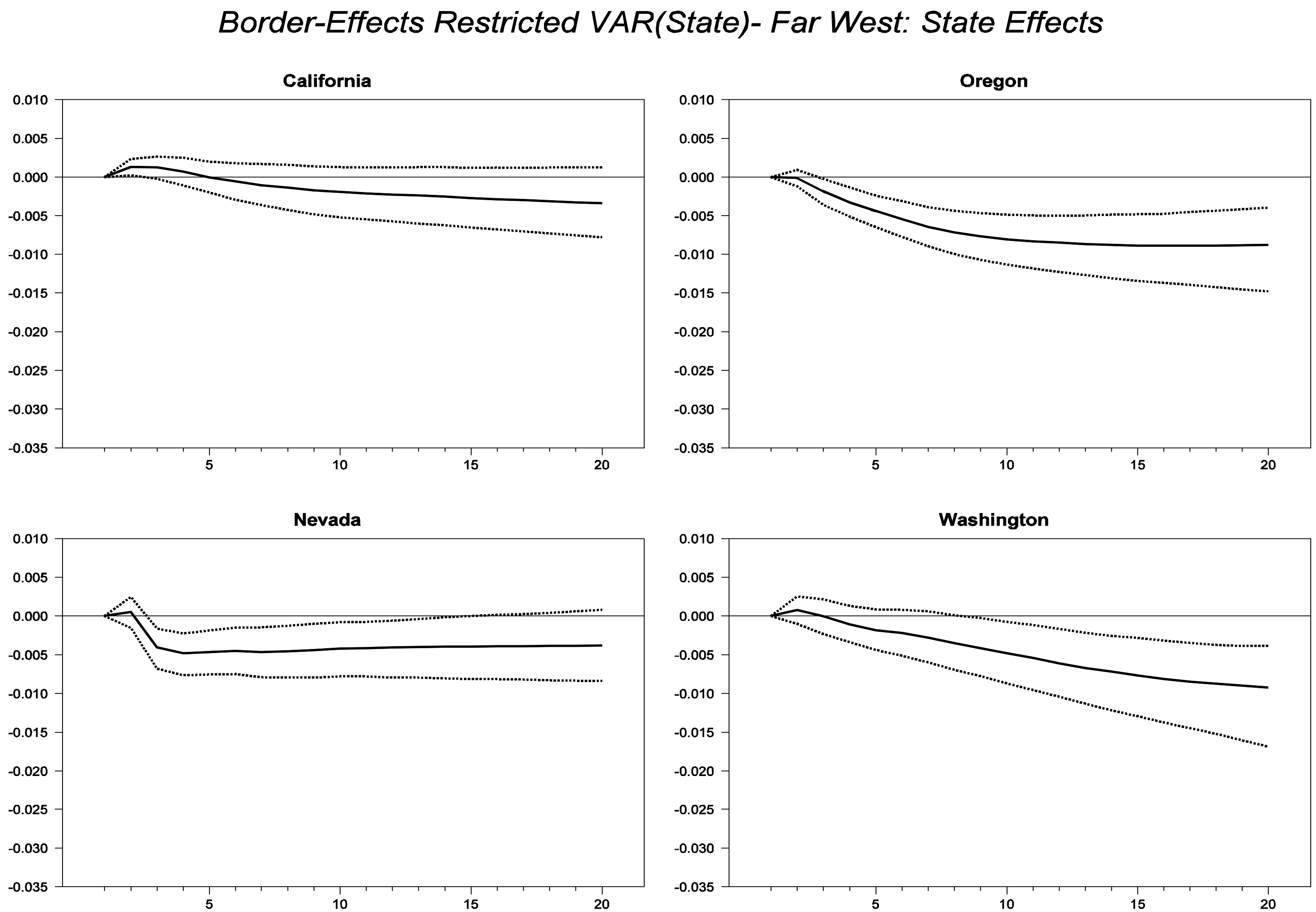


Figure 3.4.8 — Border-Effects VAR (State) – Far West: State Effects

For example, we found in the Southwest region the effects are very persistent but eventually personal income returns to its initial level beyond the 5 year horizon shown (see Figure 2.7 — Border-effects VAR: Regional Effects). However, only one of the four states that make up the Southwest region (New Mexico) shows a similar response in the border-effects (state) VAR model. Arizona is considerably more responsive than in the border-effects (region) VAR model, Texas's effects are weakly significant after long lags, and Oklahoma has no significant effect on state PI to monetary policy shocks in the border-effects (state) VAR model. Being part of a region that has a high response to monetary policy actions is no guarantee that each state in the region will respond similarly. In general, there is much less variation in regional responses to monetary policy shocks than in state responses.

3.6 Conclusion

In the previous chapter, we found that the effects of monetary policy were different across regions of the U.S. However, recent studies (Carlino (2007), Carlino and Sill (2001), and Crone (2006)) suggest that there are differences in business cycles across states and regions. In this chapter, therefore, we extend the analysis from 8 BEA regions to the 48 contiguous states. Since different states in the same region may have quite different responses to monetary policy shocks, it is important to extend the analysis from the regional level to the state level. For example, the mix of industries may differ from one state to another within the region so the effects of monetary policy may be different for one state than for another. Results from previous studies of the state level effects of monetary policy show differences in timing and magnitude for the same state, but use different sample periods, different identification schemes, and different set of variables. This chapter isolates the effects of different identification schemes by using a common sample period and the same set of model variables.

In this chapter, we use two Lastrapes-type restricted VAR approaches to examine whether monetary policy has symmetric effects across U.S. states during the 1960: I – 2007: III period. We consider a 53-variable VAR which was partitioned into two blocks. The first block is a macro variable that includes aggregate real personal income, the price level (PCE), a commodity price index (COP), the federal funds rate (FFR), and a long-term bond rate (TB). The ordering of the macro block within this block is national output (aggregate real personal income), price level (PCE), commodity price (COP), federal funds rate (FFR), and 10-year Treasury Bill (TB). The second block is state-level model that consists of real personal income from the 48 states. Additionally, lags of the oil shock dummy discussed in the previous chapter are included as exogenous variables in each equation of the model along with an intercept term. The monetary policy variable is FFR, and a structural monetary policy shock is identified using a Choleski decomposition using the ordering just described. We assume policy makers respond only to contemporaneous and lagged movements in national block but policy actions affect both the national and regional blocks. The first block (national block) is ordered before the second block (state block). This ordering assumes that monetary policymakers respond contemporaneously to shocks to the national personal income variable, the aggregate price level, and the commodity price index in setting FFR, but policy actions affect these variables only with a lag. We also order commodity prices before the funds rate in order to allow a contemporaneous response by policymakers to shocks to commodity prices. We further assume that monetary policy actions affect the long-term bond rate within the period, but that policymakers respond to movements in the long-term bond rate only with a lag. We assume that within the state block a shock to personal income in one state has no contemporaneous effect on personal income in other states.

Comparisons of states responses to monetary policy shocks reveal that an individual state's response is often quite different from the average response of its region and from the response of the other states in that region. For example, we found in the Southwest region the effects are very persistent but eventually personal income returns to its initial level beyond the 5 year horizon shown. However, only two of the four states that makes up the Southwest region (New Mexico and Texas) are matched the regional response in the Lastrapes-type (state) VAR model. Arizona is considerably more responsive than in the Lastrapes-type (region) VAR model and Oklahoma is less responsive to monetary policy shocks than in the Lastrapes-type (region) VAR model. Being part of a region that has a low response to monetary policy actions is no guarantee that each state in the region will respond similarly. In general, there is much less variation in regional responses to monetary policy shocks than in state responses.

Chapter 4. Robustness Analysis of Regional Effects of Monetary Policy
4.1 Introduction

Robustness of results is a concern in empirical economic work. In time series analysis, small changes in specification can sometimes lead to widely different results. Therefore, robustness analysis is an important part of the literature. In modern empirical economics, one of common applications of robustness analysis is the examination of whether regression coefficient estimates change when the regression specification is altered by including or excluding regressors. Leamer (1983) suggests fragility of the regression coefficient estimates could be an indication of specification error, and that robustness analysis should be commonly conducted to check and diagnose misspecification. The coefficients are robust when the coefficients do not change much even though model's assumptions are changed.

This chapter presents the results of various sensitivity analyses regarding the specification of model and the use of an alternative definition for aggregate economic activity. We consider three types of robustness checks for the estimates of the regional effects of monetary policy: 1) including fiscal policy variables; 2) including a measure of aggregate economic uncertainty; and 3) replacing real national personal income as the measure of national economy activity with real GDP. We use the same methods used in the previous chapters to check the robustness of our models.

Section 2 estimates the regional effects of monetary policy for a model includes fiscal variables. Section 3 explains the uncertainty effect on the personal income. Section 4 describes the regional effects of monetary policy if personal income is replaced with real GDP as a measurement of national economy activity. Section 5 is the conclusion.

4.2 Fiscal Variables

Although much of the monetary policy analysis literature using VAR systems includes only monetary variables but no fiscal variables (see, for example, Sims (1980), Bernanke and Mihov (1998), and Christiano, Eichenbaum and Evans (1999)), it is important to consider a system that includes fiscal policy variables for two reasons. One is that monetary policymakers may take the stance of fiscal policy into account when setting monetary policy. If fiscal policy is very expansionary, monetary policymakers may decide on a less expansionary policy than if fiscal policy were less expansionary. For this reason, omitting fiscal variables from a VAR may lead to a misspecification of monetary policy shocks. The second reason is that if monetary policy and fiscal policy are both simultaneously expansionary and fiscal variables are omitted, then some of the effects attributed to monetary policy may actually be due to fiscal policy. Hence it is important to see if including fiscal policy variables in the model affects the previous estimates of monetary policy.

The basic structure of model is the same as in the previous chapters except that two fiscal variables are included as additional variables in the national block: Ramey's military expenditure variable and Romer and Romer's change tax variable. Ramey and Shapiro (1998) used a dummy variable for military events that led to significant rises in defense spending as an exogenous measure of spending changes. The original military dates were 1950: III, 1965: I, and 1980: I corresponding to the Korean War, the Vietnam War, and the Carter-Reagan military buildup. Since the simple dummy variable approach does not exploit potential quantitative information, Ramey (2011) refines Ramey and Shapiro (1998) war dates by constructing a new variable of government spending shocks. Information from the press such as Business Week is used to construct a historical series of expected changes in government military spending which are

expressed in present value. She divides this series by the previous quarter's GDP to create a news series which we call the Ramey military expenditure and include in our model.

Romer and Romer (2010) use a narrative record describing the history and motivation of tax policy changes to separate legislated tax changes into two broad categories; endogenous tax changes affect output growth in the near future and exogenous tax change is any tax change not motivated by a desire to return output growth to normal. In Romer and Romer (2010), exogenous tax changes are defined as tax changes for deficit-reduction and those to stimulate long-run growth. They divide their measure of exogenous tax changes by the previous quarter's nominal GDP to create an exogenous tax changes series and we call this variable the Romer and Romer change tax variable and include it in our model.

To allow for monetary policy response to the fiscal variables, monetary policy shocks in the expanded model are identified by using a Choleski decomposition in which the fiscal variables are ordered before the monetary policy variables. Since fiscal policy shocks are not being identified, all that matters for the identification of monetary policy shocks is that they are ordered before the federal funds rate. Impulse response functions are estimated for a shock to monetary policy and compared to earlier estimates to check to see if the regional effects of monetary policy are altered when we include fiscal variables in the models.

We want to see if the effects from the model with the fiscal variable are significantly different from the basic model so we plot the point estimates from the model with the fiscal variables along with the confidence intervals from the basic model.

4.2.1 Eight BEA Regions Case

4.2.1.1 Owyang-Wall-Type Restricted VAR Model

We calculate the point estimates from OW-type VAR including the fiscal variables and then plot these point estimates along with confidence intervals from the OW-type VAR without

the fiscal variables. Figure 4.1 and 4.2 show these results. Figure 4.1 represents the national effects and Figure 4.2 shows the regional effects. In Figure 4.1, all four macro variables' point estimates with the fiscal variables well inside the confidence intervals from the OW-type VAR without the fiscal variables. In Figure 4.2, all eight regions' point estimates with the fiscal variables stay comfortably inside the confidence intervals from the OW-type VAR without the fiscal variables.

The results from the OW-type restricted VAR with the fiscal variables suggest some differences in the timing and duration of the effects of monetary policy shocks across regions. However, even though we include the fiscal variables, the results look similar to the original OW-type restricted VAR without the fiscal variables.

4.2.1.2 Lastrapes-Type Restricted VAR Model

We calculate the point estimates from Lastrapes-type VAR with the fiscal variables and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR without the fiscal variables. Figure 4.3 and 4.4 show these results. Figure 4.3 represents the national effects and Figure 4.4 shows the regional effects. In Figure 4.3, all five macro variables' point estimates with the fiscal variables well inside the confidence intervals from the Lastrapes-type VAR without the fiscal variables. In Figure 4.4, all eight regions' point estimates with the fiscal variables stay comfortably inside the confidence intervals from the Lastrapes-type VAR without the fiscal variables.

The results from the Lastrapes-type restricted VAR with the fiscal variables suggest some differences in the timing and duration of the effects of monetary policy shocks across regions. However, even though we include the fiscal variables, the results look similar to the original Lastrapes-type restricted VAR without the fiscal variables.

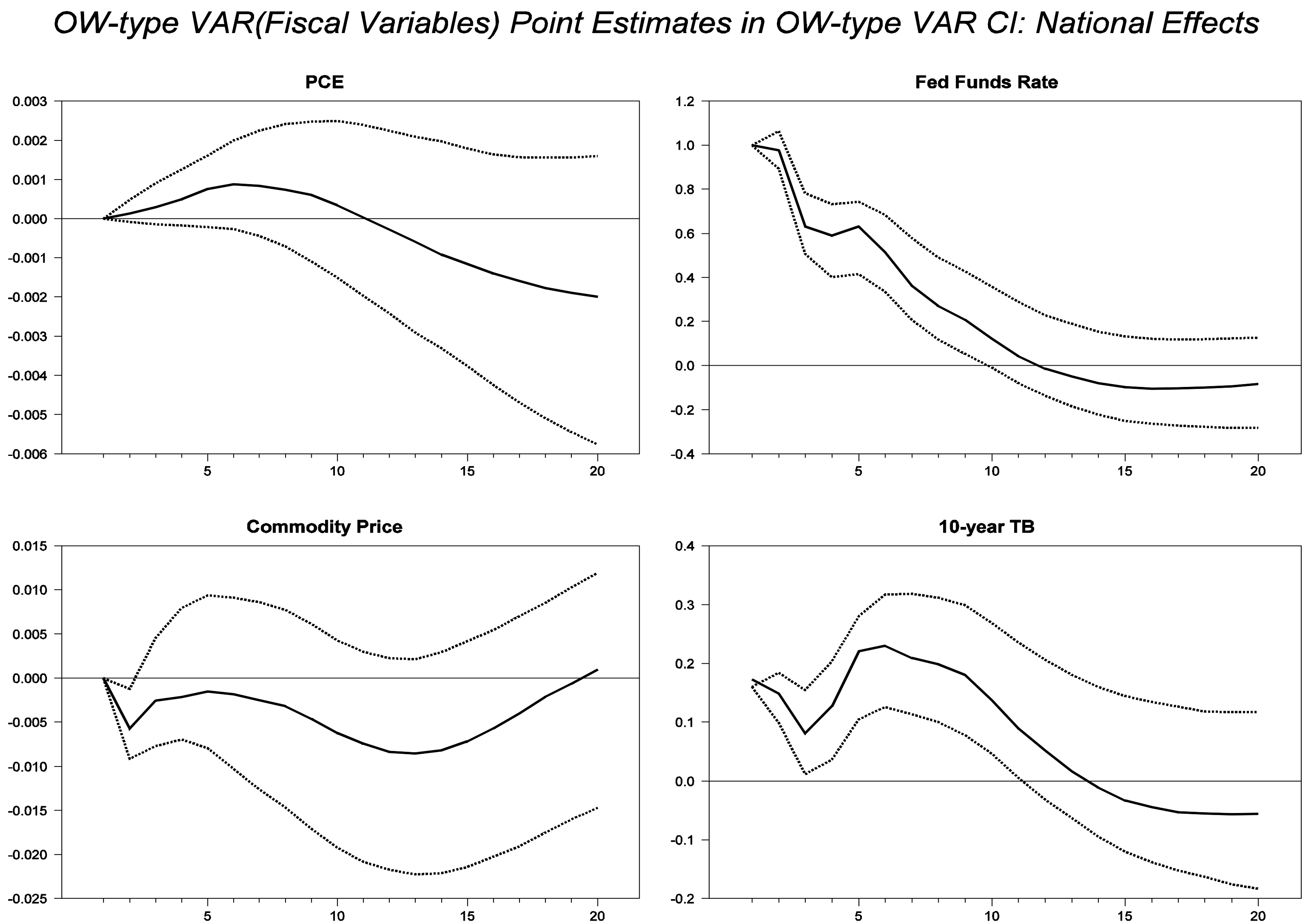


Figure 4.1 — OW-Type VAR (Fiscal Variable) Point Estimates in OW-Type VAR Confidence Intervals: National Effects

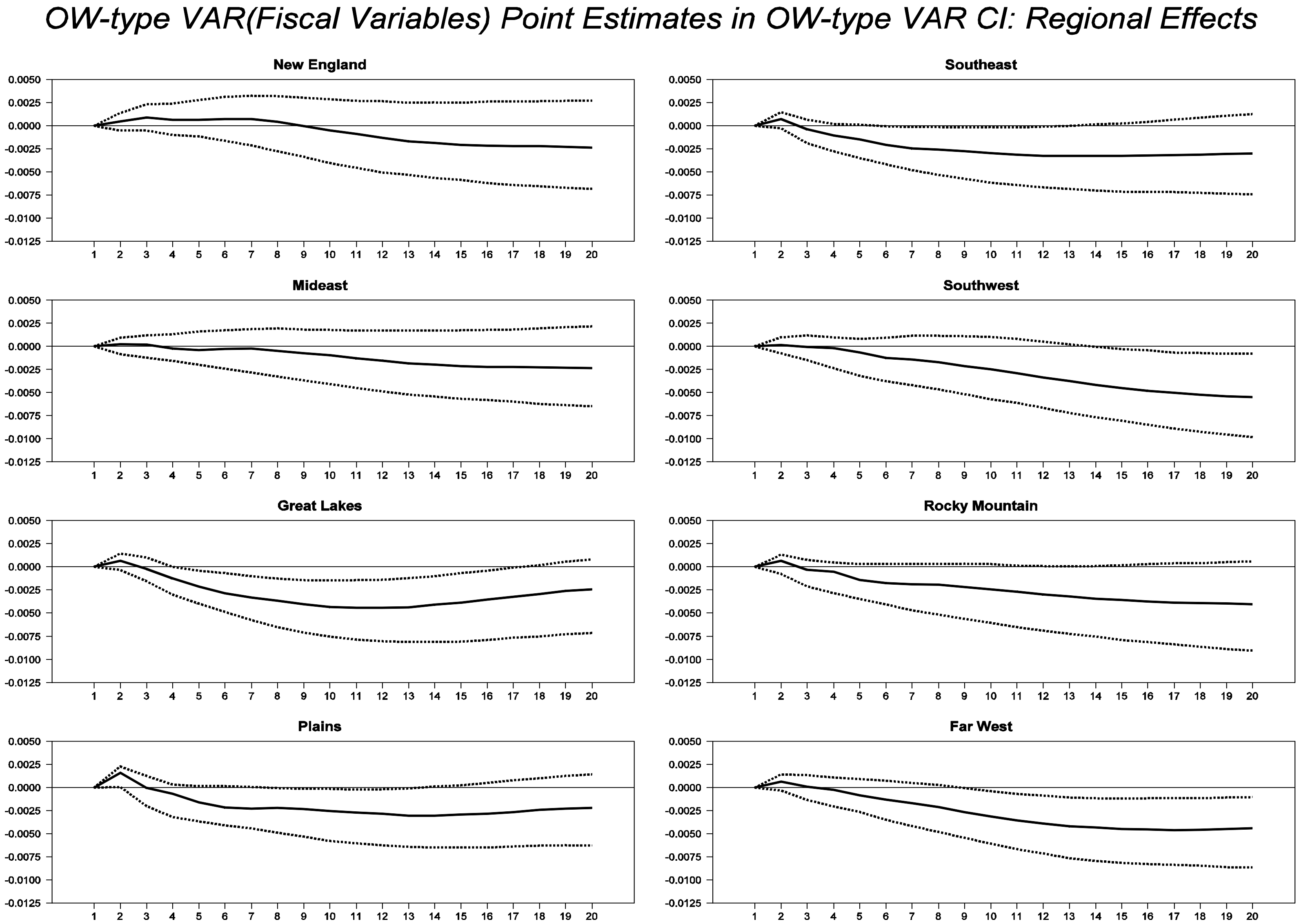


Figure 4.2 — OW-Type VAR (Fiscal Variable) Point Estimates in OW-Type VAR Confidence Intervals: Regional Effects

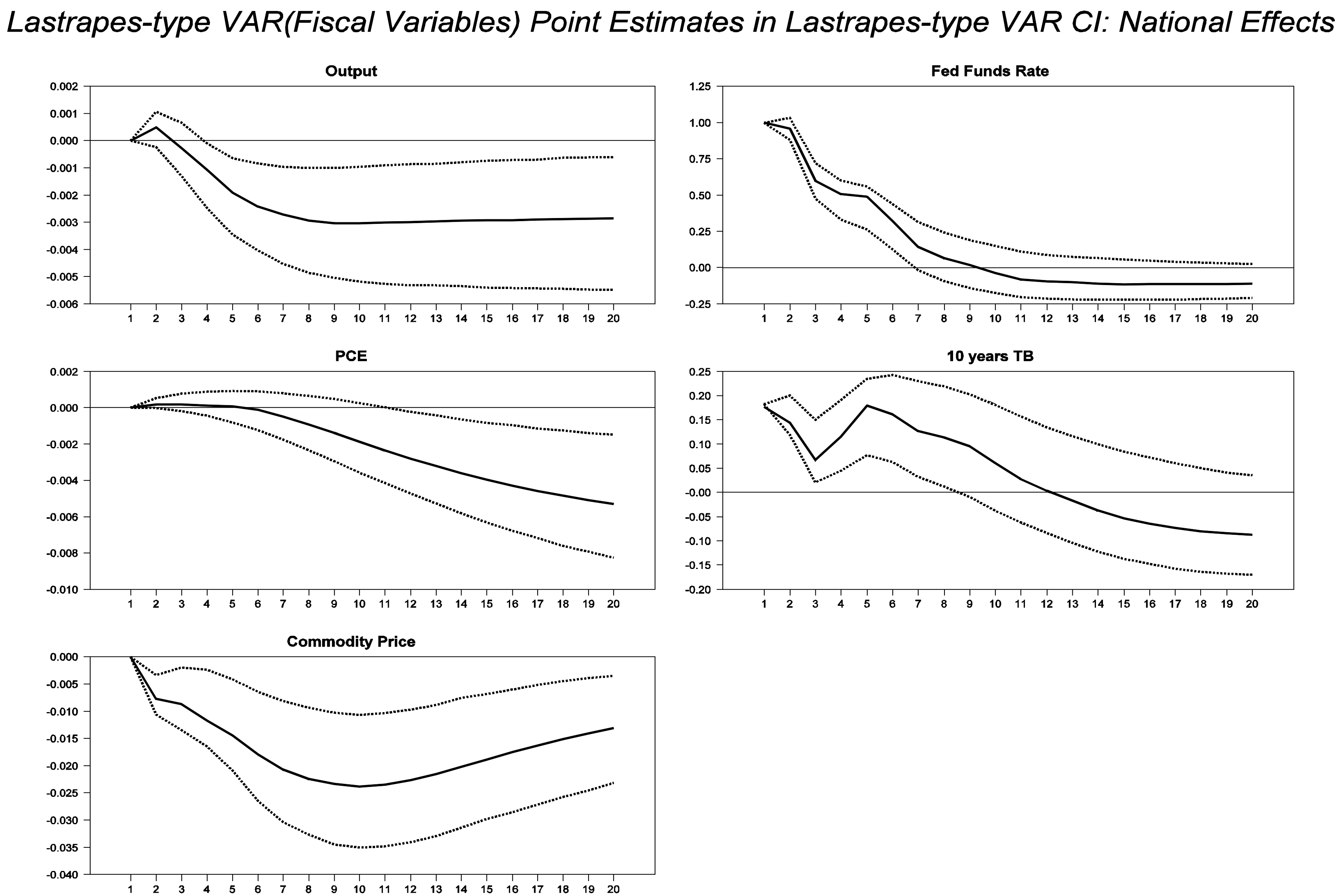


Figure 4.3 — Lastrapes-Type VAR (Fiscal Variable) Point Estimates in Lastrapes-Type VAR Confidence Intervals: National Effects

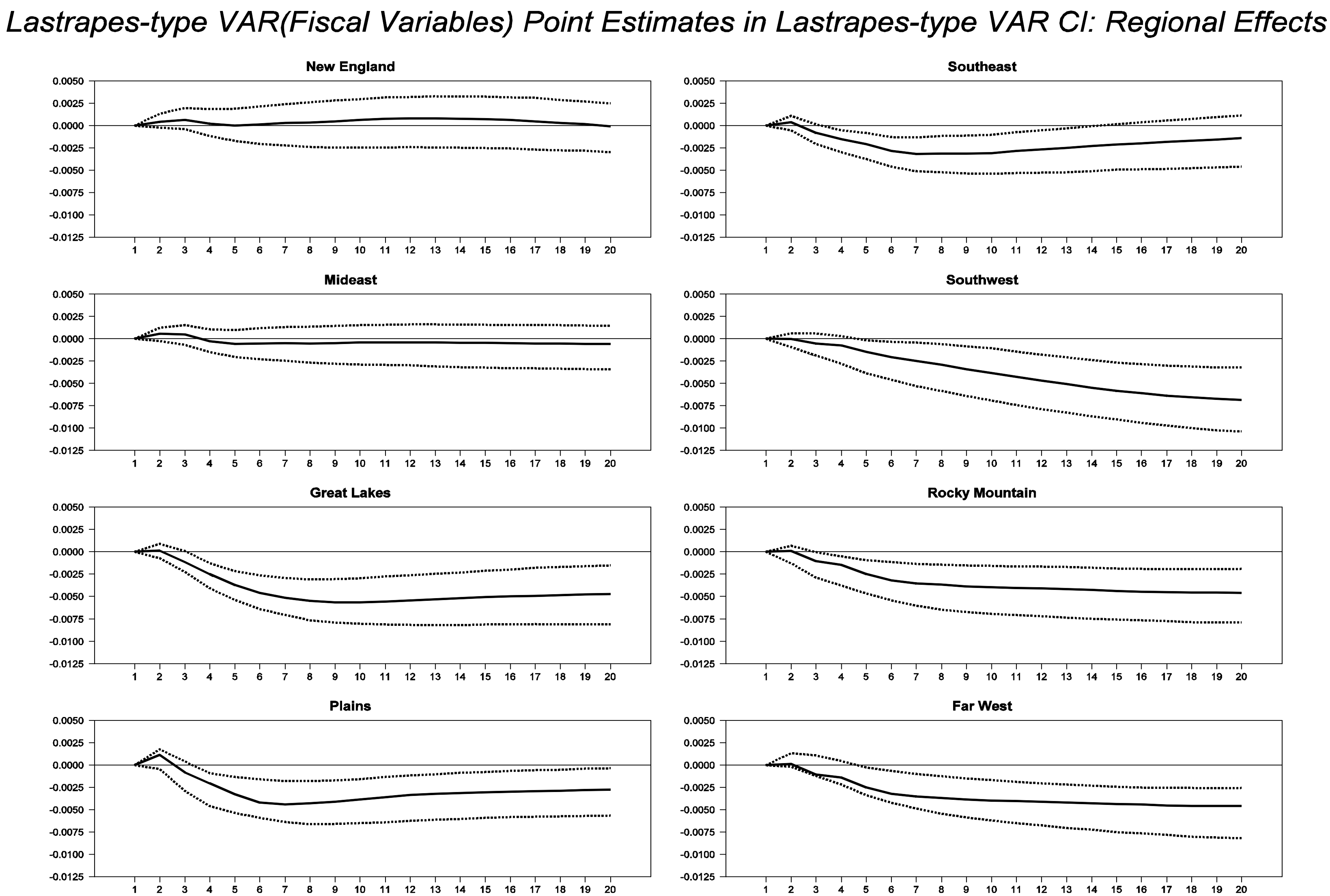


Figure 4.4 — Lastrapes-Type VAR (Fiscal Variable) Point Estimates in Lastrapes-Type VAR Confidence Intervals: Regional Effect

4.2.1.3 Border-Effects Restricted VAR Model

We calculate the point estimates from border-effects VAR with the fiscal variables and then plot these point estimates along with the border-effects VAR without the fiscal variables confidence intervals. Figure 4.5 and 4.6 show these results. Figure 4.5 represents the national effects and Figure 4.6 shows the regional effects. In Figure 4.5, all five macro variables' point estimates in the model with the fiscal variables are well inside the confidence intervals from the border-effects VAR without the fiscal variables. In Figure 4.6, all eight regions of point estimates are inside the confidence intervals from the border-effects VAR without the fiscal variables.

The results from the border-effects restricted VAR with the fiscal variables suggest some differences in the timing and duration of the effects of monetary policy shocks across regions. However, even though we include the fiscal variables, the results look similar to the original border-effects restricted VAR without the fiscal variables.

4.2.2 Forty Eight Contiguous States Case

4.2.2.1 Lastrapes-Type Restricted VAR Model

We calculate the point estimates from Lastrapes-type VAR (state) with the fiscal variables and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR (state) without the fiscal variables. Figure 4.7 and Figure 4.8.1 through 4.8.8 show these results. In Figure 4.8.1 through 4.8.8, 48 states' point estimates with the fiscal variables stay well inside the confidence intervals from the Lastrapes-type VAR (state) without the fiscal variables. From Figure 4.7, we found all five macro variables point estimates with the fiscal variables remain well inside the confidence intervals from the Lastrapes-type VAR (state) without the fiscal variables.

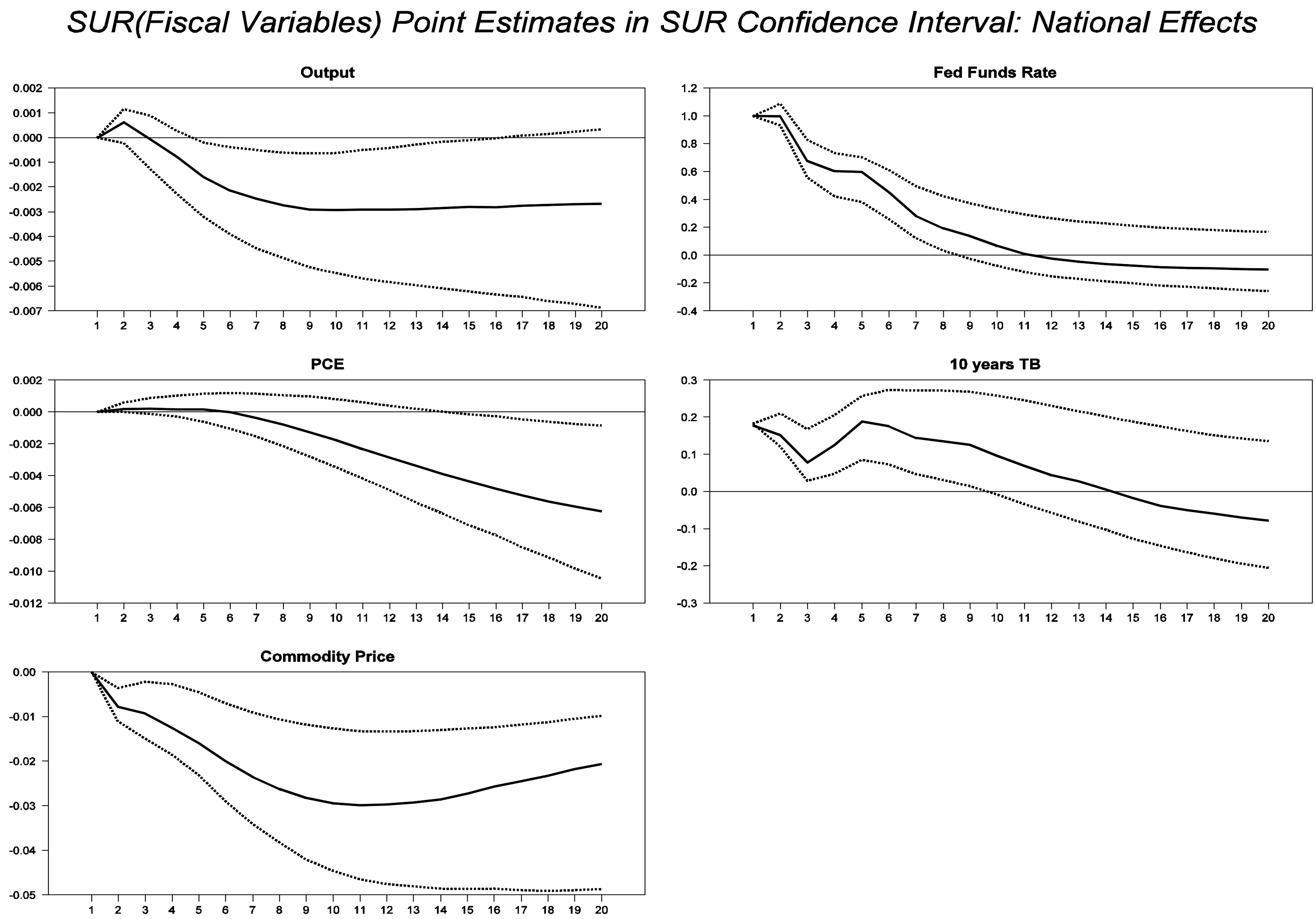


Figure 4.5 — Border-Effects VAR (Fiscal Variable) Point Estimates in Border-Effects VAR Confidence Intervals: National Effect

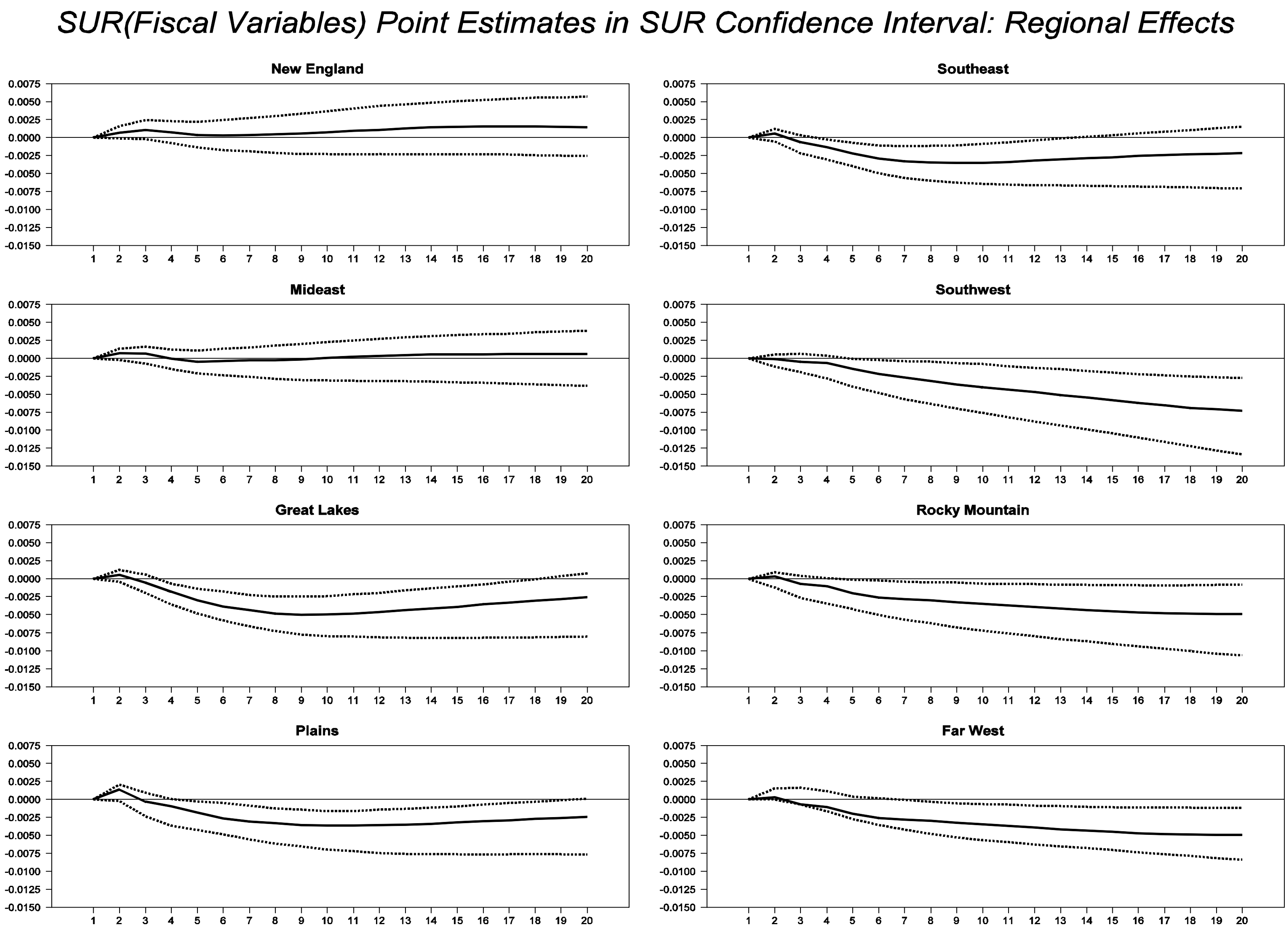


Figure 4.6 — Border-Effects VAR (Fiscal Variable) Point Estimates in Border-Effects VAR Confidence Intervals: Regional Effect

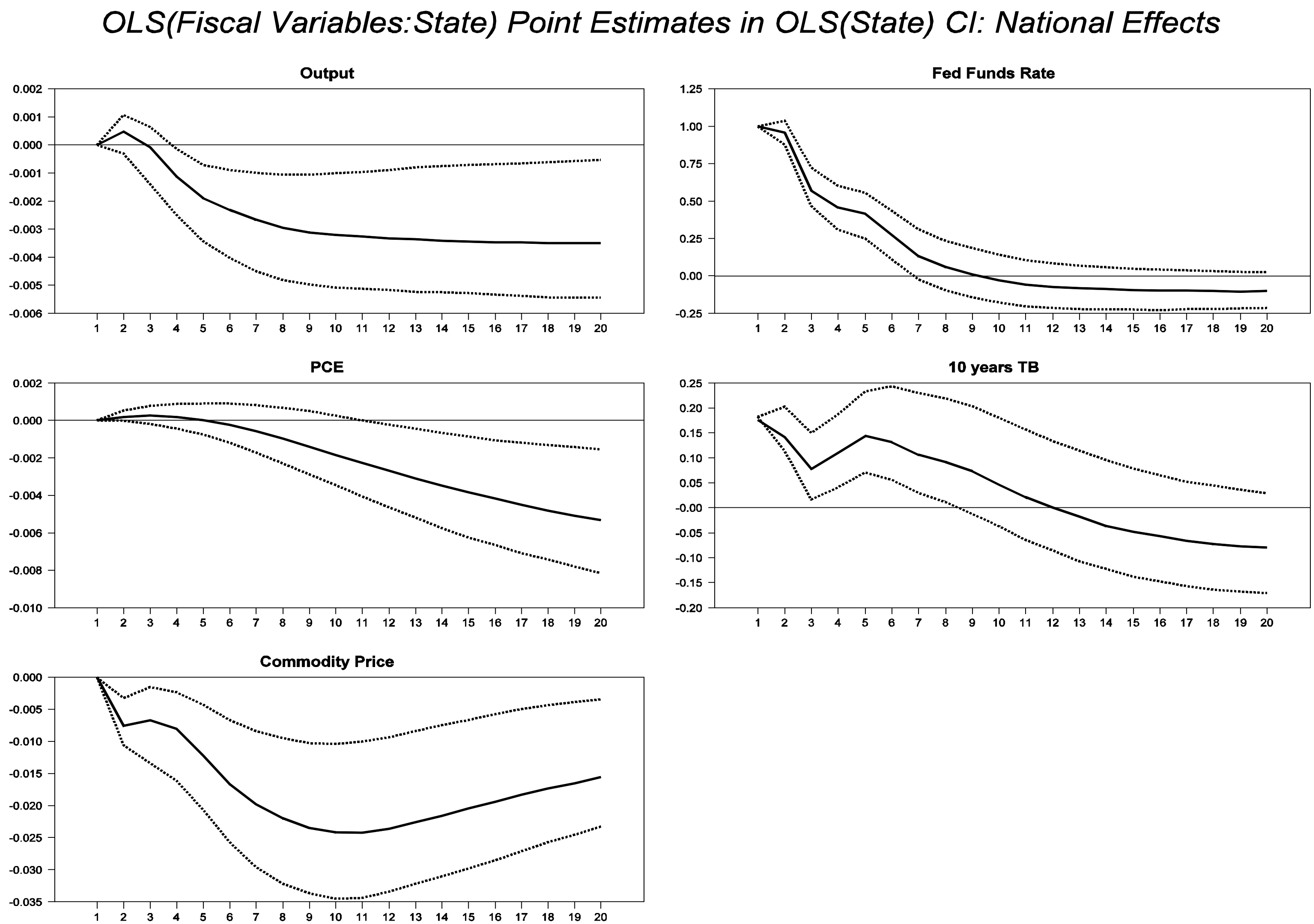


Figure 4.7 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval: National Effects

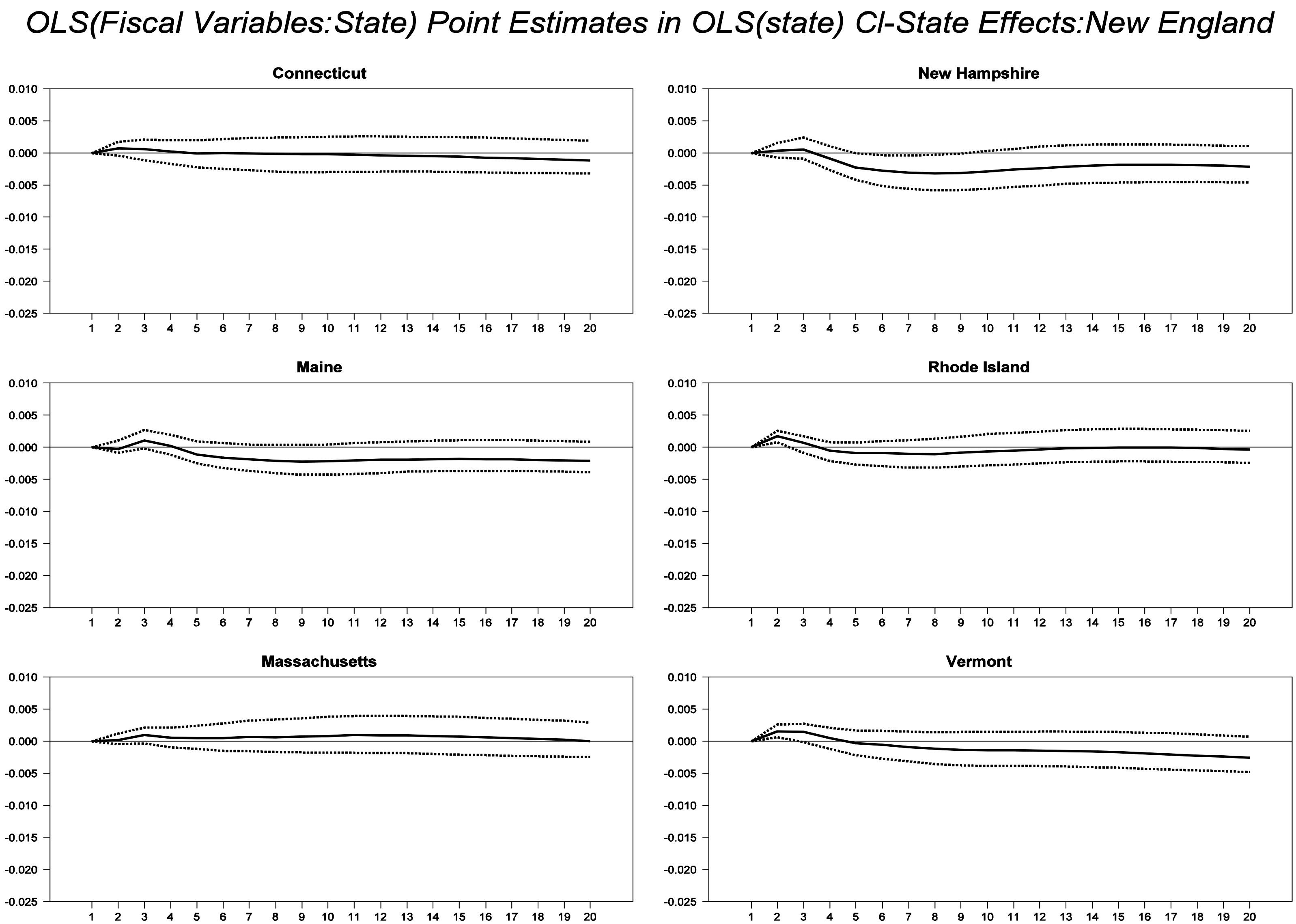


Figure 4.8.1 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– New England

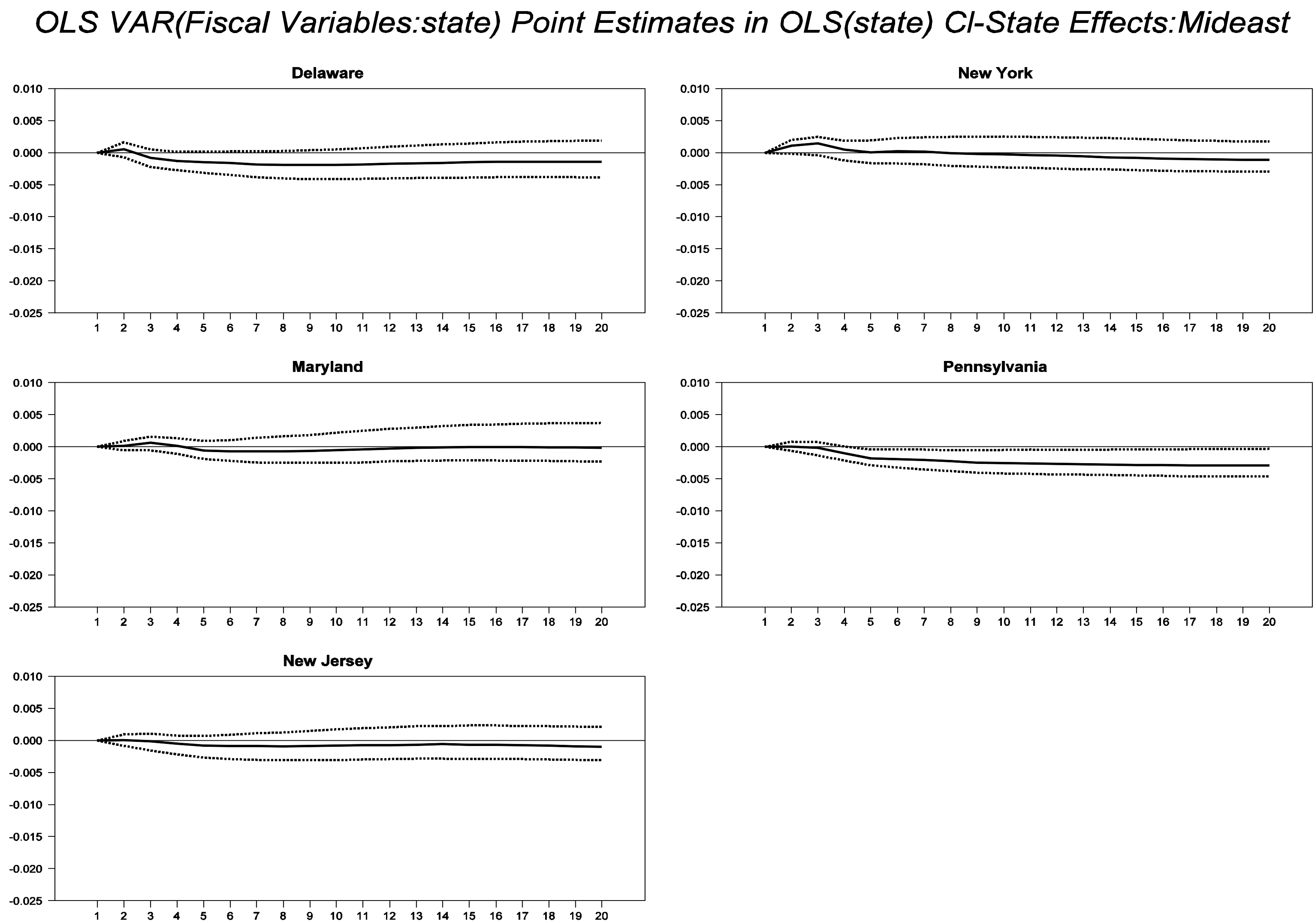


Figure 4.8.2 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Mideast

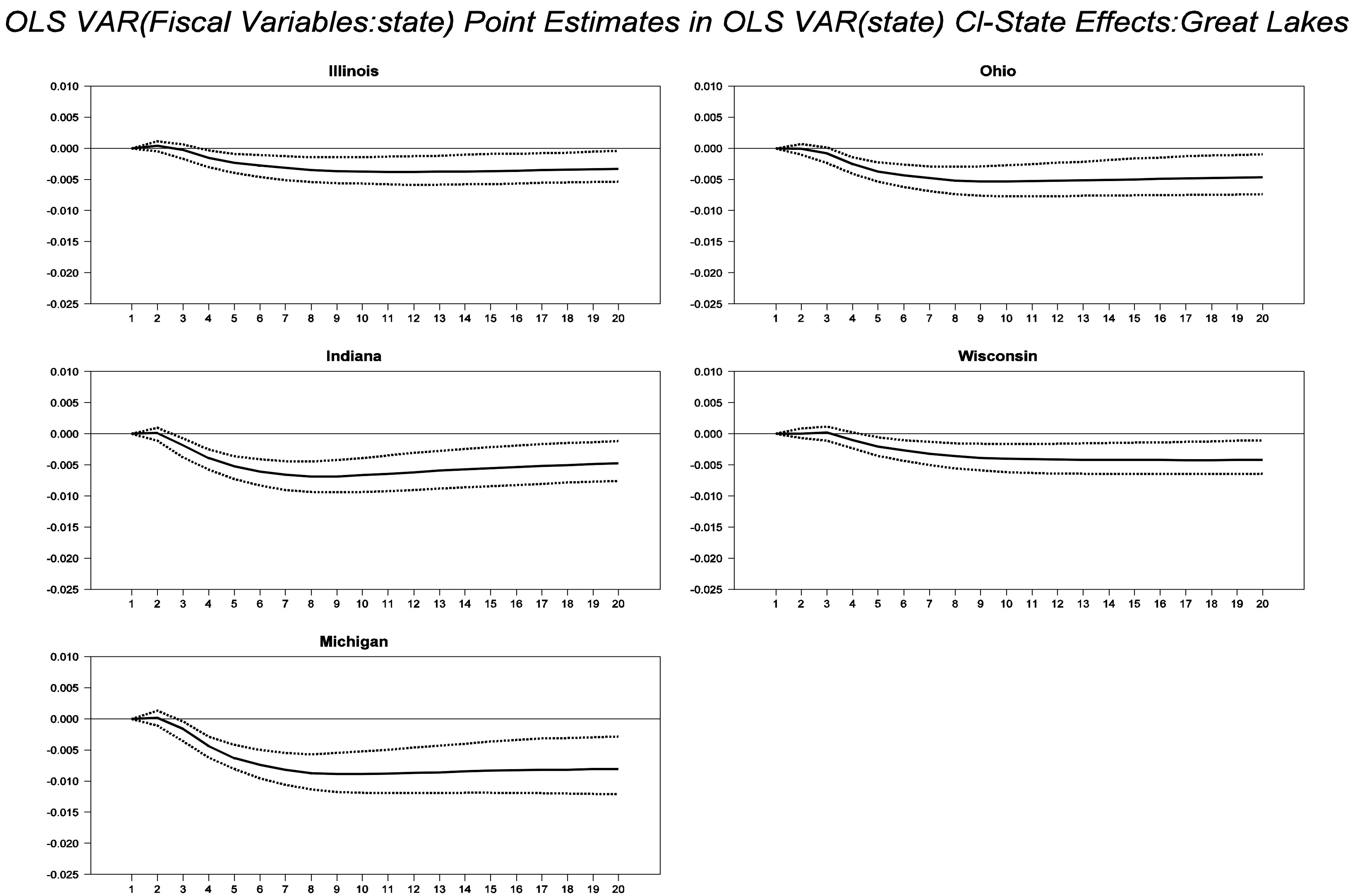


Figure 4.8.3 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Great Lakes

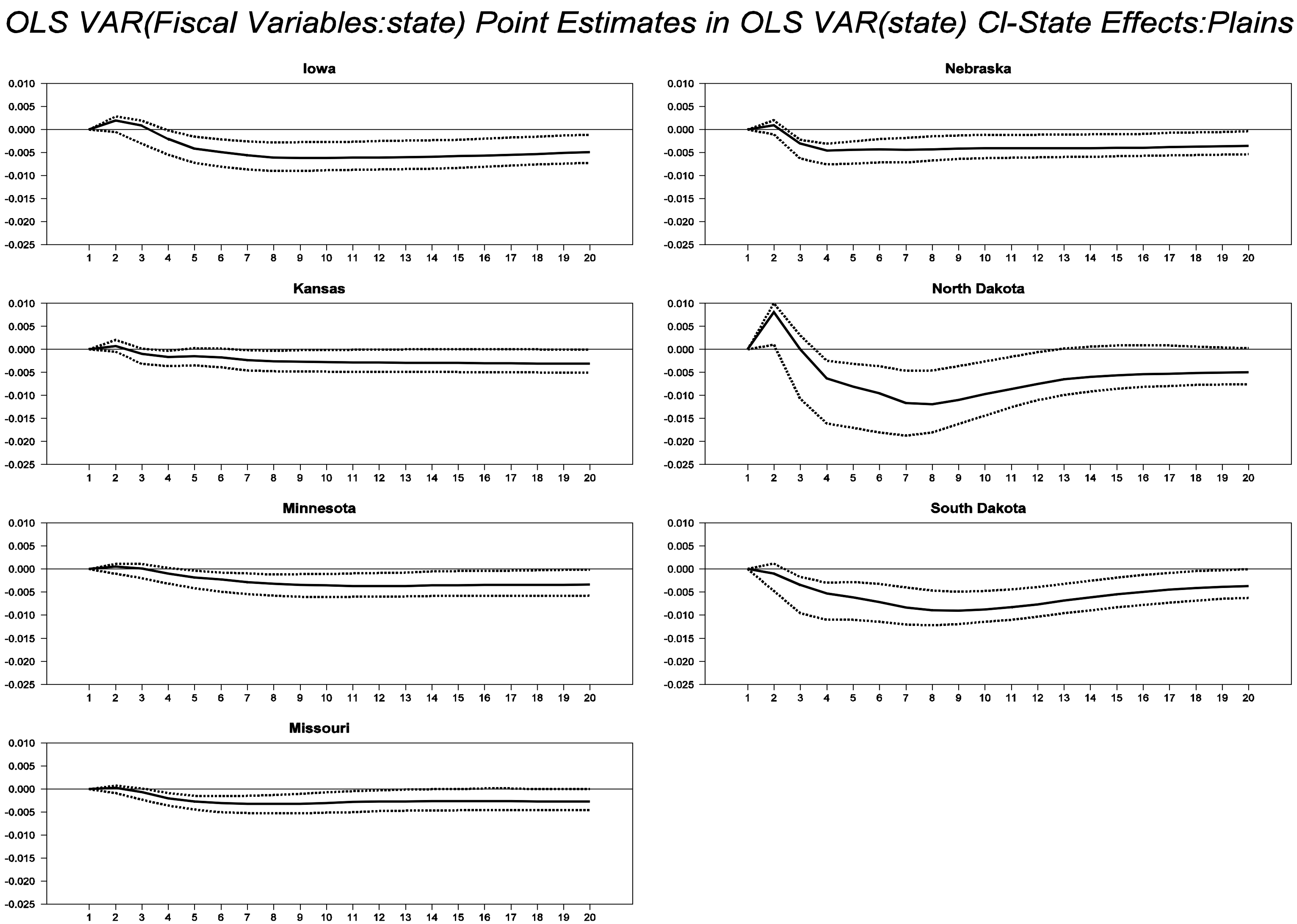


Figure 4.8.4 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Plains

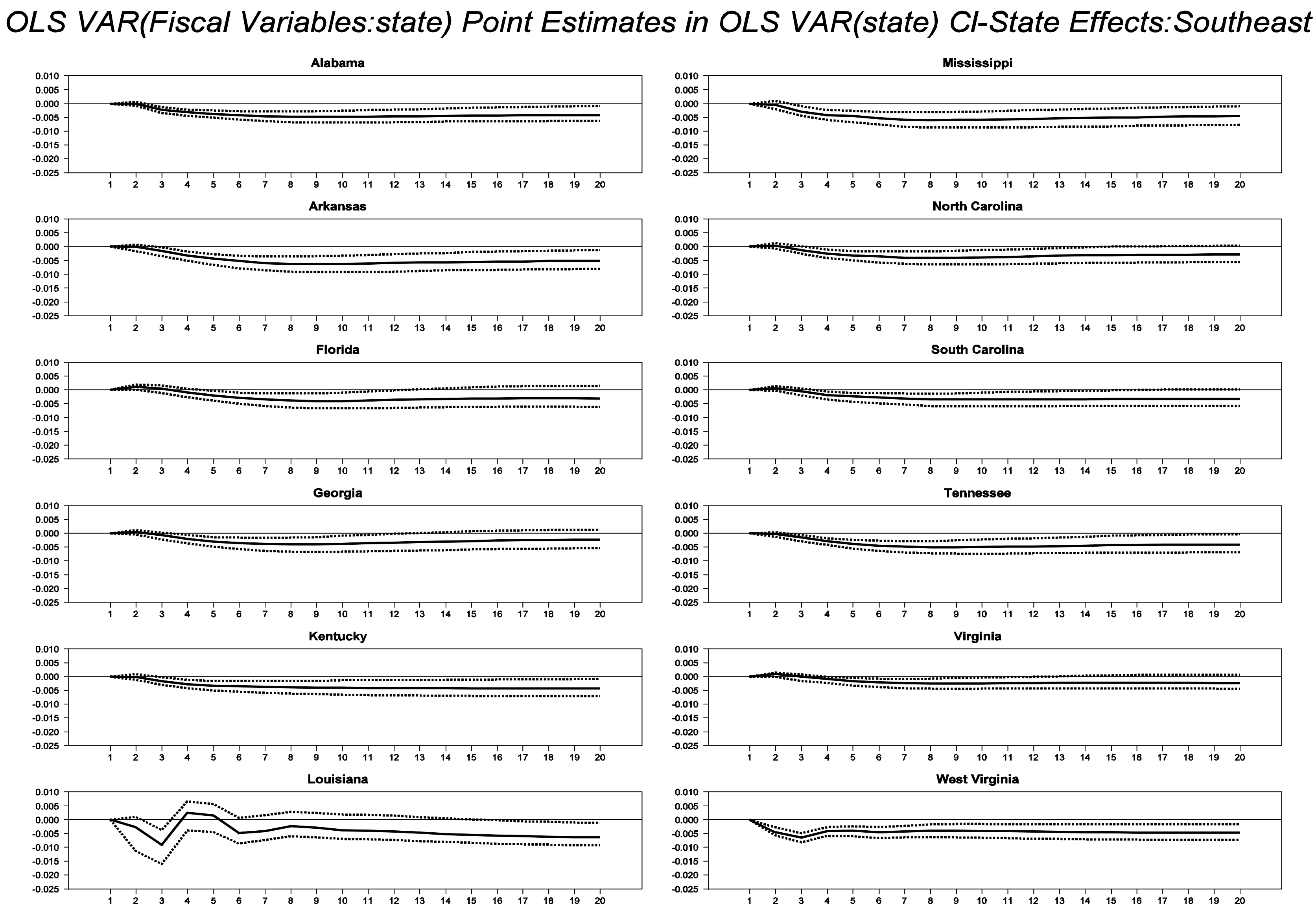


Figure 4.8.5 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Southeast

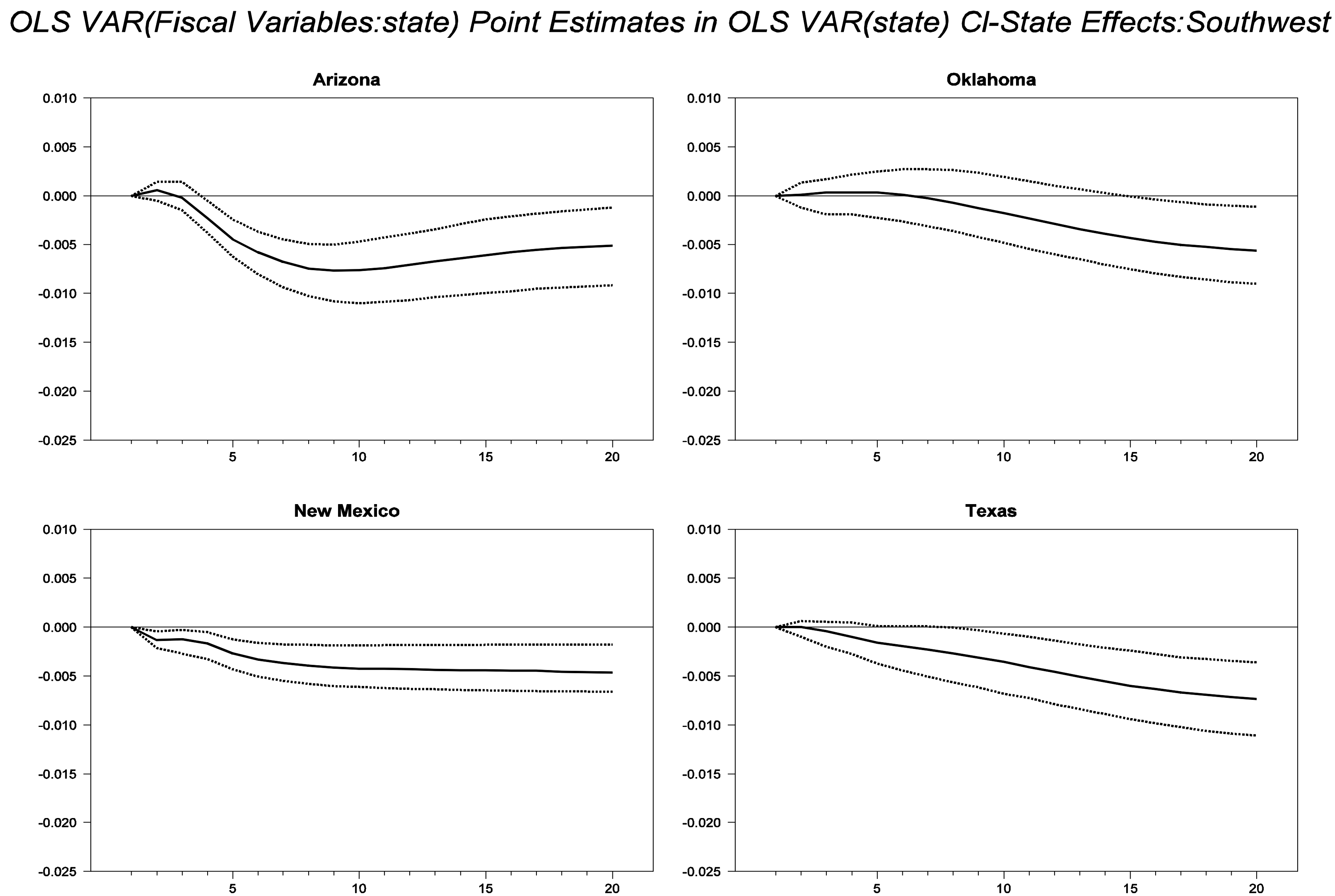


Figure 4.8.6 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Southwest

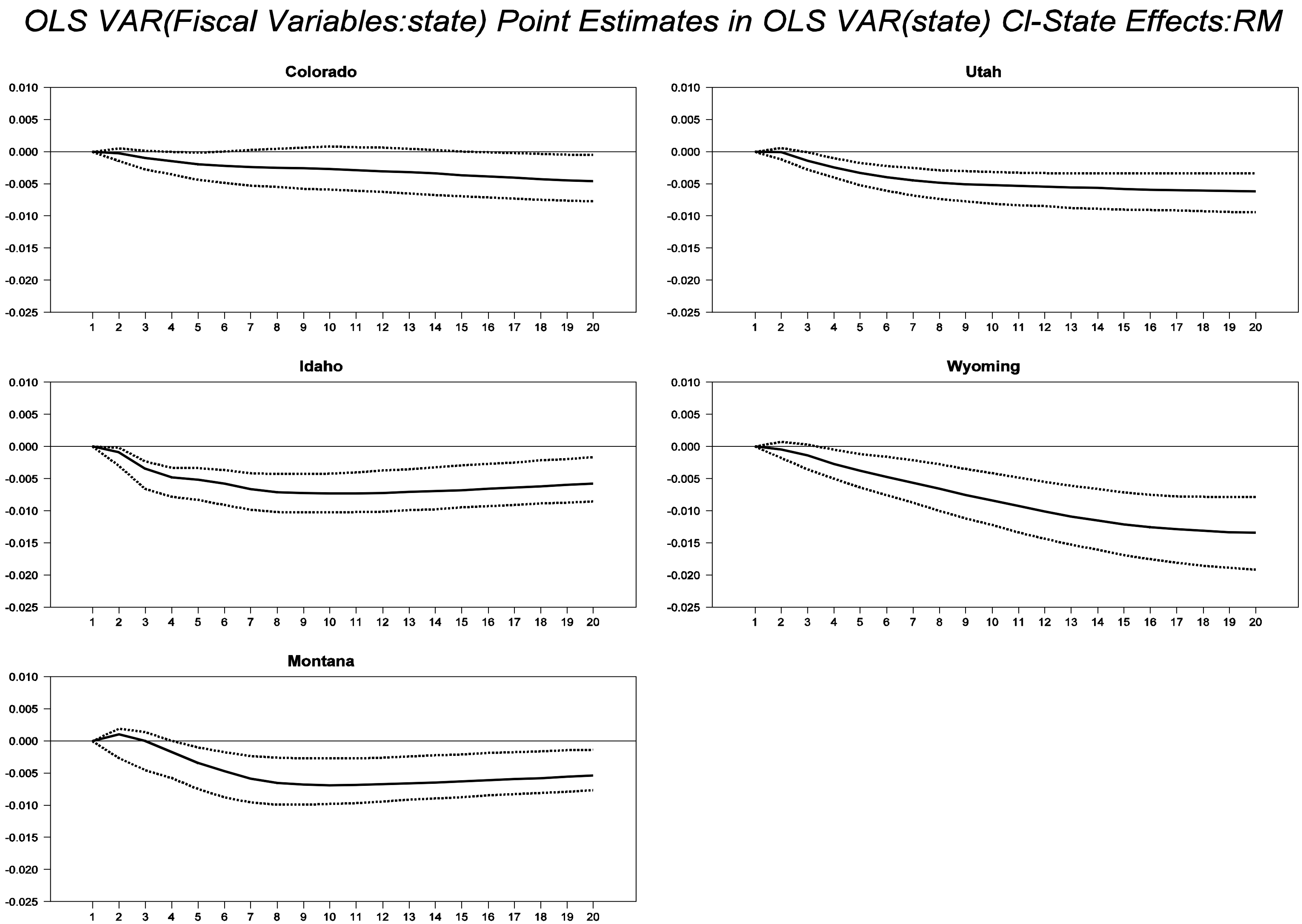


Figure 4.8.7 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Rocky Mountain

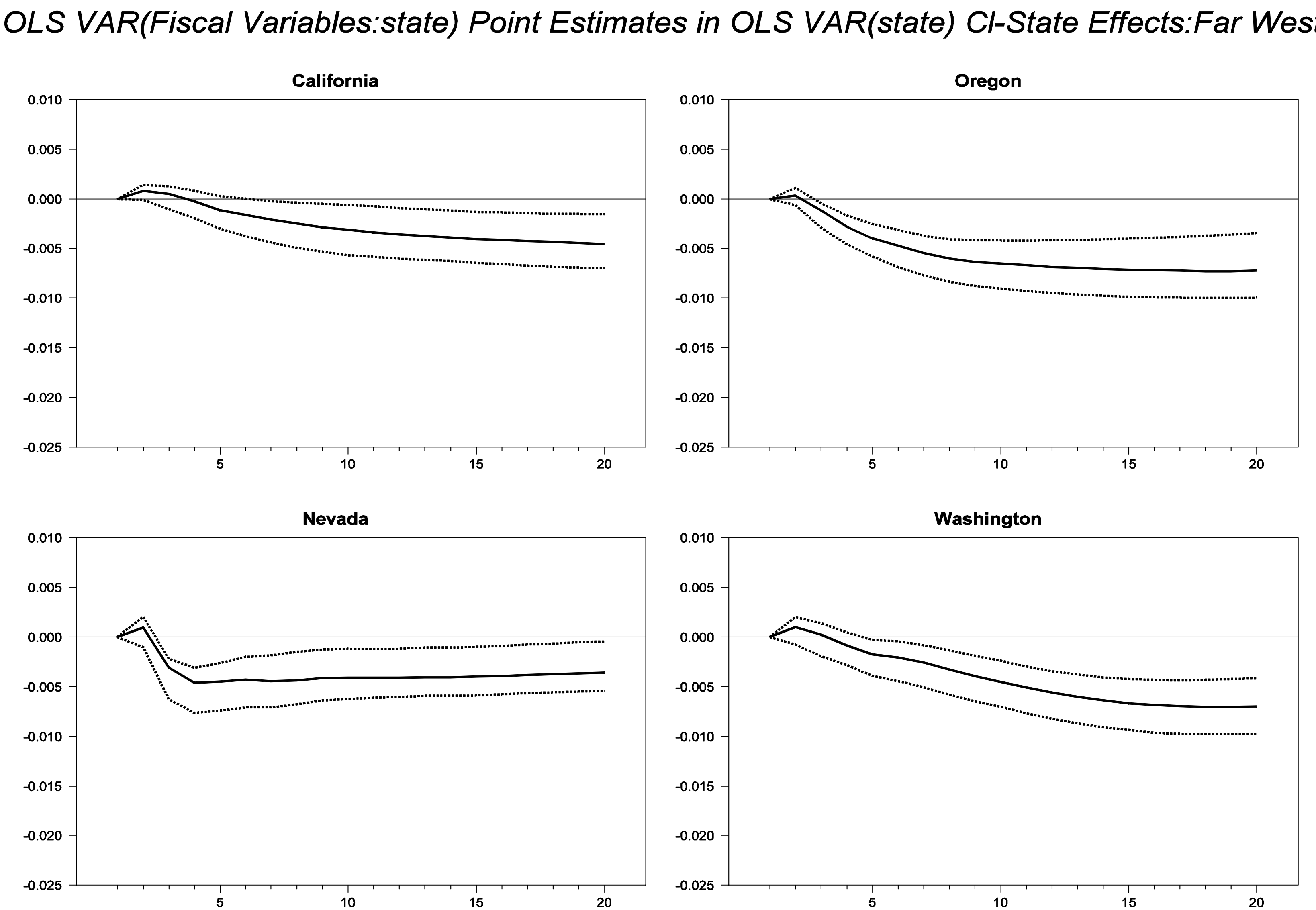


Figure 4.8.8 — Lastrapes-Type VAR (Fiscal Variables: State) in Lastrapes-Type VAR (State) Confidence Interval– Far West

4.2.2.2 Border-Effects Restricted VAR Model

We can get the point estimates from border-effects VAR (state) that includes the fiscal variables and then plot these point estimates along with the confidence intervals from the border-effects VAR (state) without the fiscal variables'. Figure 4.9 and Figures 4.10.1 through 4.10.8 report these results. In Figure 4.9, we can see all five macro variables' point estimates stay well inside the confidence intervals from the border-effects VAR (state) without the fiscal variables. In all of the state effects figures in this section, the point estimates for the model with the fiscal variables are inside the confidence intervals from the border-effects VAR (state) without the fiscal variables.

4.3 Uncertainty

Uncertainty comes in many forms and increases dramatically after major economic and political fluctuations. Economists and policymakers have tried to develop methods for thinking about and analyzing uncertainty, all of which offer important knowledge of how policymakers might manage the problem. For example, after 9/11 the Federal Open Market Committee (FOMC) stated in October 2001 that "the events of September 11 produced a marked increase in uncertainty [. . .] depressing investment by fostering an increasingly widespread wait-and see attitude." Similarly, during the recent financial crisis the FOMC noted that "Several [survey] participants reported that uncertainty about the economic outlook was leading firms to defer spending projects until prospects for economic activity became clearer." The main concern of this section is to analyze the regional effects of monetary policy in models that include Bloom's (2009) measure of aggregate uncertainty shocks.

The earlier work of Bernanke (1983) and Hassler (1996) examine the importance of variations in uncertainty. Bernanke formalizes the negative effects of uncertainty in causing

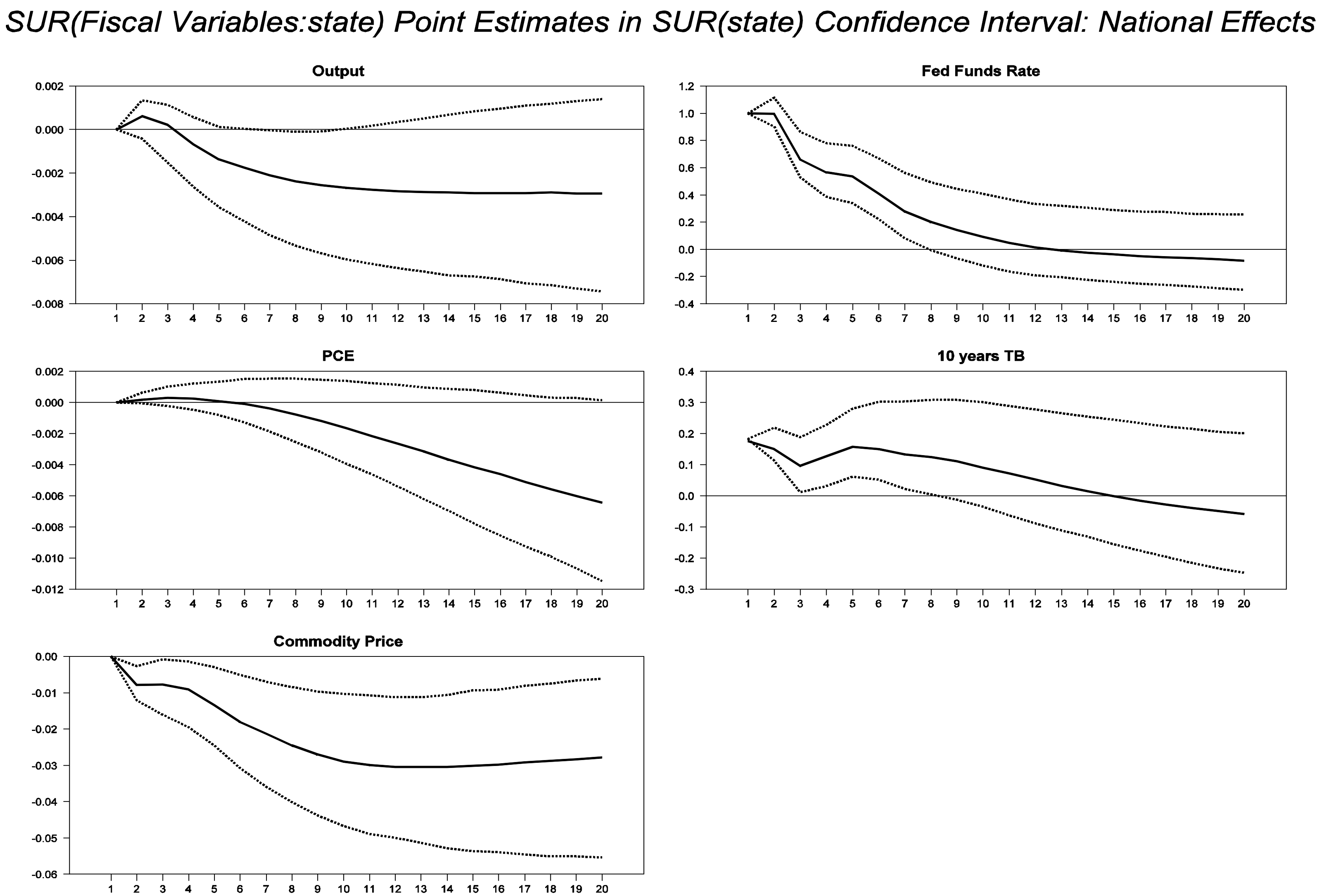


Figure 4.9 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– National Effects

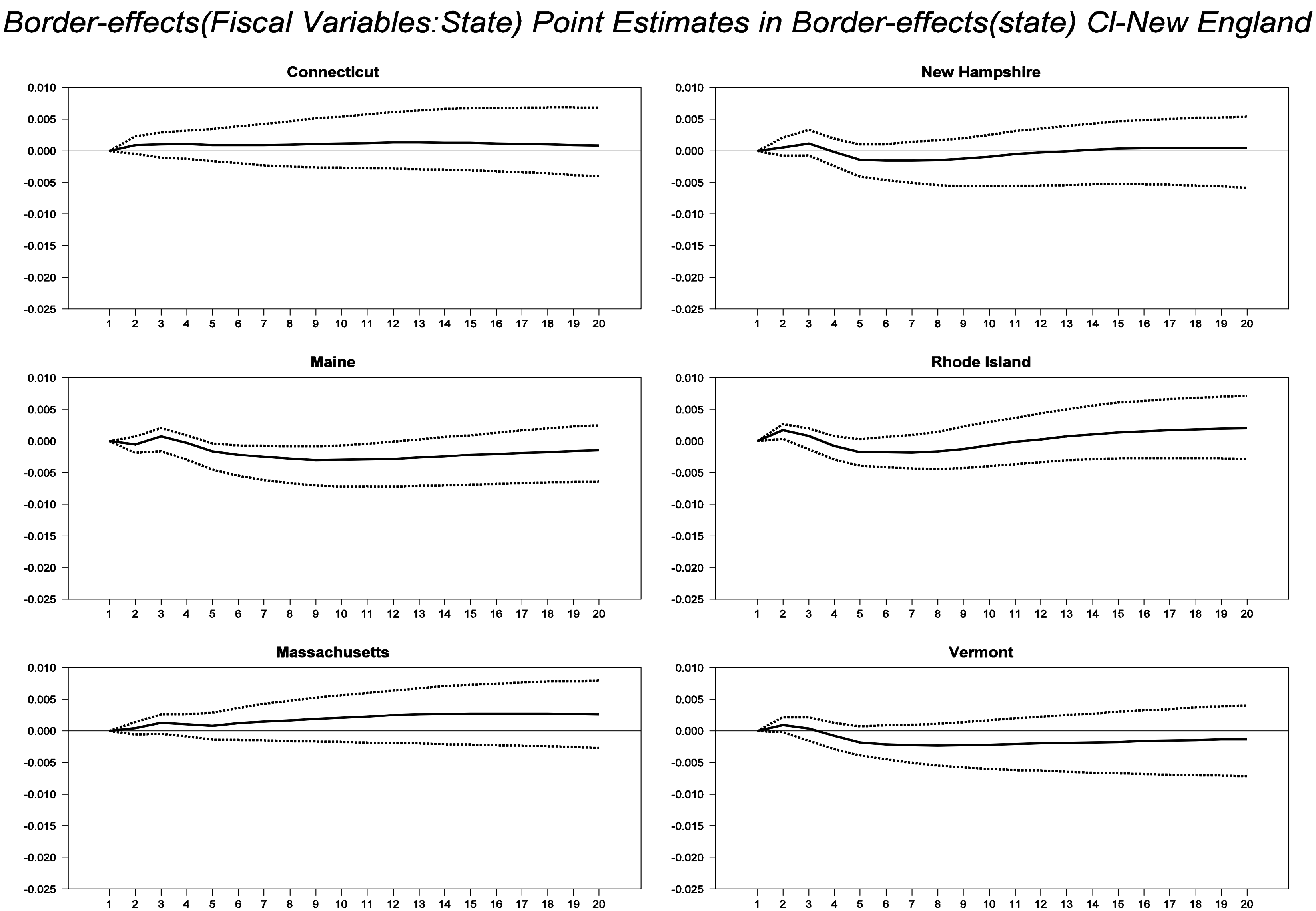


Figure 4.10.1 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– New England

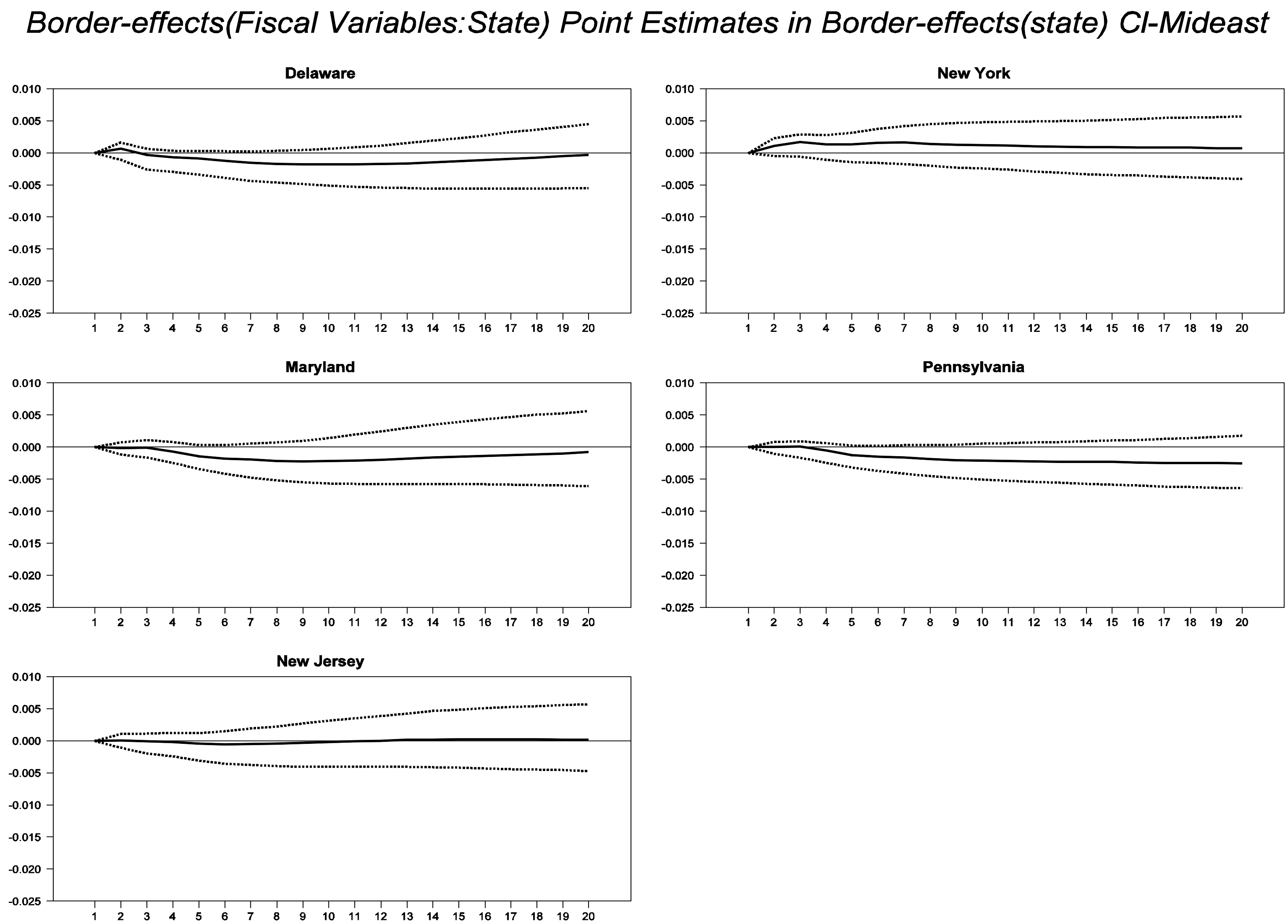


Figure 4.10.2 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Mideast

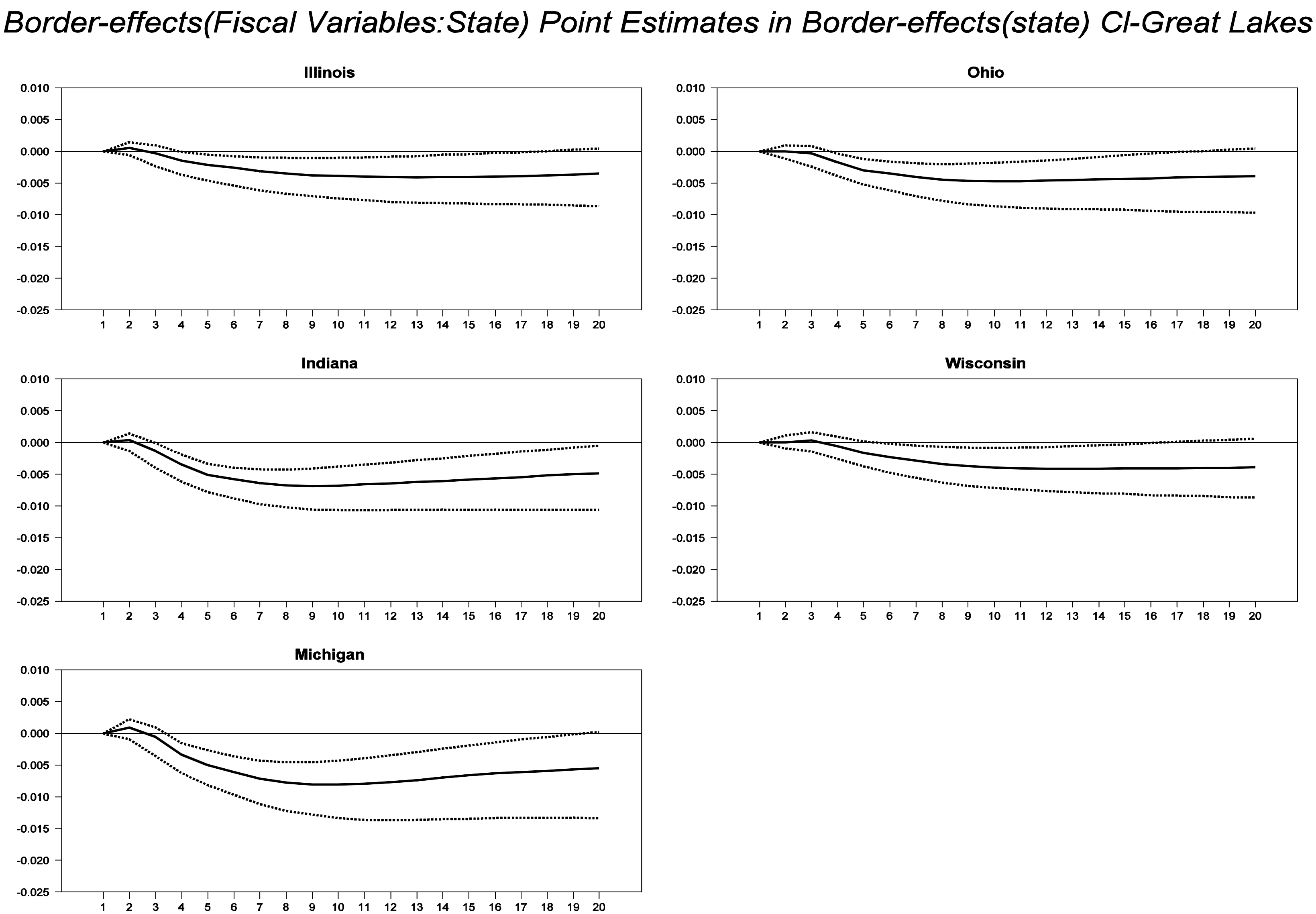


Figure 4.10.3 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Great Lakes

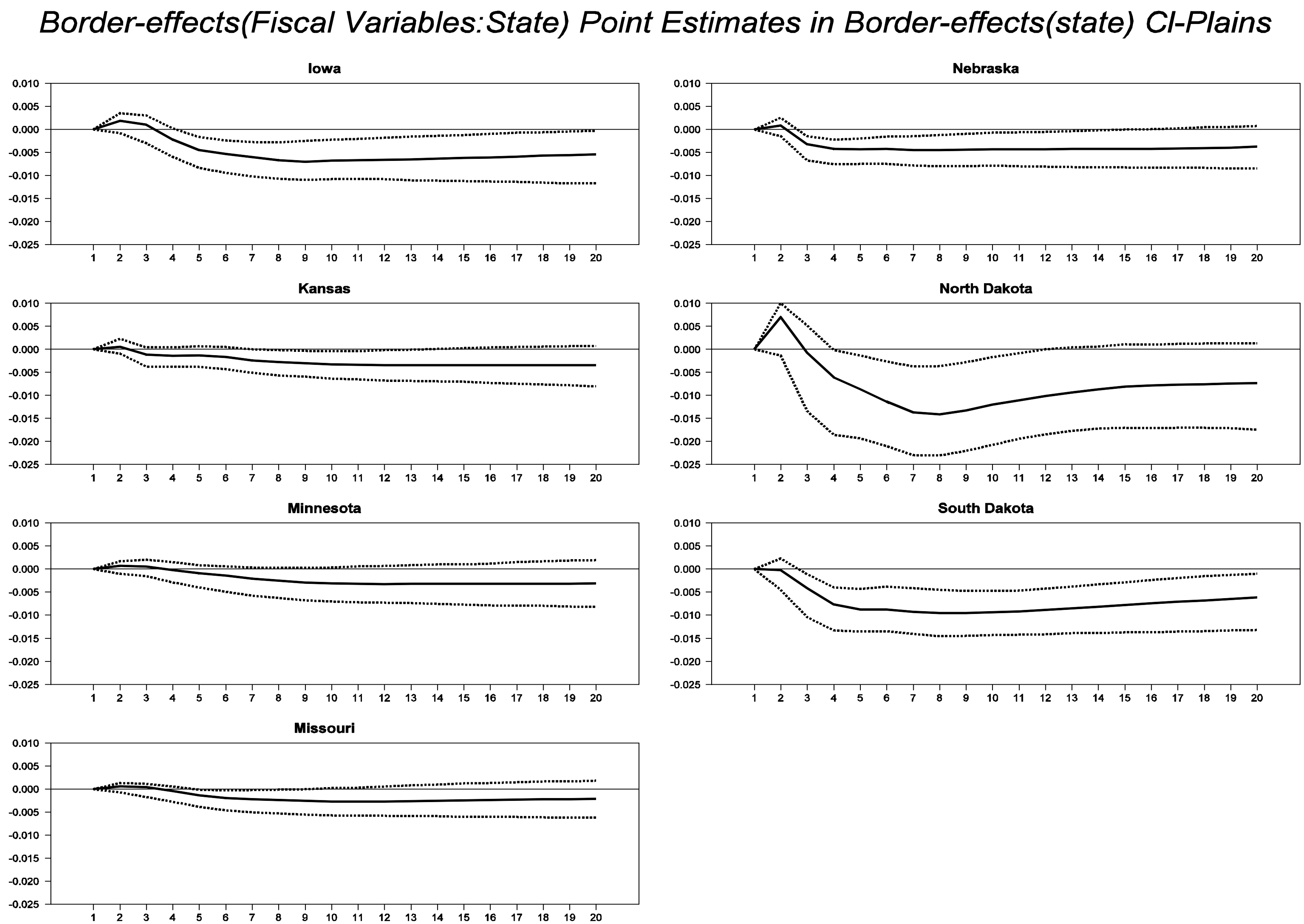


Figure 4.10.4 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Plains

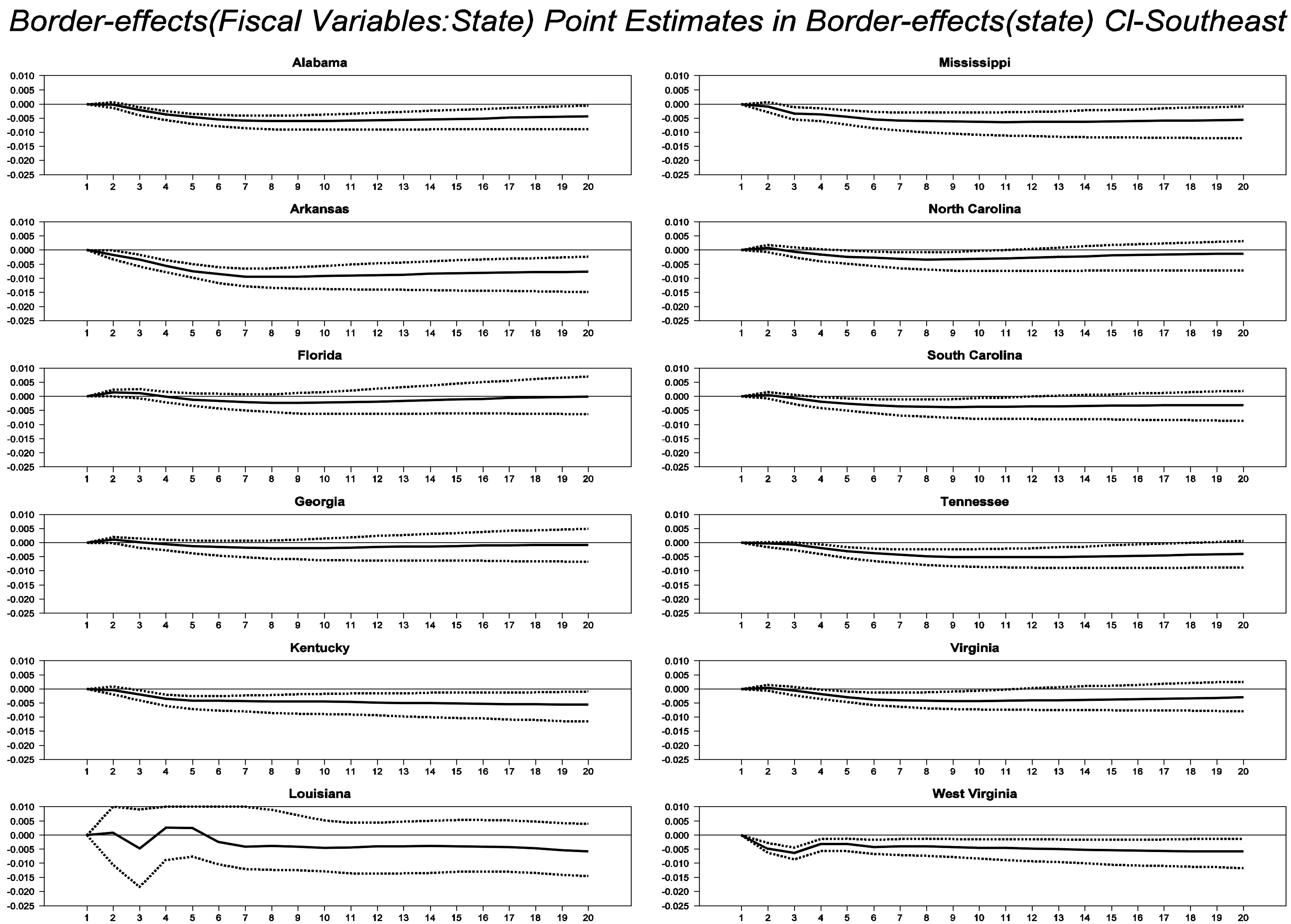


Figure 4.10.5 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Southeast

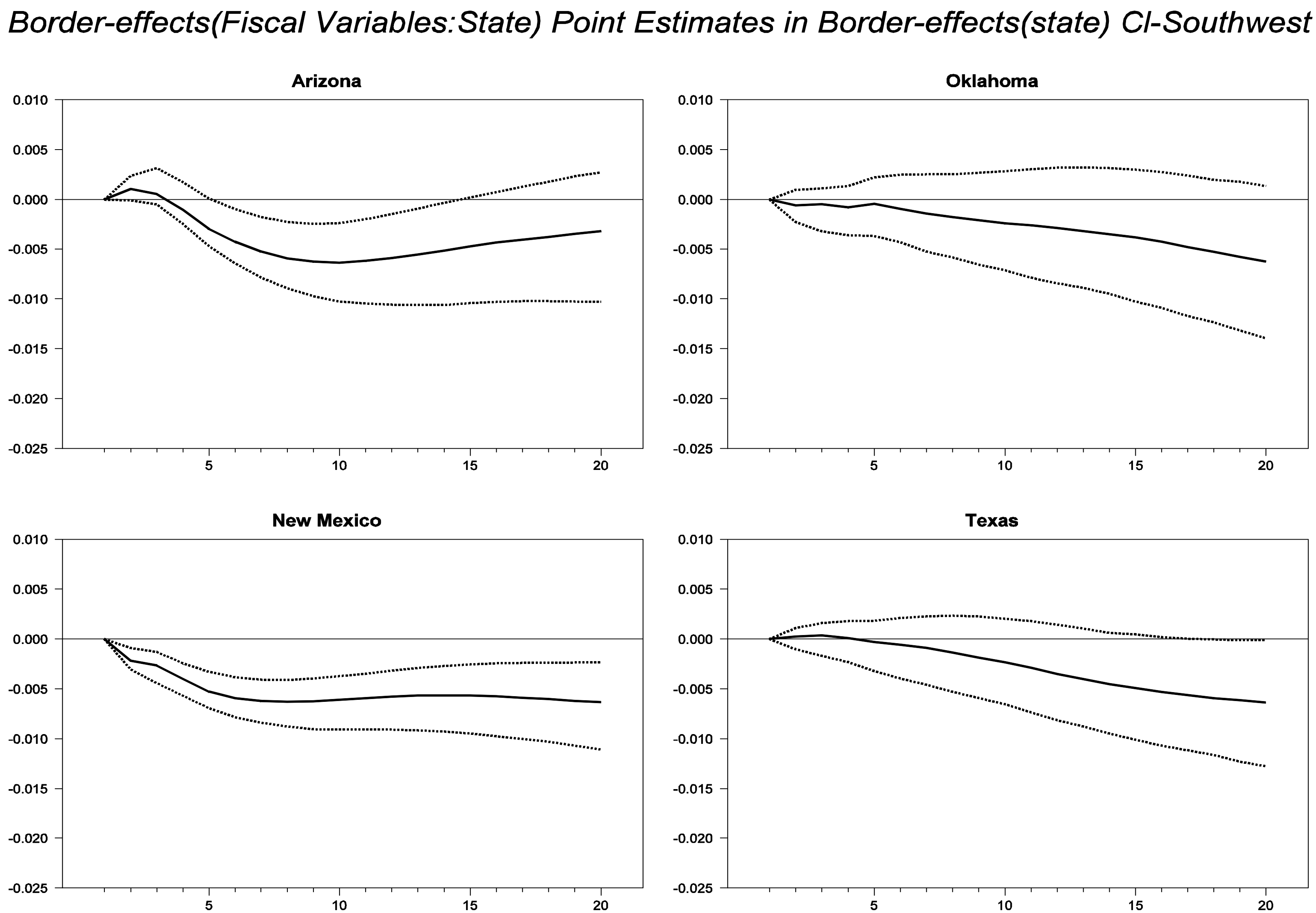


Figure 4.10.6 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Southwest

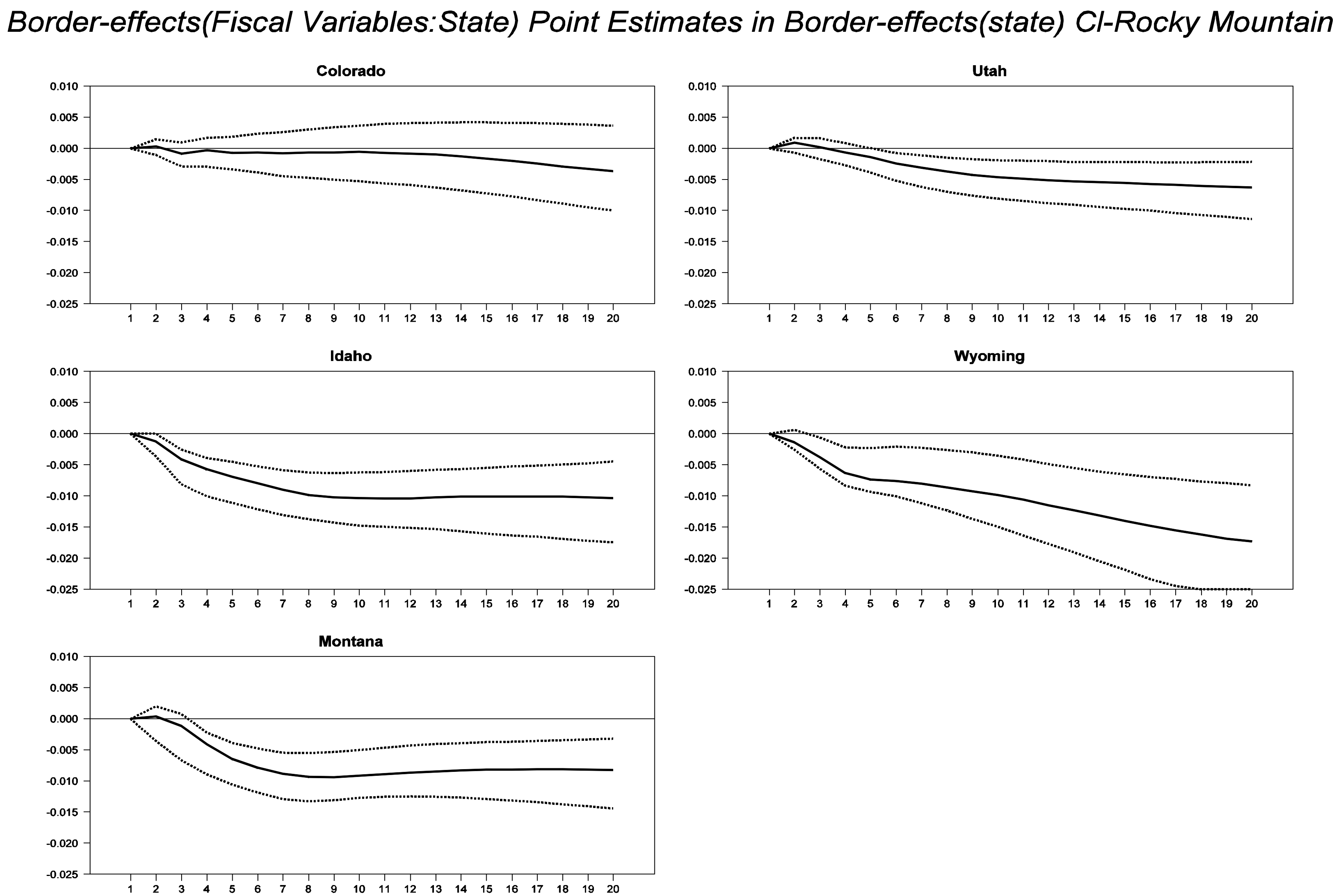


Figure 4.10.7 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Rocky Mountain

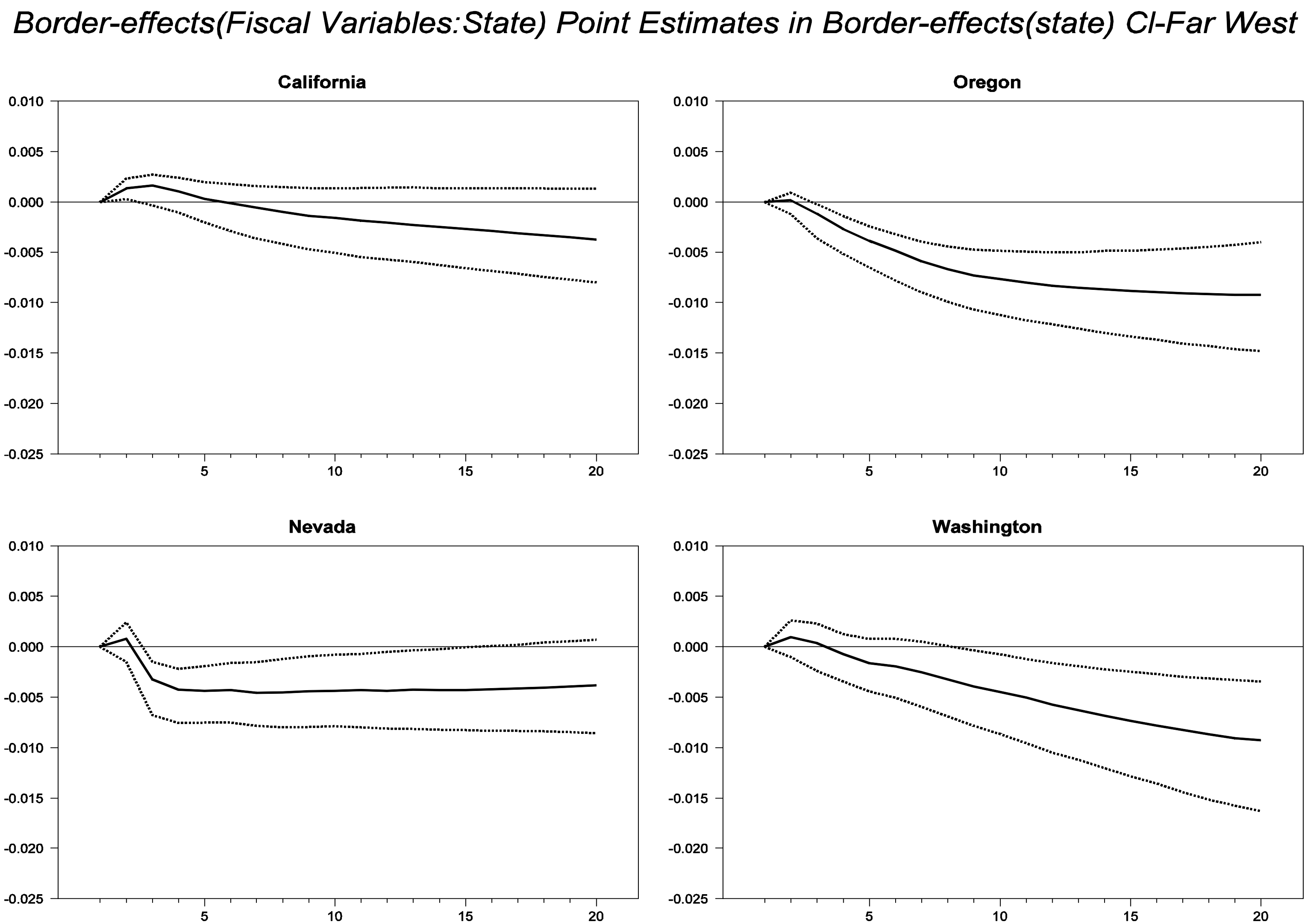


Figure 4.10.8 — Border-Effects VAR (Fiscal Variables: State) in Border-Effects VAR (State) Confidence Interval– Far West

recessions, noting that: “events whose long-run implications are uncertain can create an investment cycle by temporarily increasing the returns to waiting for information.” Hassler finds uncertainty can directly influence firm-level investment and employment in the presence of adjustment costs. Recent empirical studies show that economic uncertainty has real effects. When economic uncertainty increases, employment and output sharply decrease (see Bloom (2009) and Bloom, Floetotto and Jaimovich (2010)).

Bloom (2009) uses stock market volatility—one proxy for uncertainty—to create an index of exogenous volatility shocks. We utilize the seventeen uncertainty shocks identified by Bloom (2009). Table 1 shows Bloom’s 17 uncertainty shocks. The first column reports the 17 events, the second column is the month of maximum volatility (the parenthesis shows the quarterly frequency), the third column is the month of first volatility, and the last column shows the type of shock.

Table 1 Major Stock-Market Volatility Shocks

Event	Max Volatility	First Volatility	Type
Cuban missile crisis	October 1962 (IV)	October 1962 (IV)	Terror
Assassination of JFK	November 1963 (IV)	November 1963 (IV)	Terror
Vietnam buildup	August 1966 (III)	August 1966 (III)	War
Cambodia and Kent State	May 1970 (II)	May 1970 (II)	War
OPEC I, Arab–Israeli War	December 1973 (IV)	December 1973 (IV)	Oil
Franklin National	October 1974 (IV)	September 1974 (III)	Economics
OPEC II	November 1978 (IV)	November 1978 (IV)	Oil
Afghanistan, Iran hostages	March 1980 (I)	March 1980 (I)	War
Monetary cycle turning point	October 1982 (IV)	August 1982 (III)	Economics
Black Monday	November 1987 (IV)	October 1987 (IV)	Economics
Gulf War I	October 1990 (IV)	September 1990 (III)	War
Asian Crisis	November 1997 (IV)	November 1997 (IV)	Economics
Russian, LTCM default	September 1998 (III)	September 1998 (III)	Economics
9/11 terrorist attack	September 2001 (III)	September 2001(III)	Terror
Worldcom and Enron	September 2002 (III)	July 2002 (III)	Economics
Gulf War II	February 2003 (I)	February 2003 (I)	War
Credit crunch	October 2008 (IV)	August 2007 (III)	Economics

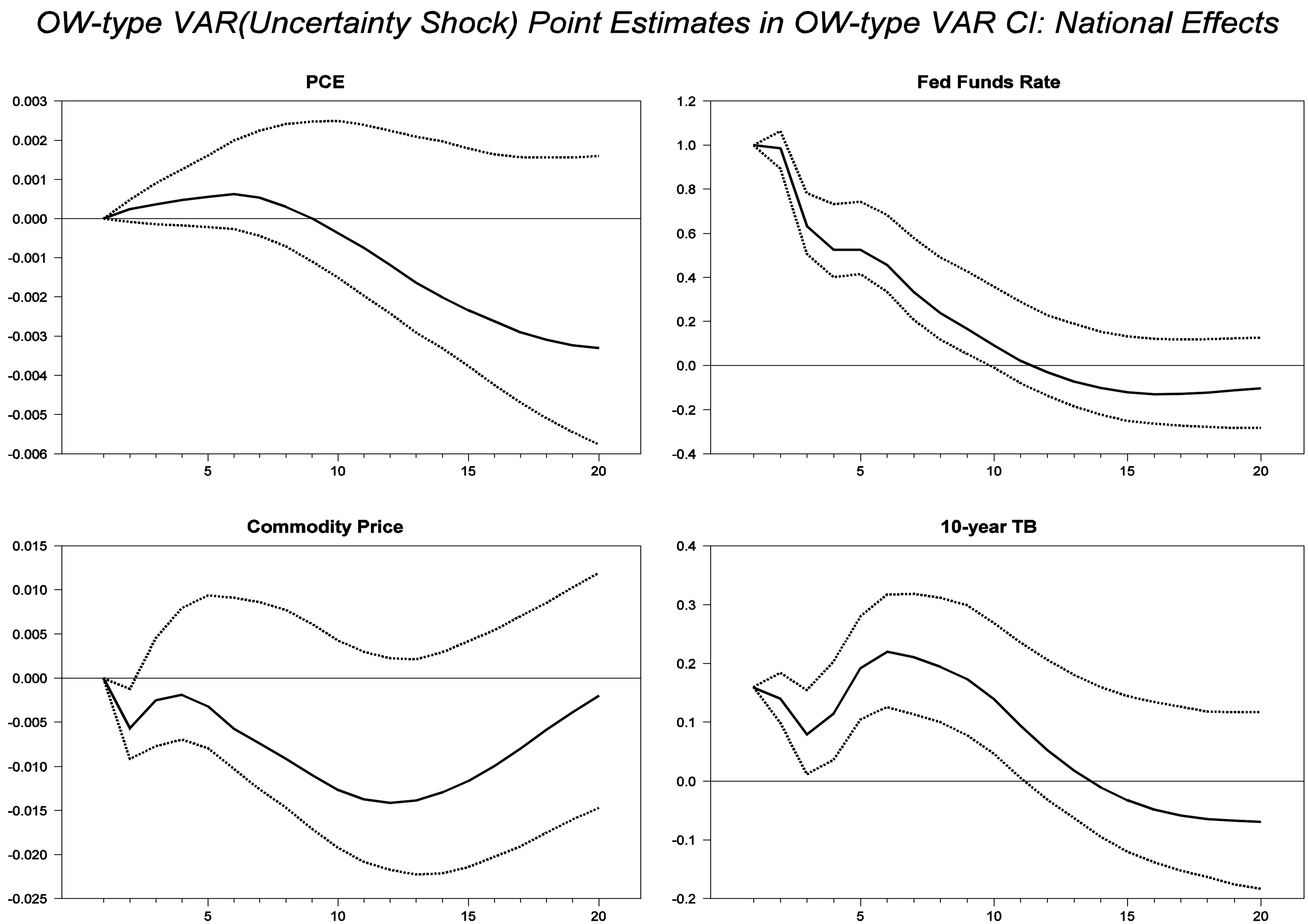


Figure 4.11 — OW-Type VAR (Uncertainty Shock) Point Estimates in OW-Type VAR Confidence Interval: National Effects

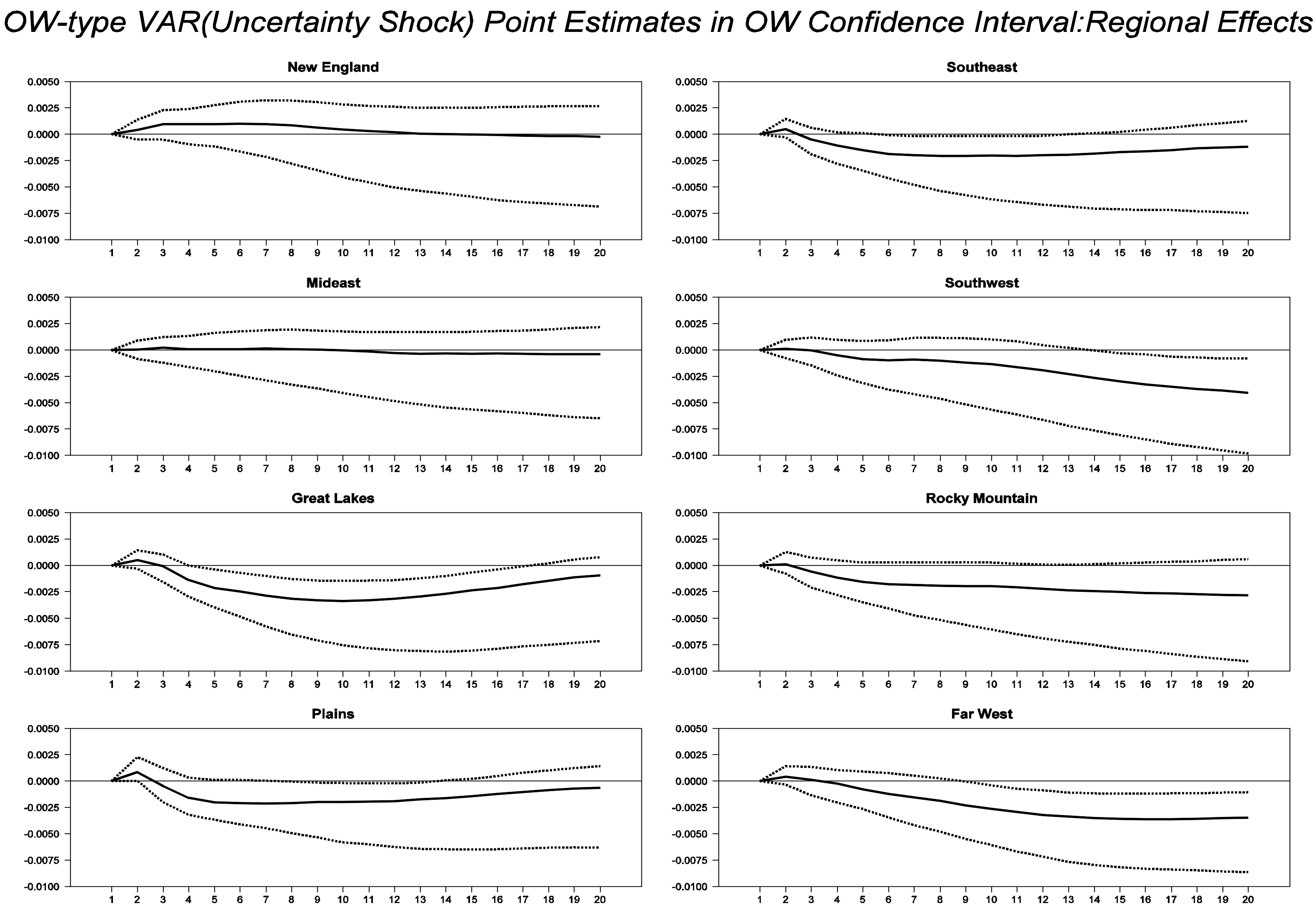


Figure 4.12 — OW-Type VAR (Uncertainty Shock) Point Estimates in OW-Type VAR Confidence Interval: Regional Effects

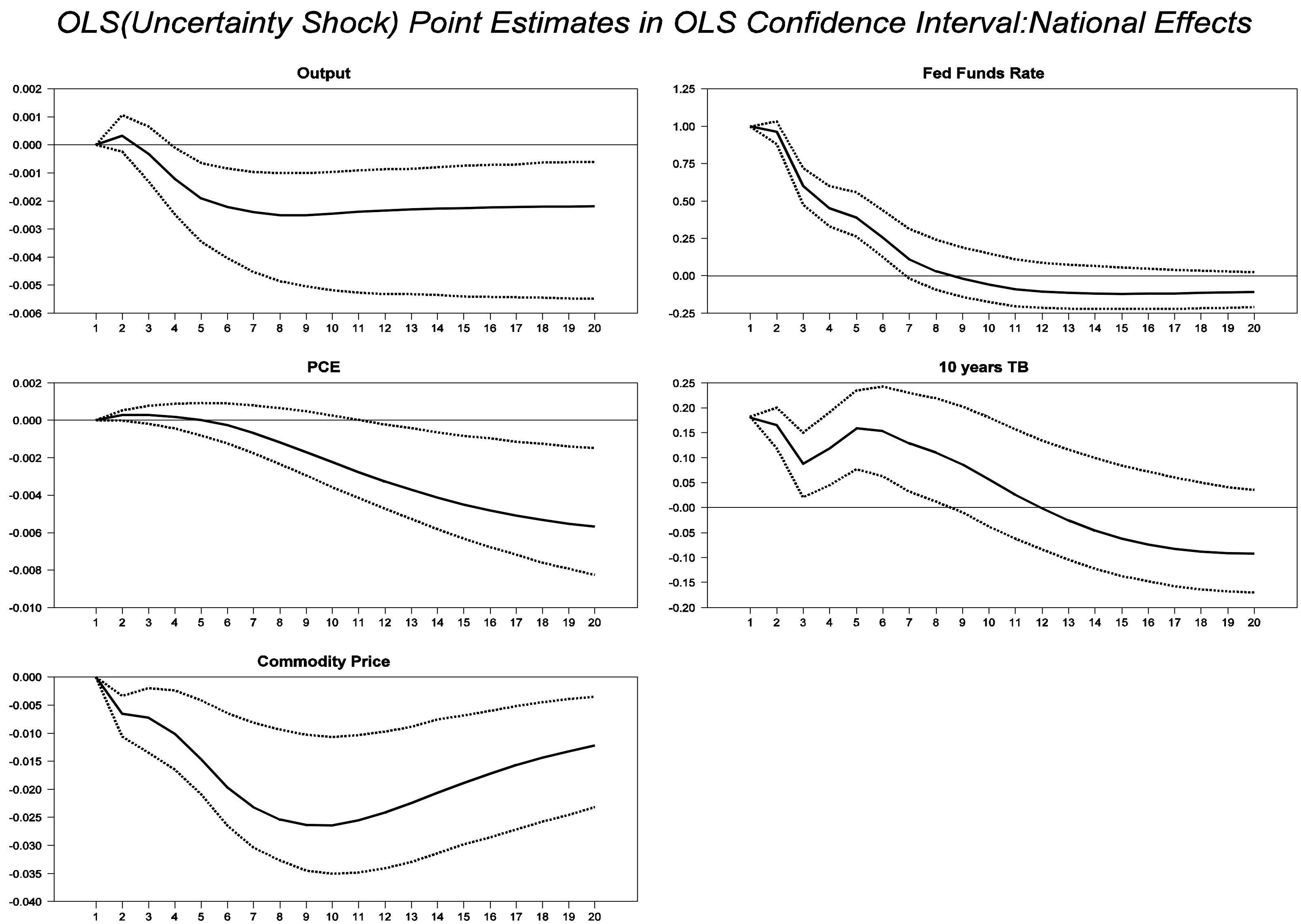


Figure 4.13 — Lastrapes-Type VAR (Uncertainty) Point Estimates in Lastrapes-Type VAR Confidence Interval: National Effects

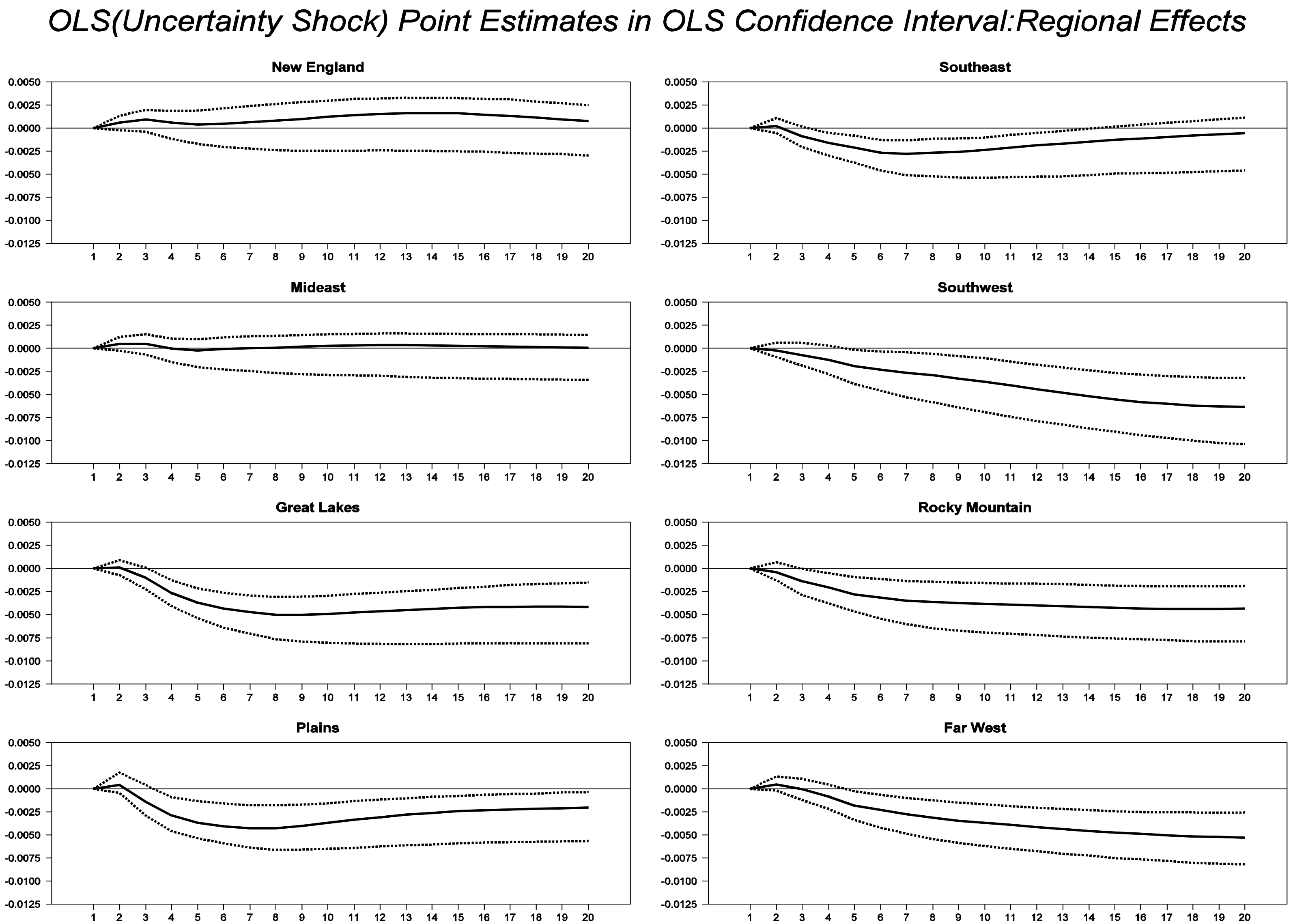


Figure 4.14 — Lastrapes-Type VAR (Uncertainty) Point Estimates in Lastrapes-Type VAR Confidence Interval: Regional Effects

Bloom (2009) constructs three alternative measures of exogenous volatility shocks. First, the main stock-market volatility indicator is constructed to take a value of 1 for the month of maximum volatility for the 17 shocks and a 0 otherwise. A second alternative is a dummy variable that equals 1 in the month of first volatility for the 17 shocks and a 0 in other months. The third alternative is a dummy variable takes a value of 1 in month of maximum volatility for terror, war & oil shocks (10 shocks) and a 0 in other months. Since the results from models that include each of these three measures are similar, we report results from only the model that includes the first dummy. This uncertainty dummy variable is added along with the HP oil shock dummy as an exogenous variable with three lags in each equation of the model. We then check to see if the regional effects of monetary policy are changed when we include the uncertainty shock in the models.

4.3.1 Eight BEA Regions Case

4.3.1.1 OW-Type Restricted VAR Model

We calculate the point estimates from OW-type VAR with the uncertainty shock and then plot these point estimates along with the confidence intervals from the OW-type VAR without the uncertainty shock. Figure 4.11 and Figure 4.12 report these results. In Figure 4.11, we see all macro variables estimates stay well inside the confidence intervals from the OW-type VAR without the uncertainty shock. In Figure 4.12, all eight regions of point estimates remain well inside the confidence intervals from the OW-type VAR without the uncertainty shock.

4.3.1.2 Lastrapes-Type Restricted VAR Model

We can calculate the point estimates from Lastrapes-type VAR with uncertainty shock and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR without the uncertainty shock. Figure 4.13 and Figure 4.14 show these results. From Figure 4.13, we see all macro variables of point estimates stay well inside the confidence intervals from

the Lastrapes-type VAR without the uncertainty shock. In Figure 4.14, all eight regions of point estimates remain well inside the confidence intervals from the Lastrapes-type VAR without the uncertainty shock.

4.3.1.3 Border-Effects Restricted VAR Model

We can calculate the point estimates from the border-effects VAR with the uncertainty shock. We then plot these point estimates along with the confidence intervals from the border-effects type VAR without the uncertainty shock. As we can see in Figure 4.16, all point estimates fit inside well in the baseline model's CI at all horizons for all regions except for the New England and the Great Lakes regions. For the New England region, the point estimate hits the upper bounds approximately 19 quarters after the shock and remains slightly outside the confidence intervals thereafter. For the Greak Lakes region, the point estimate hits the upper bounds approximately 15 quarters after the shock and stays slightly outside confidence interval thereafter. In Figure 4.15, the five macro variables point estimates remain inside the confidence intervals from the border-effects type VAR without the uncertainty shock.

4.3.2 Forty Eight Contiguous States Case

4.3.2.1 Lastrapes-Type Restricted VAR Model

We calculate the point estimates from Lastrapes-type VAR (state) with the aggregate uncertainty shock and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR (state) without the uncertainty variable. Figure 4.17 and Figures 4.18.1 through 4.18.8 report these results. As we can see in Figure 4.17, all macro variables point estimates remain well inside the confidence intervals from the Lastrapes-type VAR (state) without the uncertainty variable. In Figure 4.18.1 through 4.18.8, all states' point estimates stay well inside the confidence intervals from the Lastrapes-type VAR (state) without the uncertainty variable.

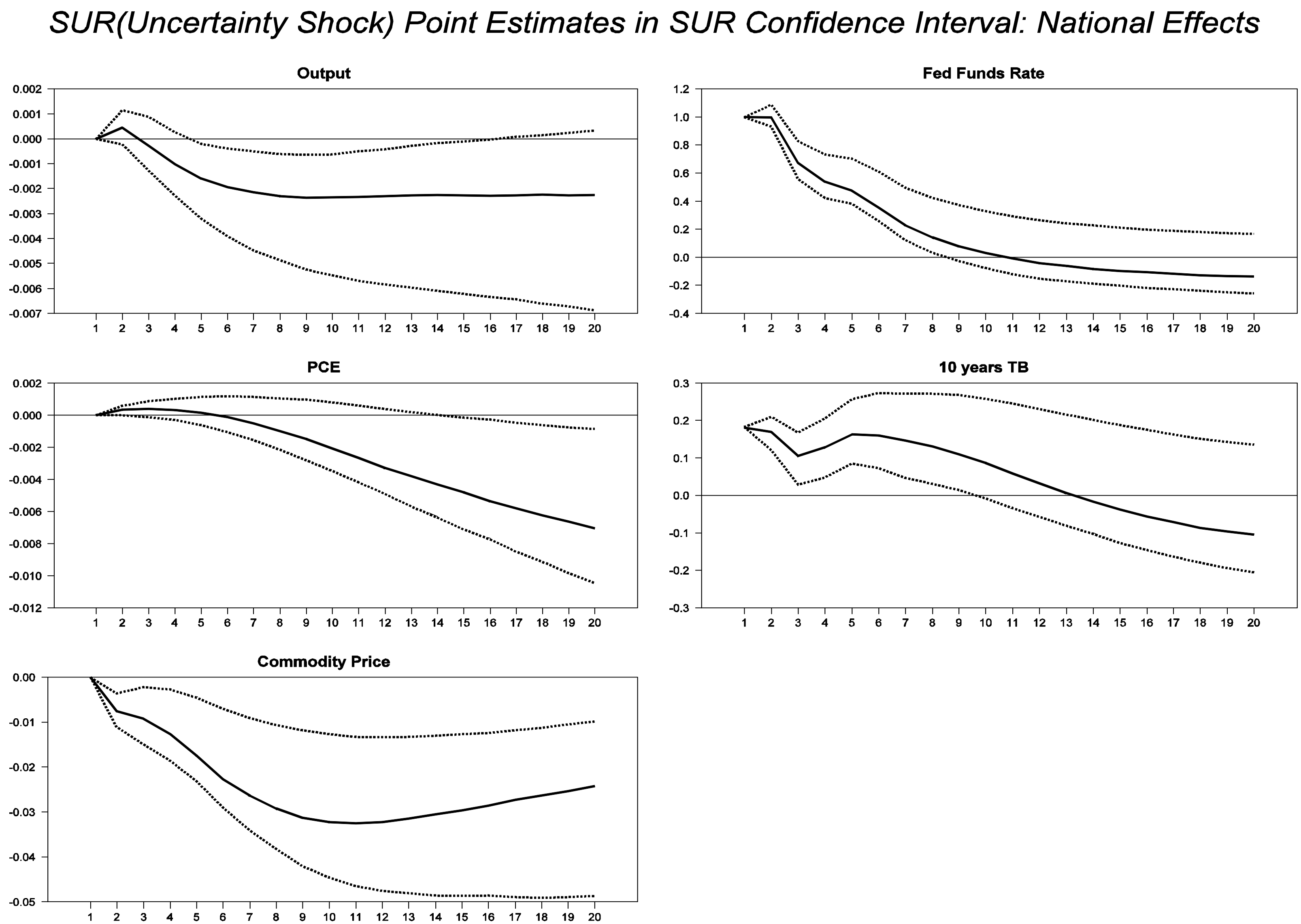


Figure 4.15 — Border-Effects VAR (Uncertainty) Point Estimates in Border-Effects VAR Confidence Interval: National Effects

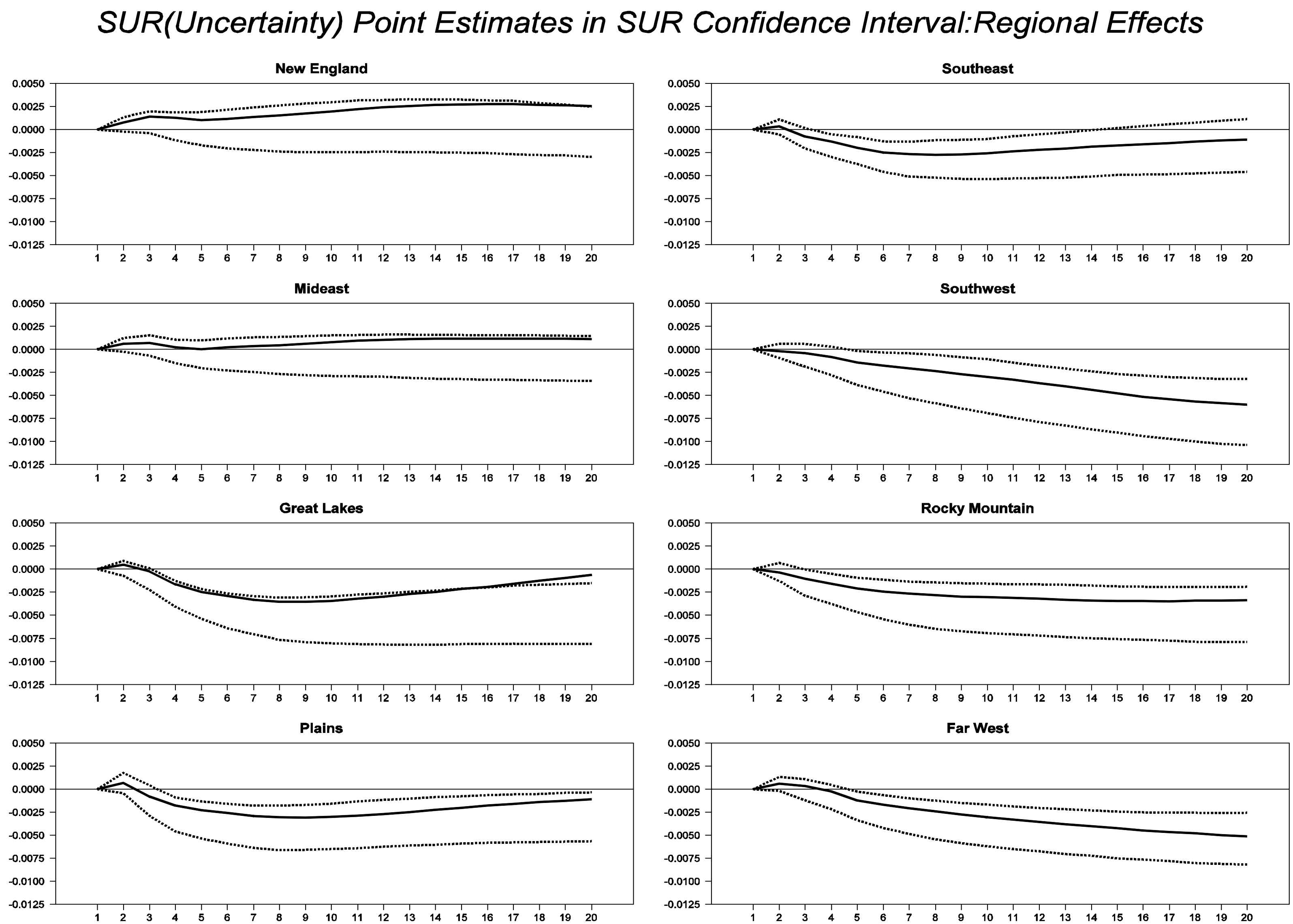


Figure 4.16 — Border-Effects VAR (Uncertainty) Point Estimates in Border-Effects VAR Confidence Interval: Regional Effects

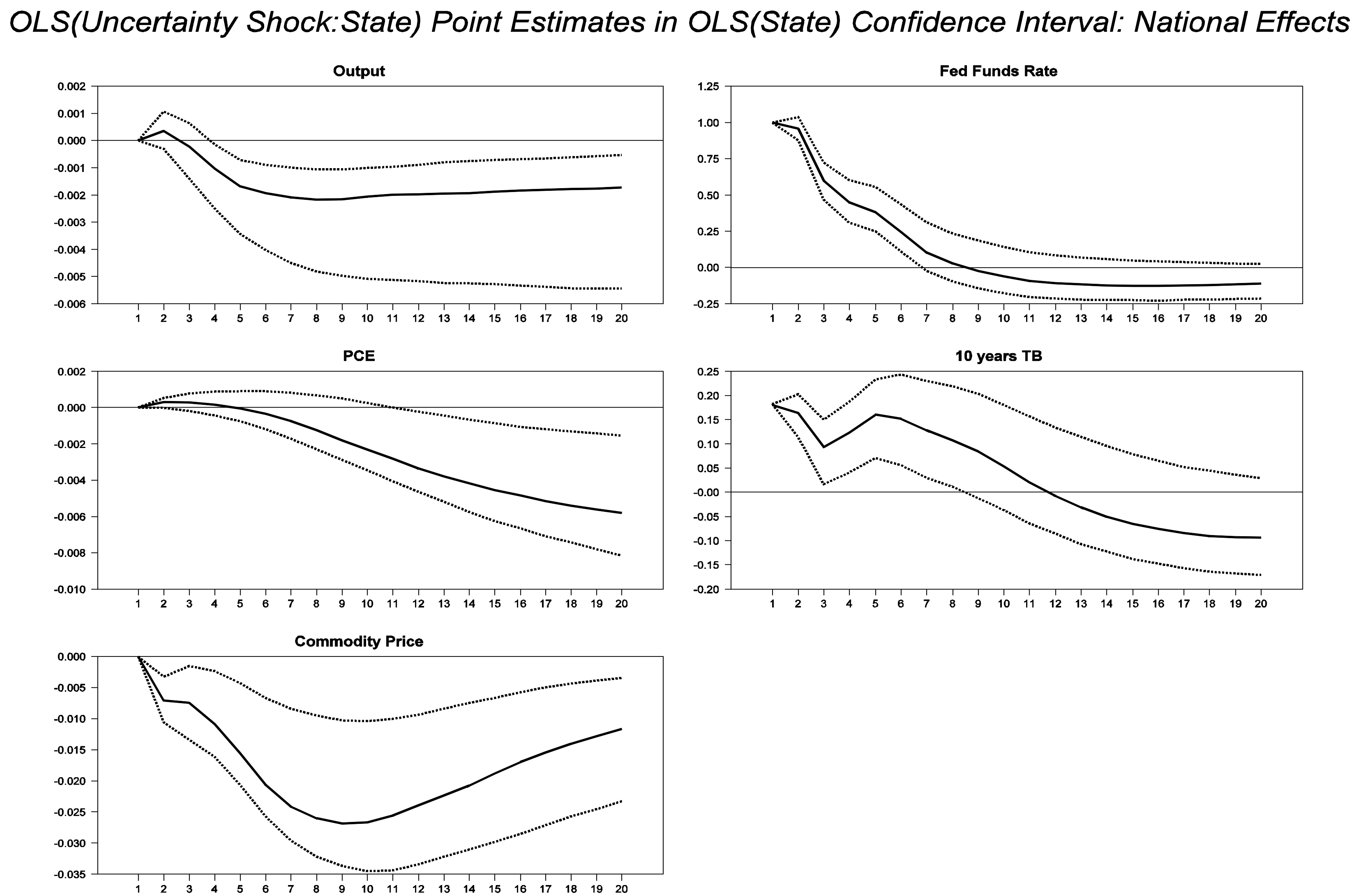


Figure 4.17 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– National Effects

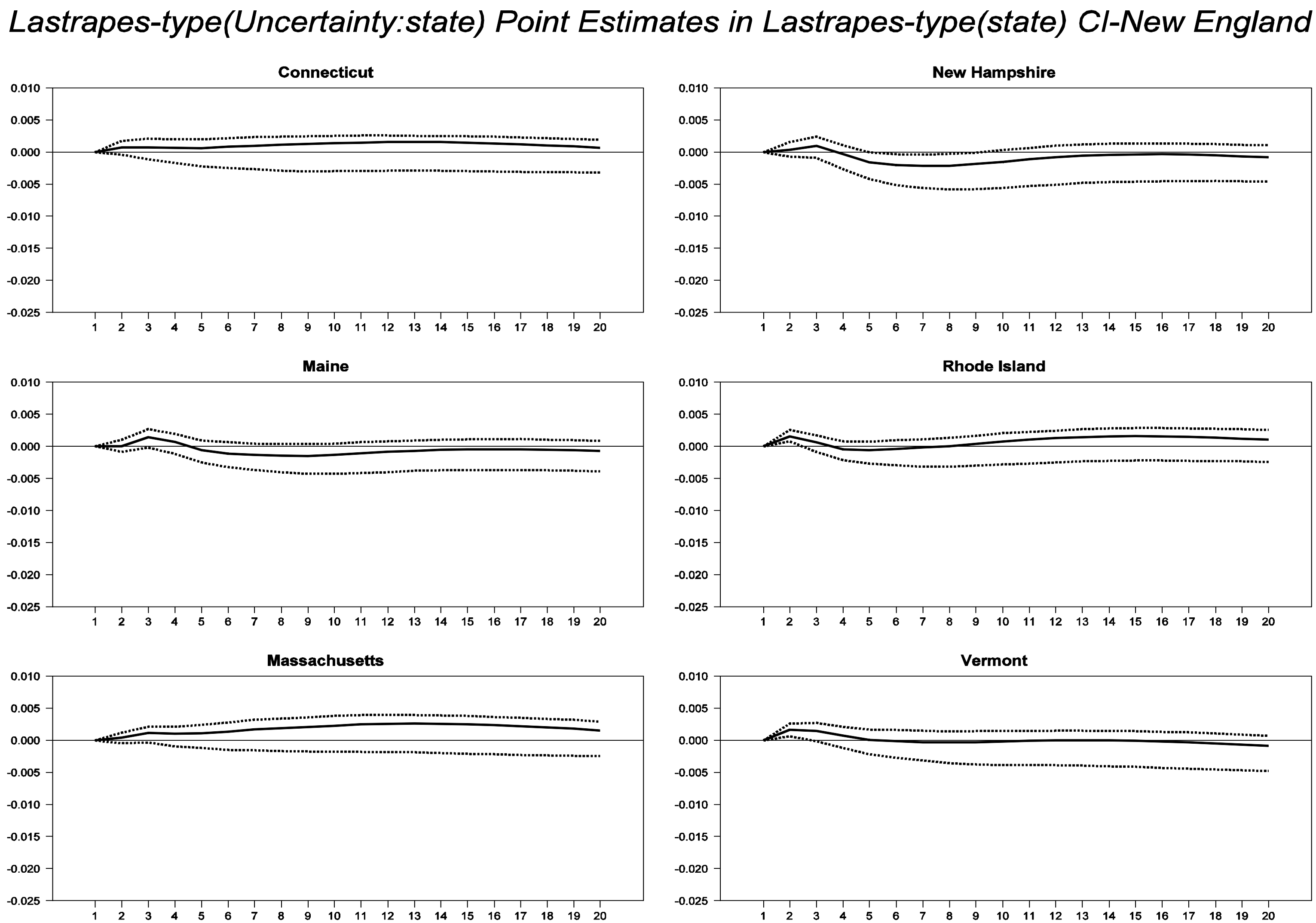


Figure 4.18.1 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– New England

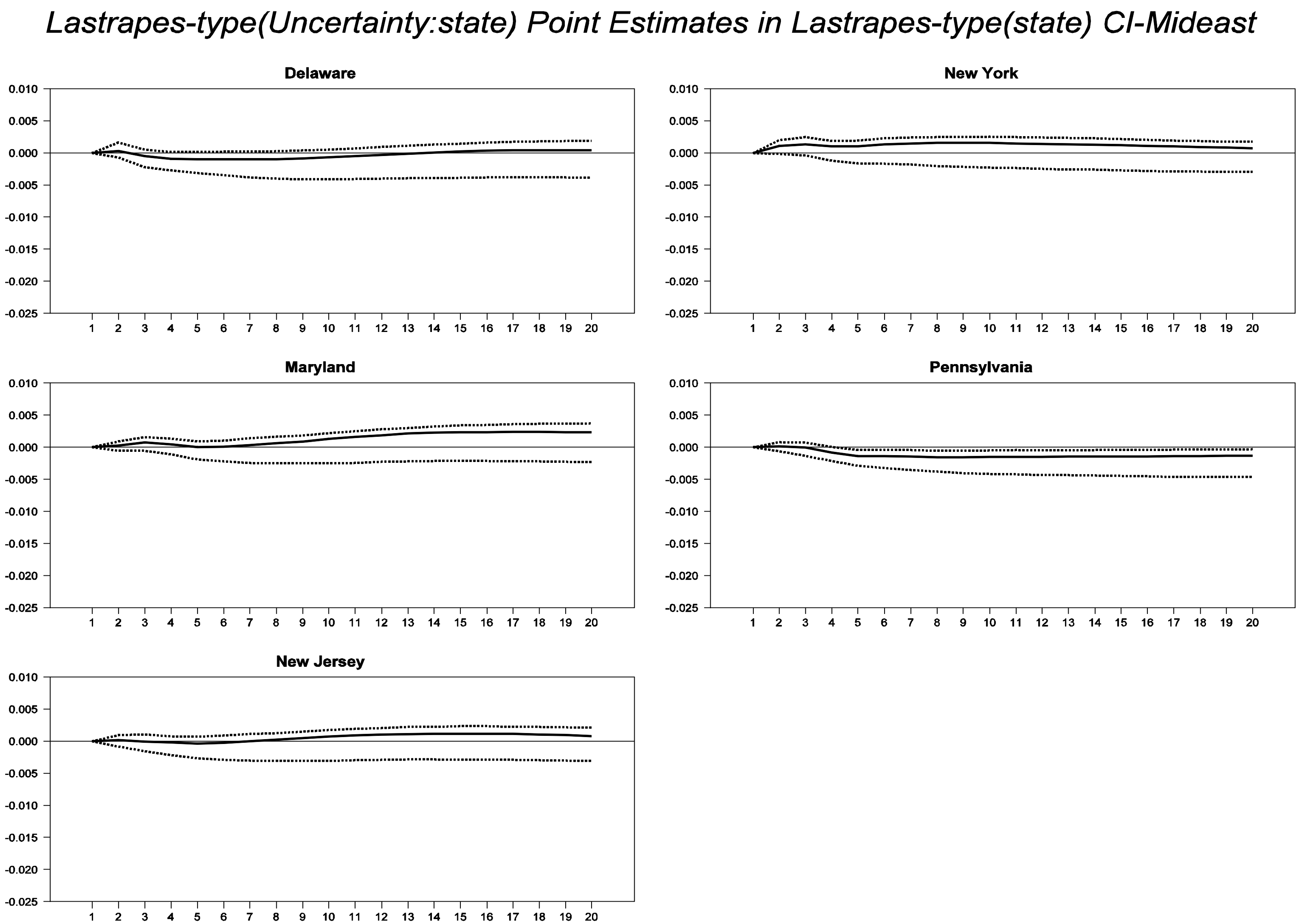


Figure 4.18.2 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Mideast

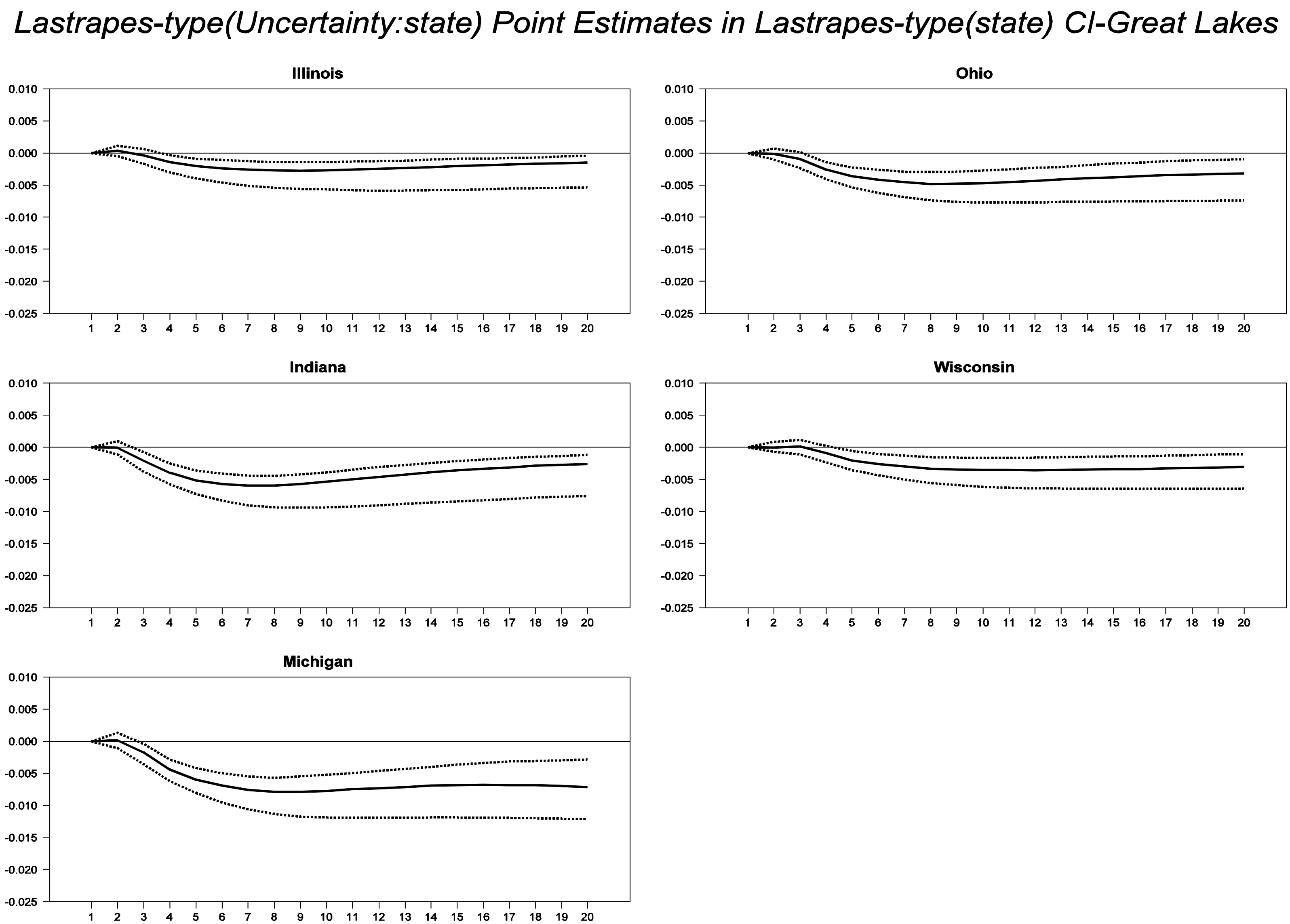


Figure 4.18.3 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Great Lakes

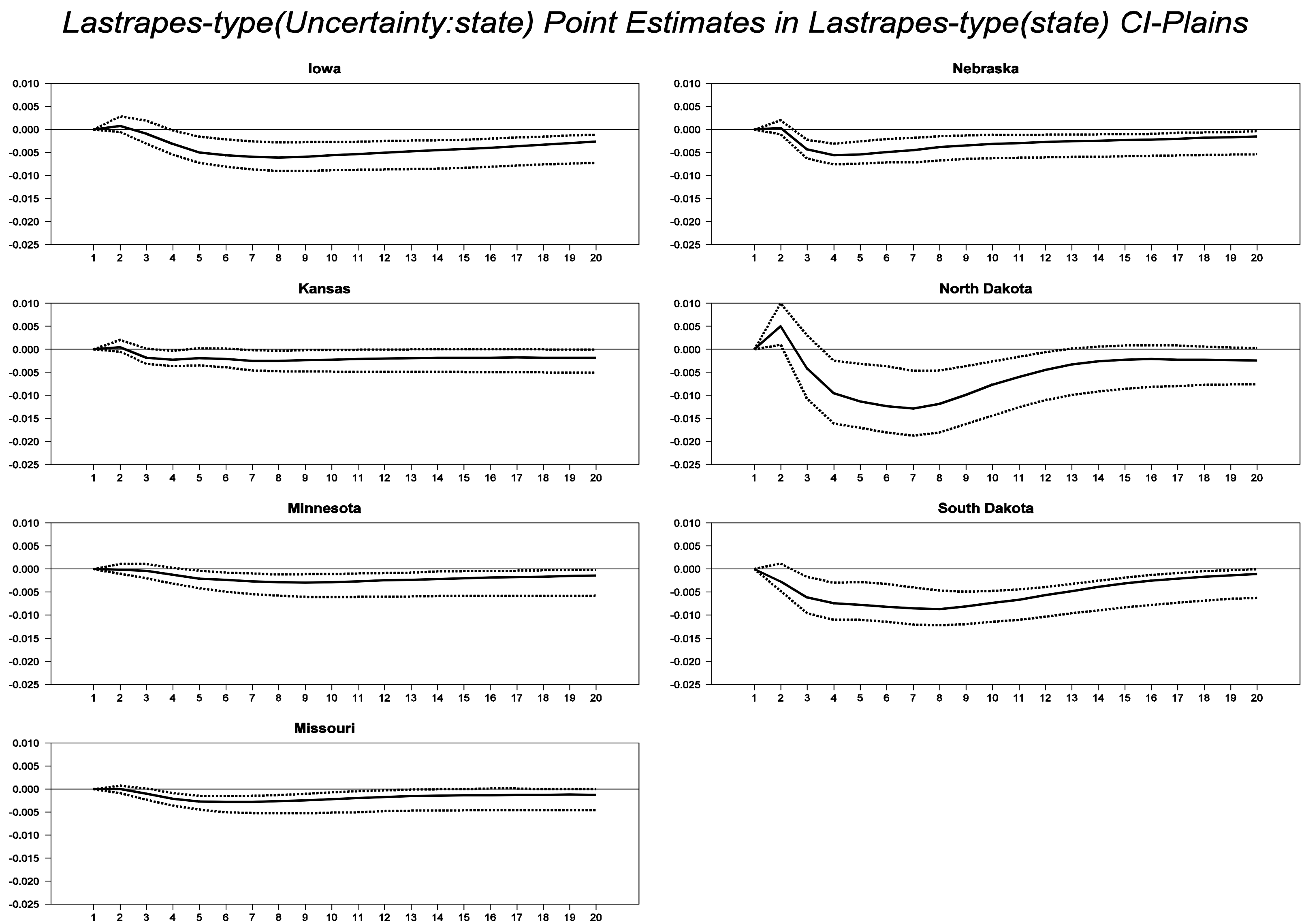


Figure 4.18.4 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Plains

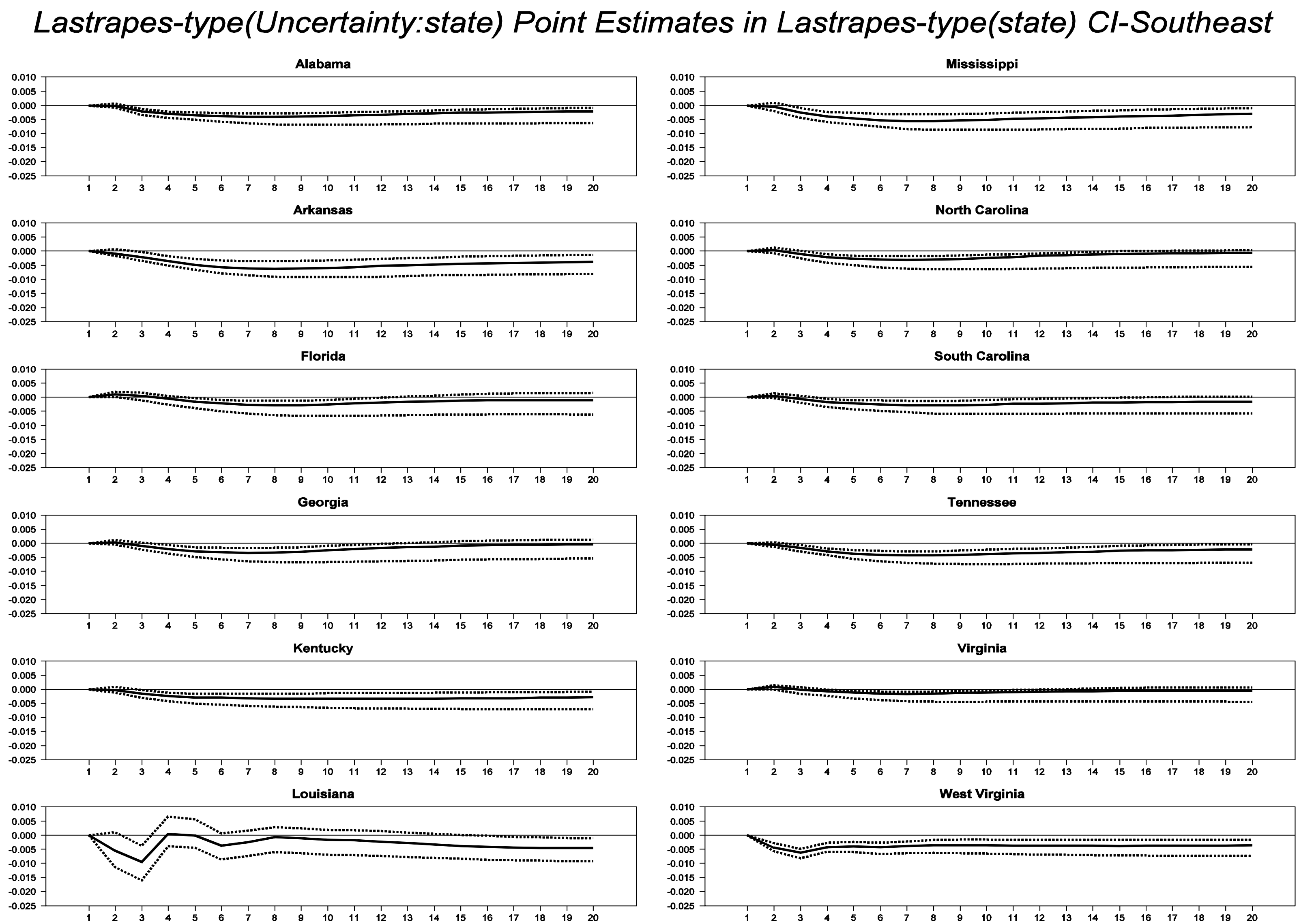


Figure 4.18.5 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Southeast

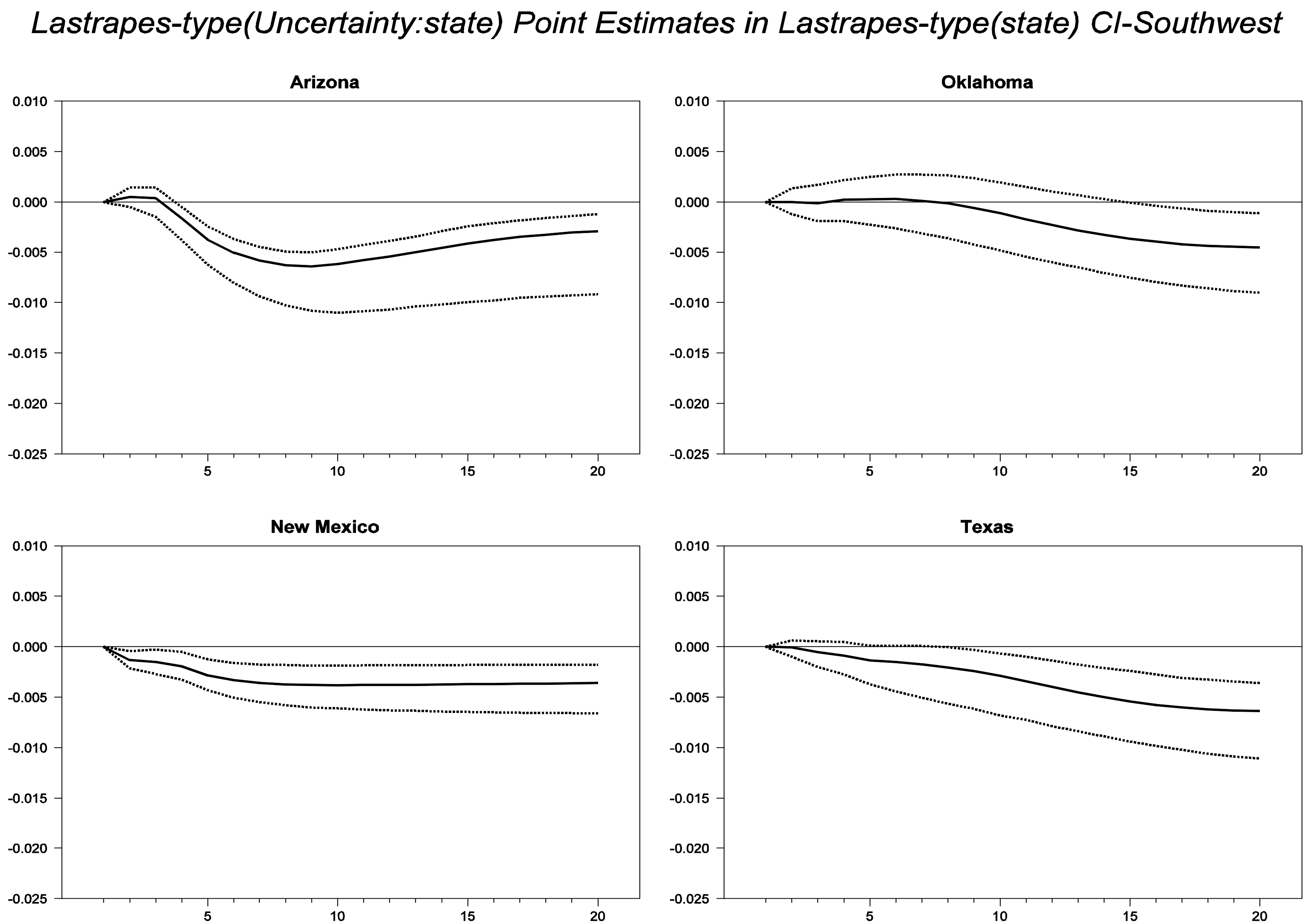


Figure 4.18.6 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Southwest

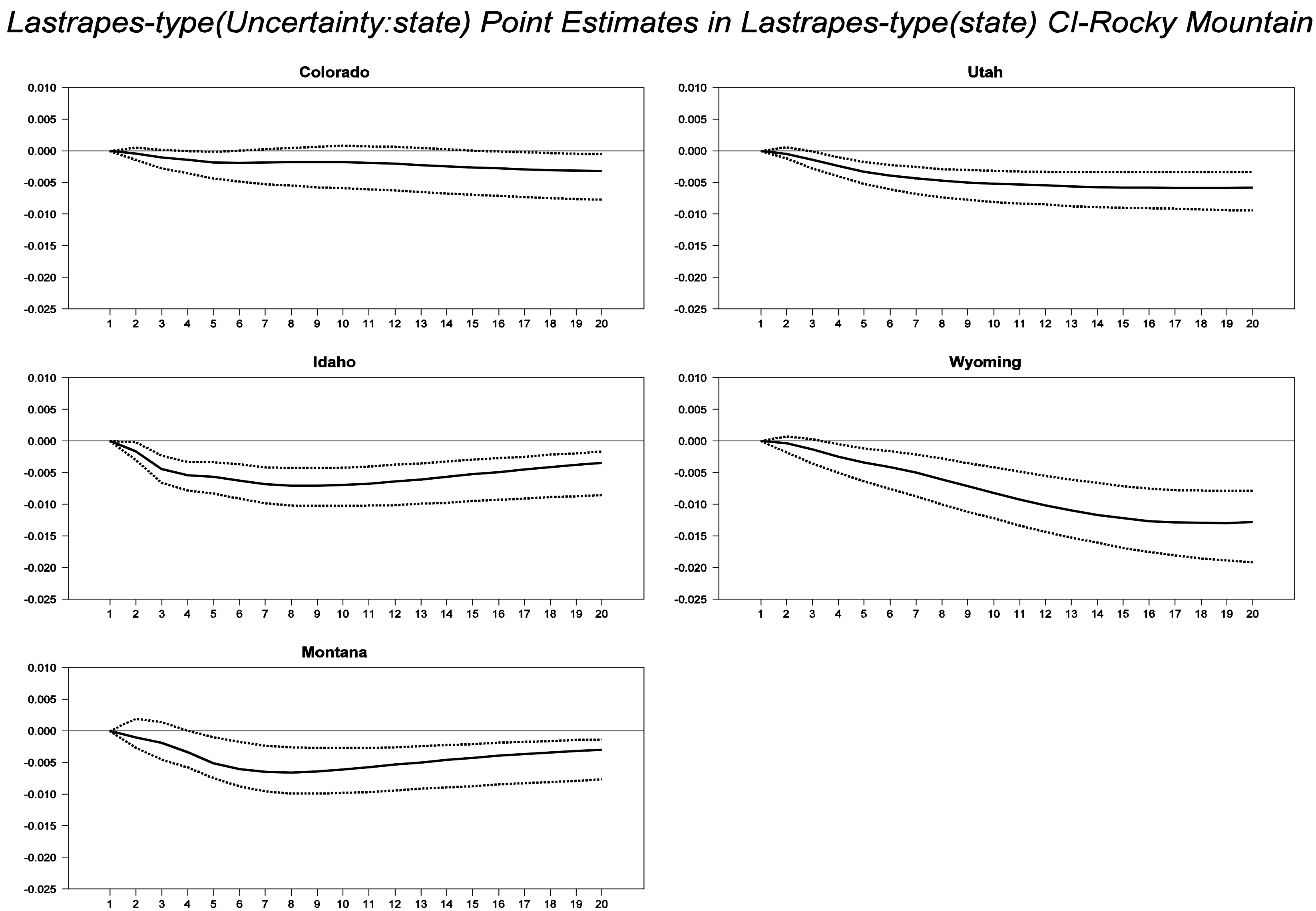


Figure 4.18.7 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Rocky Mountain

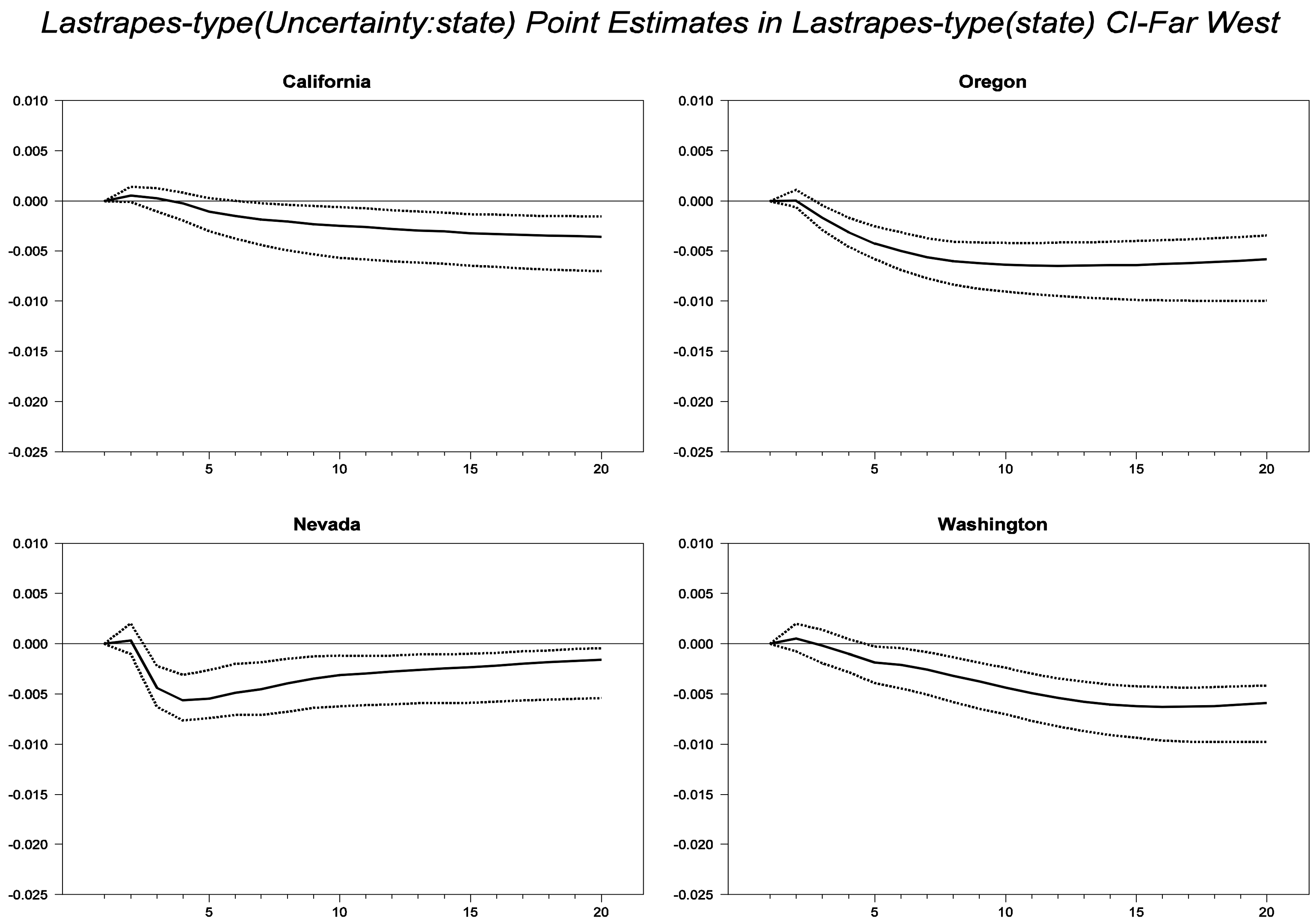


Figure 4.18.8 — Lastrapes-Type VAR (Uncertainty: State) in Lastrapes-Type VAR (State) Confidence Interval– Far West

4.3.2.2 Border-Effects Resticted VAR Model

We can get the point estimates from border-effects VAR (state) that includes the uncertainty shock and then plot these point estimates along with the confidence intervals from then border-effects VAR (state) without the uncertainty shock. Figure 4.19 and Figures 4.20.1 through 4.20.8 report these results. In Figure 4.19, In all figures, all 48 states of point estimates are inside the confidence intervals from the border-effects VAR (state) without the uncertainty shock.

4.4 Real GDP

In the previous chapters, following the earlier studies, we used real personal income to measure national economy activity. However real GDP is a much better measure of national output than national personal income and is the variable focused on by the Fed. Consequently, for the Lastrapes-type and border-effects VARs, we replace national PI with real GDP to examine the regional effects of monetary policy. We continue to use regional PI since there are no quarterly measures of regional or state-level GDP. It does not matter that we are mixing real GDP with regional PI: the key to the identification procedure in our model is that the Fed responds to national output rather than to regional or state output. If the Fed responds to real GDP rather than real personal income in setting monetary policy, the previous measures of monetary policy shocks may not be accurate. To test the robustness of the earlier results, we check to see if the results change when we use real GDP rather than personal income for measuring national output. In this section, we only consider Lastrapes-type restricted VAR and border-effects VAR model since the OW-type VAR does not include national output.

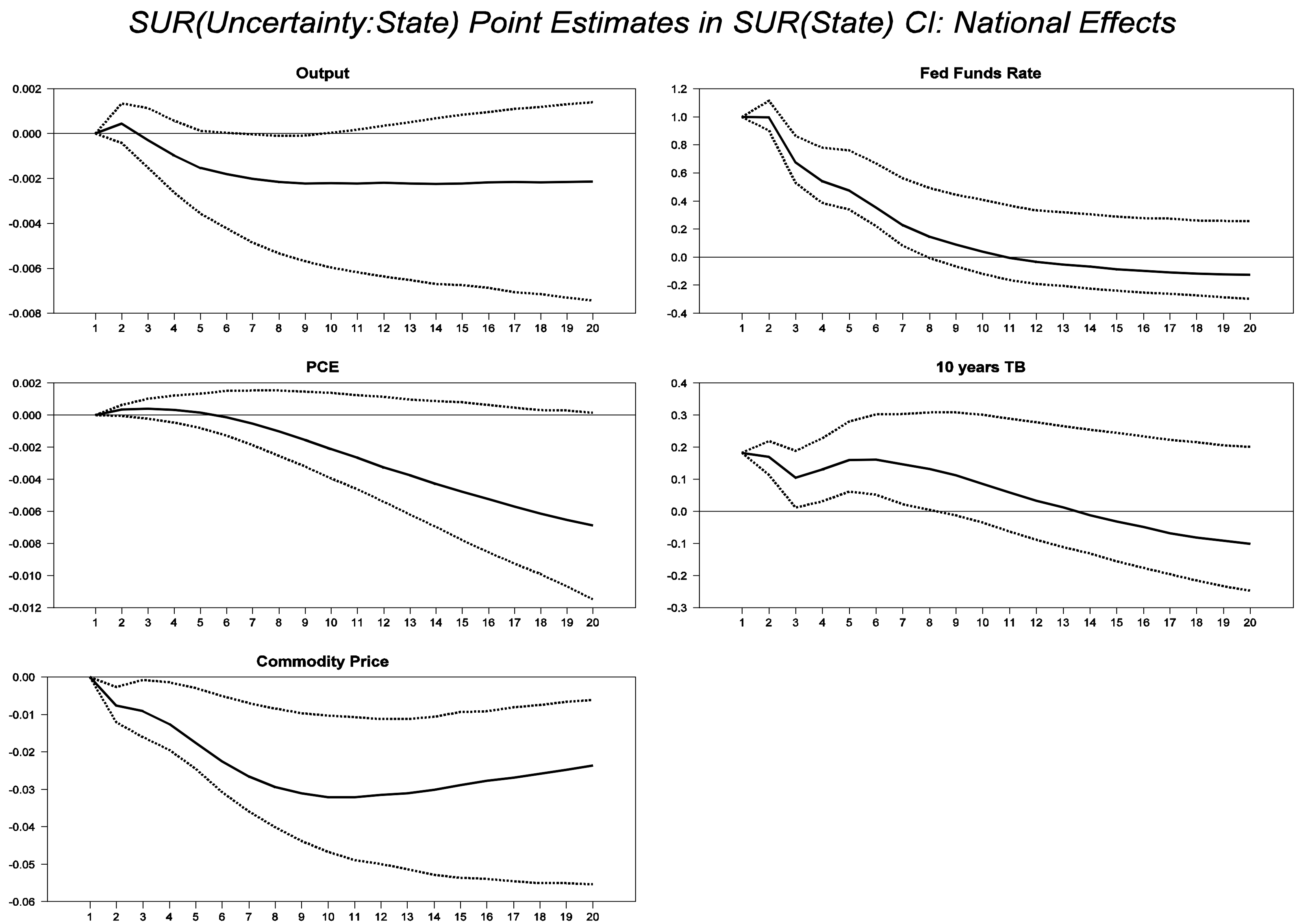


Figure 4.19 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval: National Effects

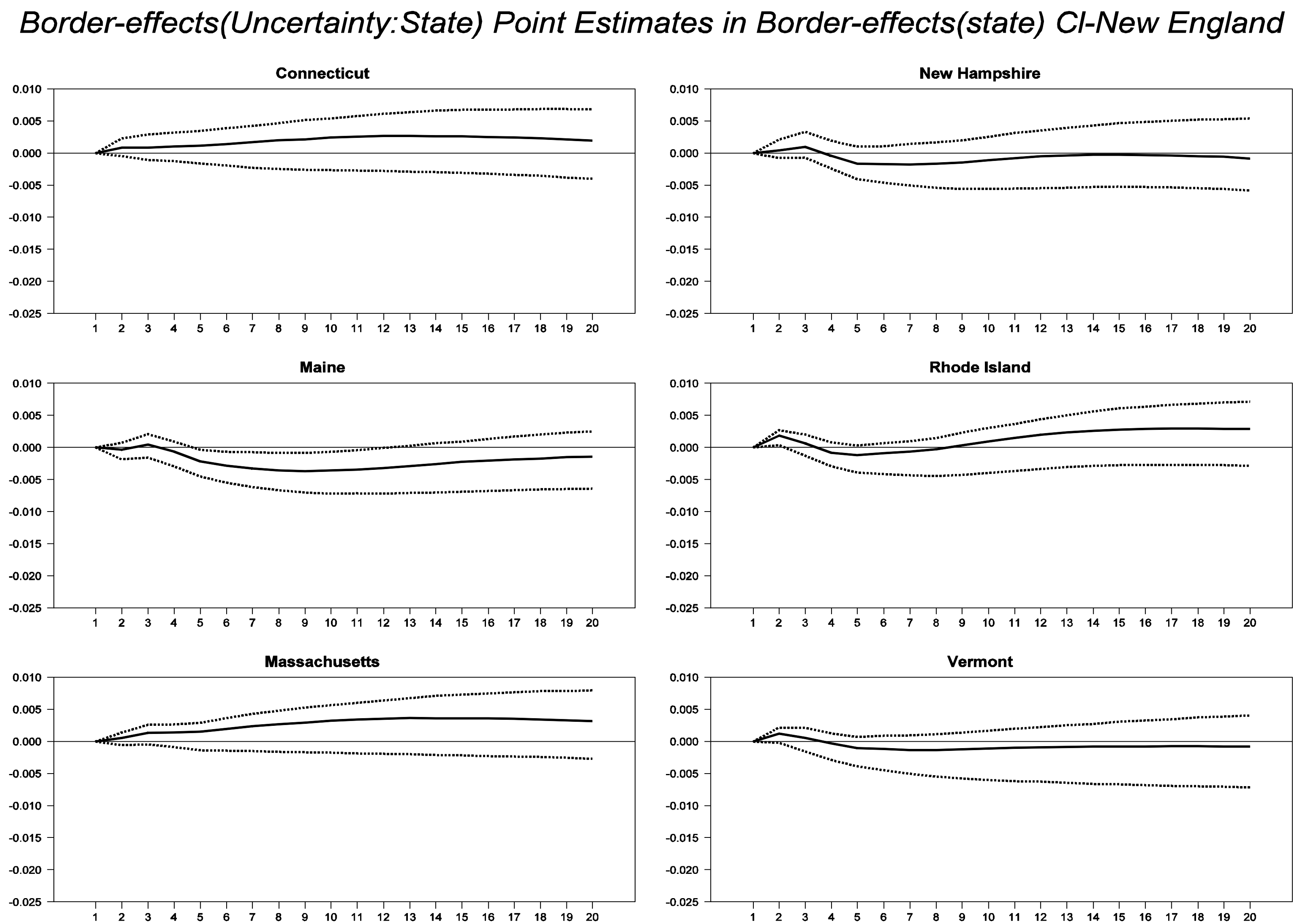


Figure 4.20.1 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– New England

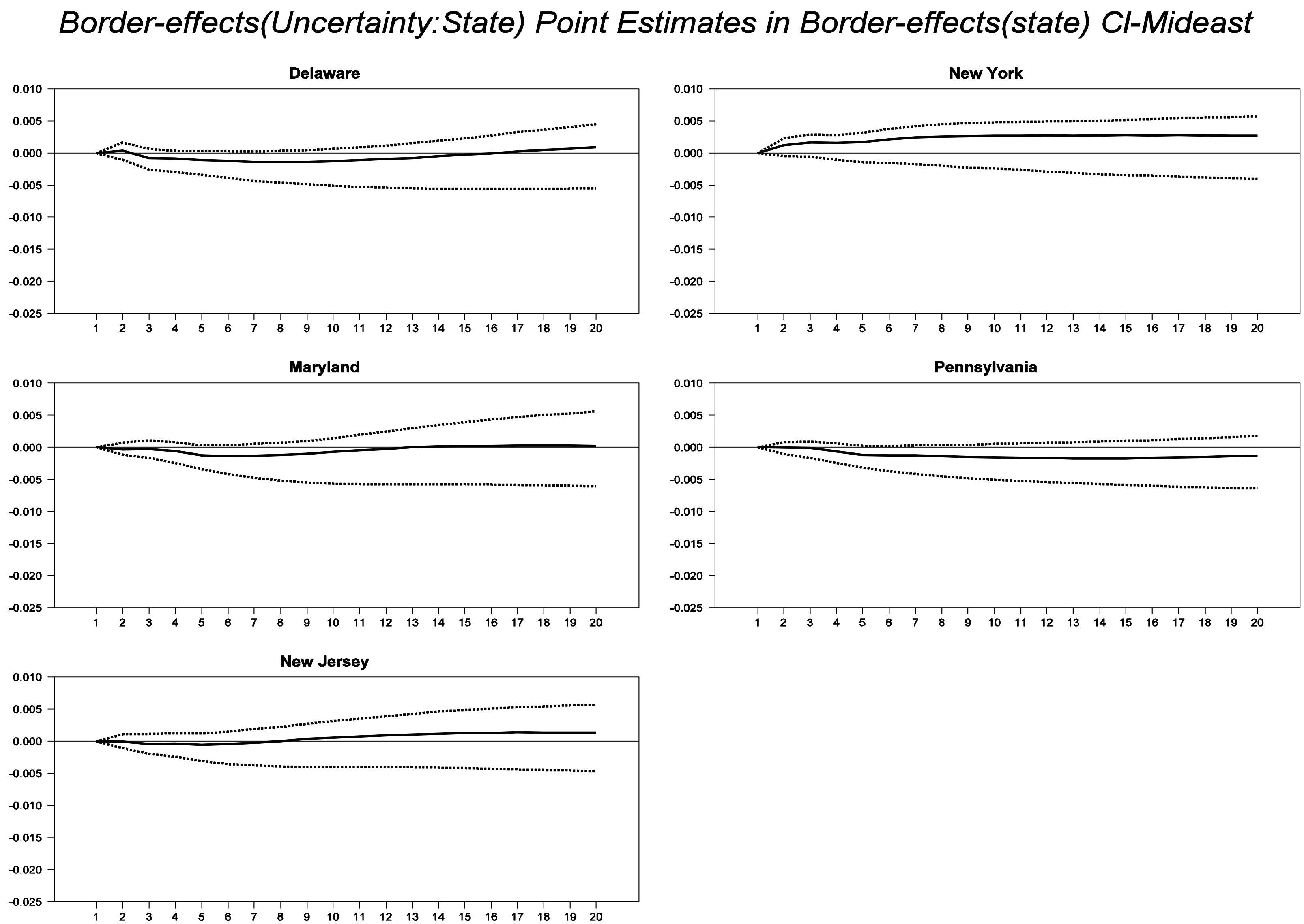


Figure 4.20.2 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Mideast

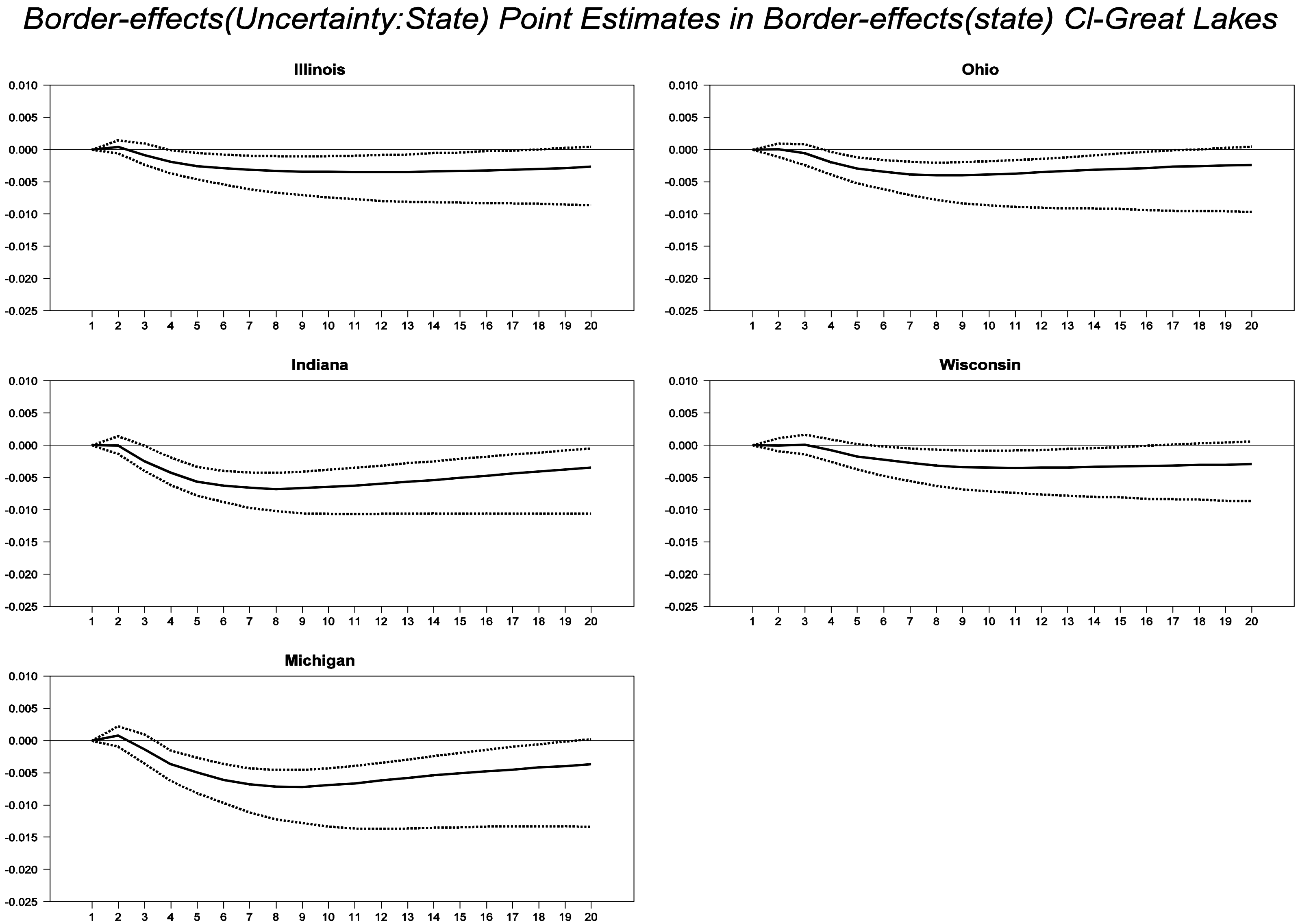


Figure 4.20.3 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Great Lakes

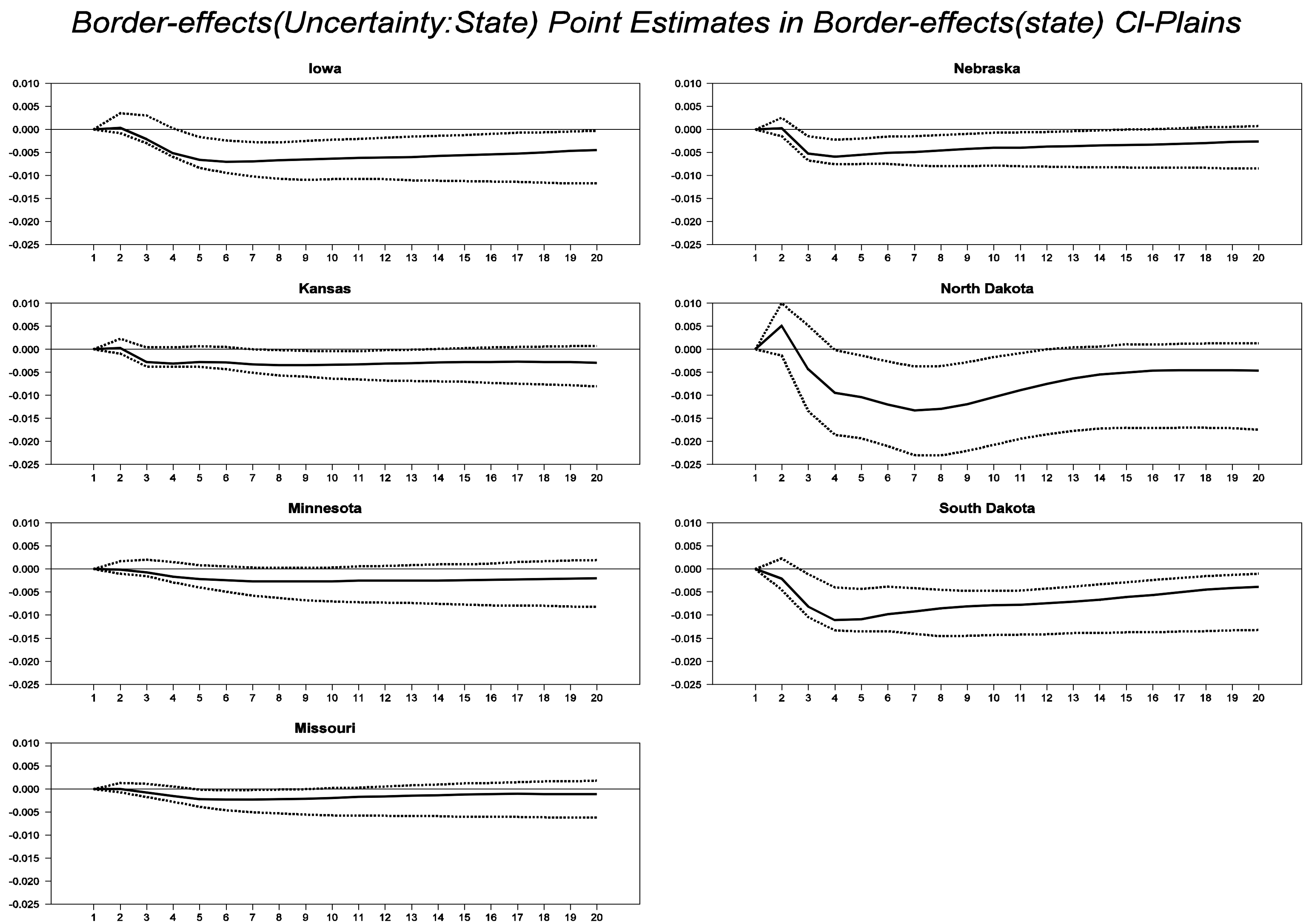


Figure 4.20.4 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Plains

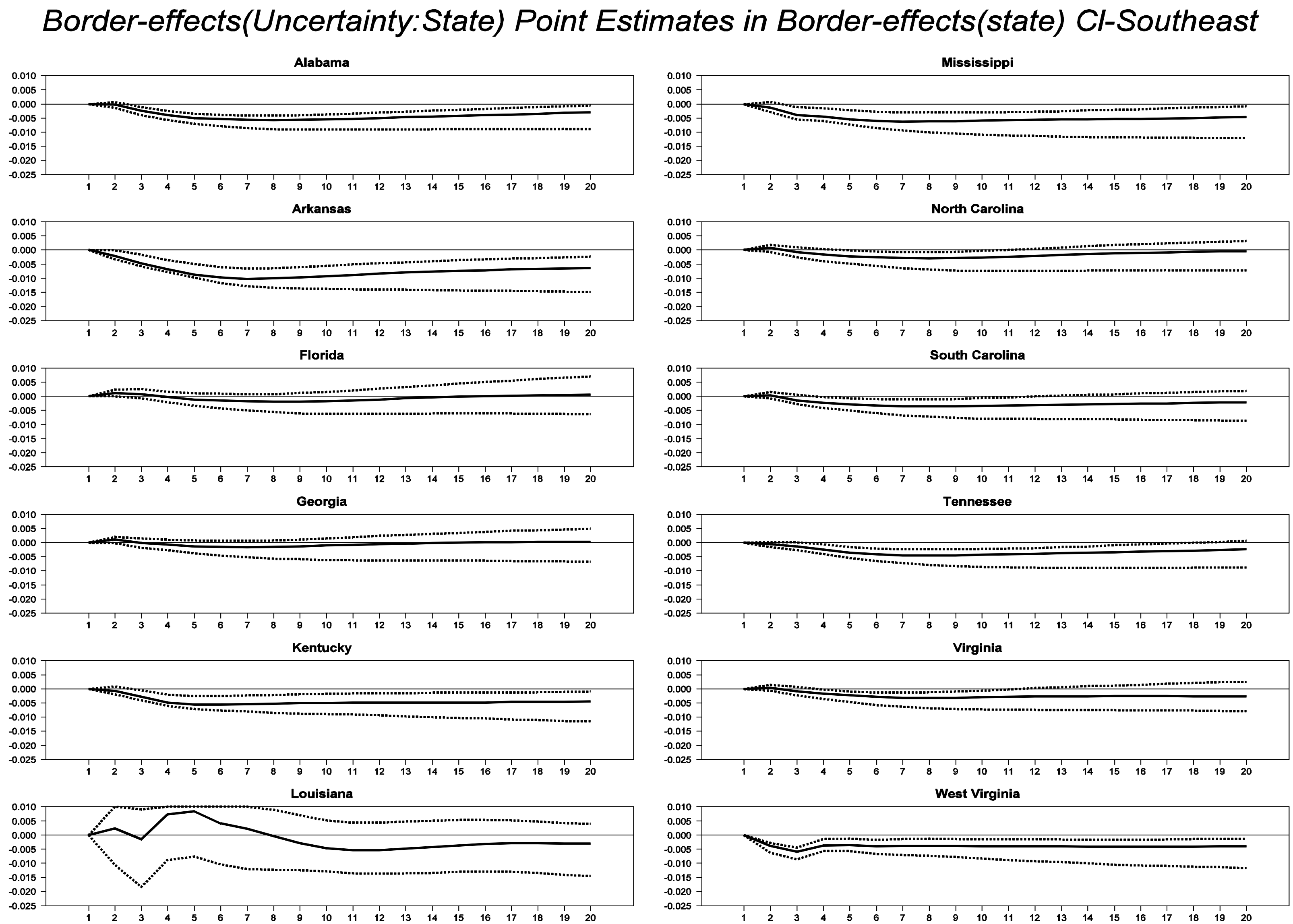


Figure 4.20.5 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Southeast

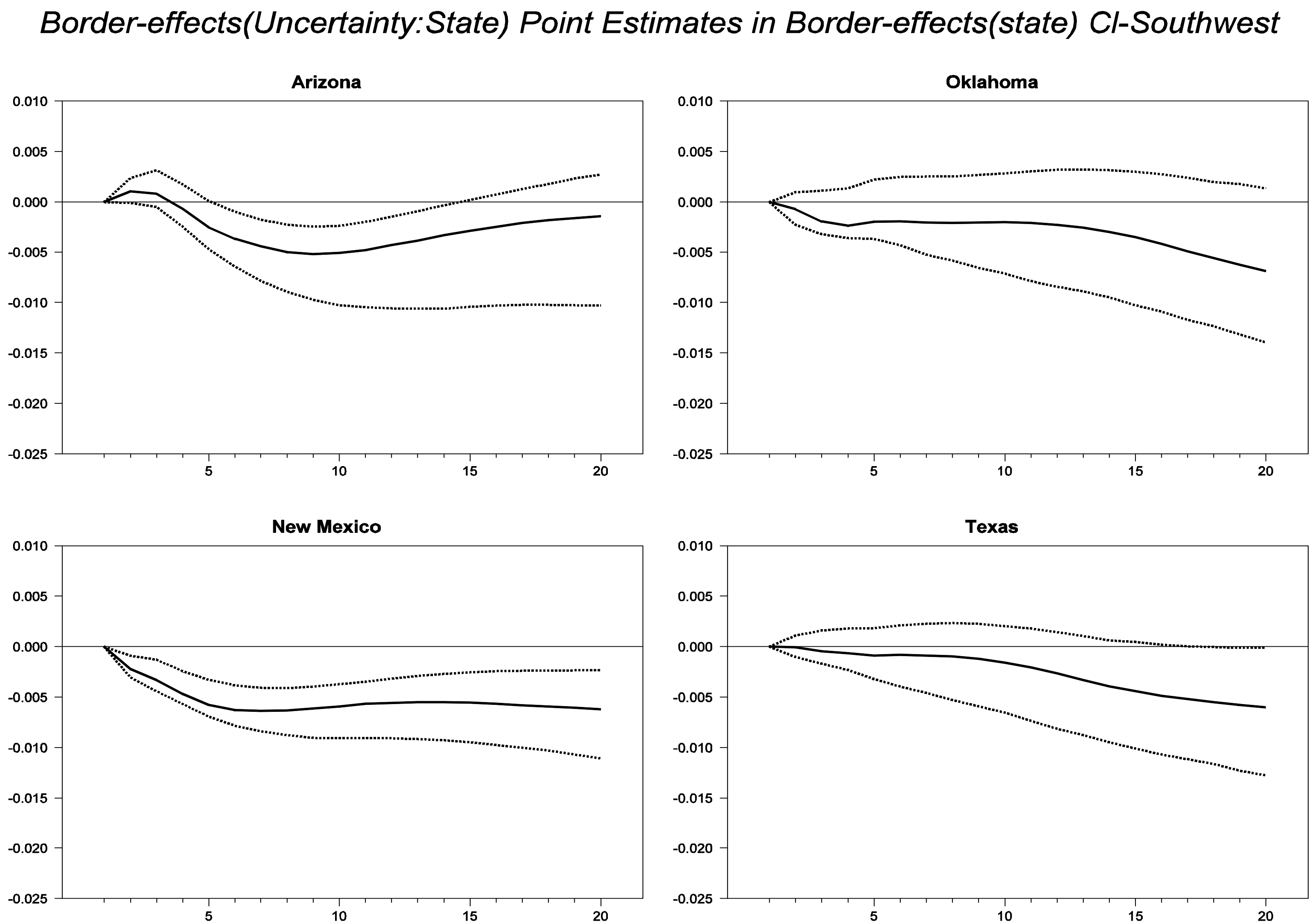


Figure 4.20.6 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Southwest

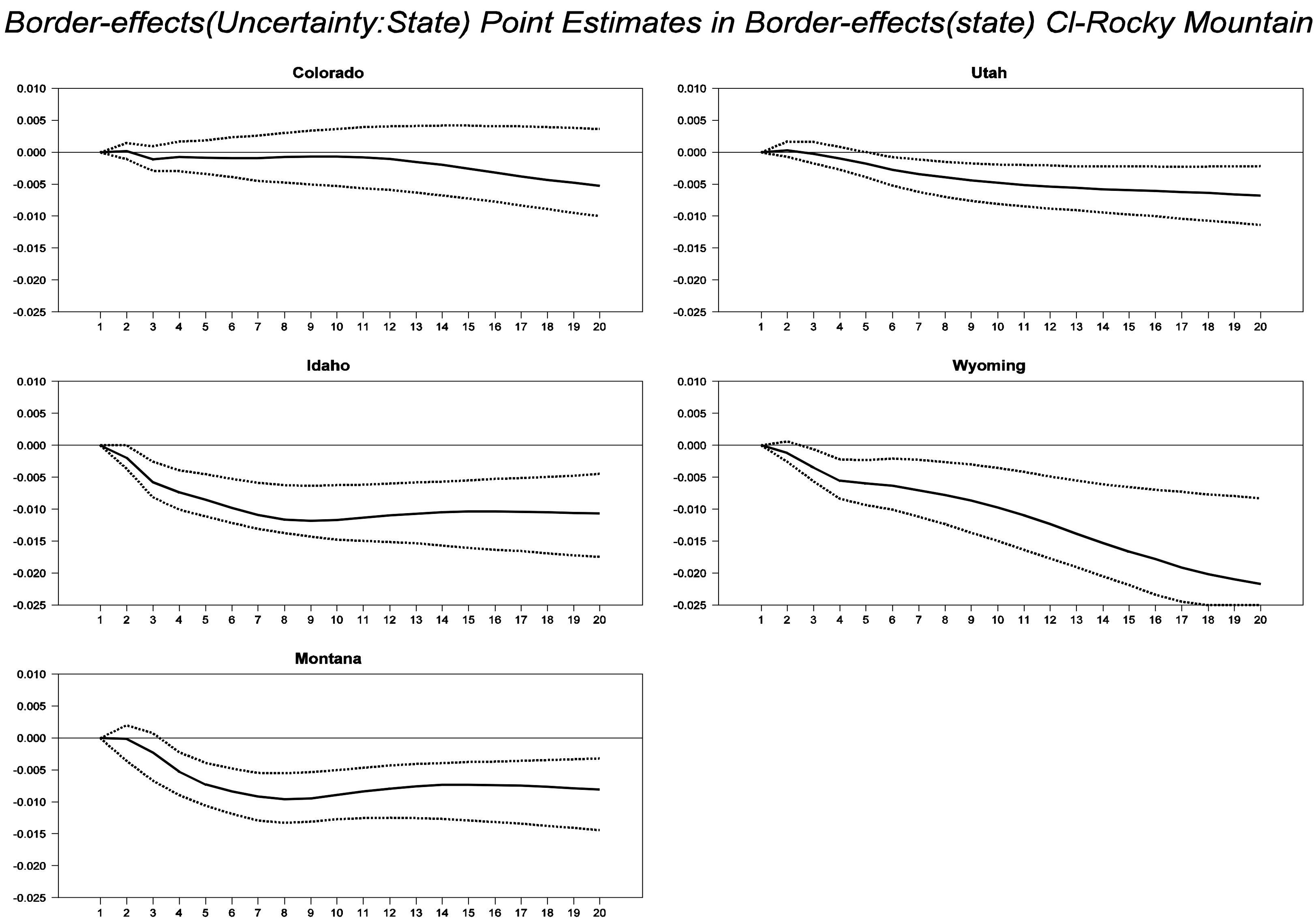


Figure 4.20.7 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Rocky Mountain

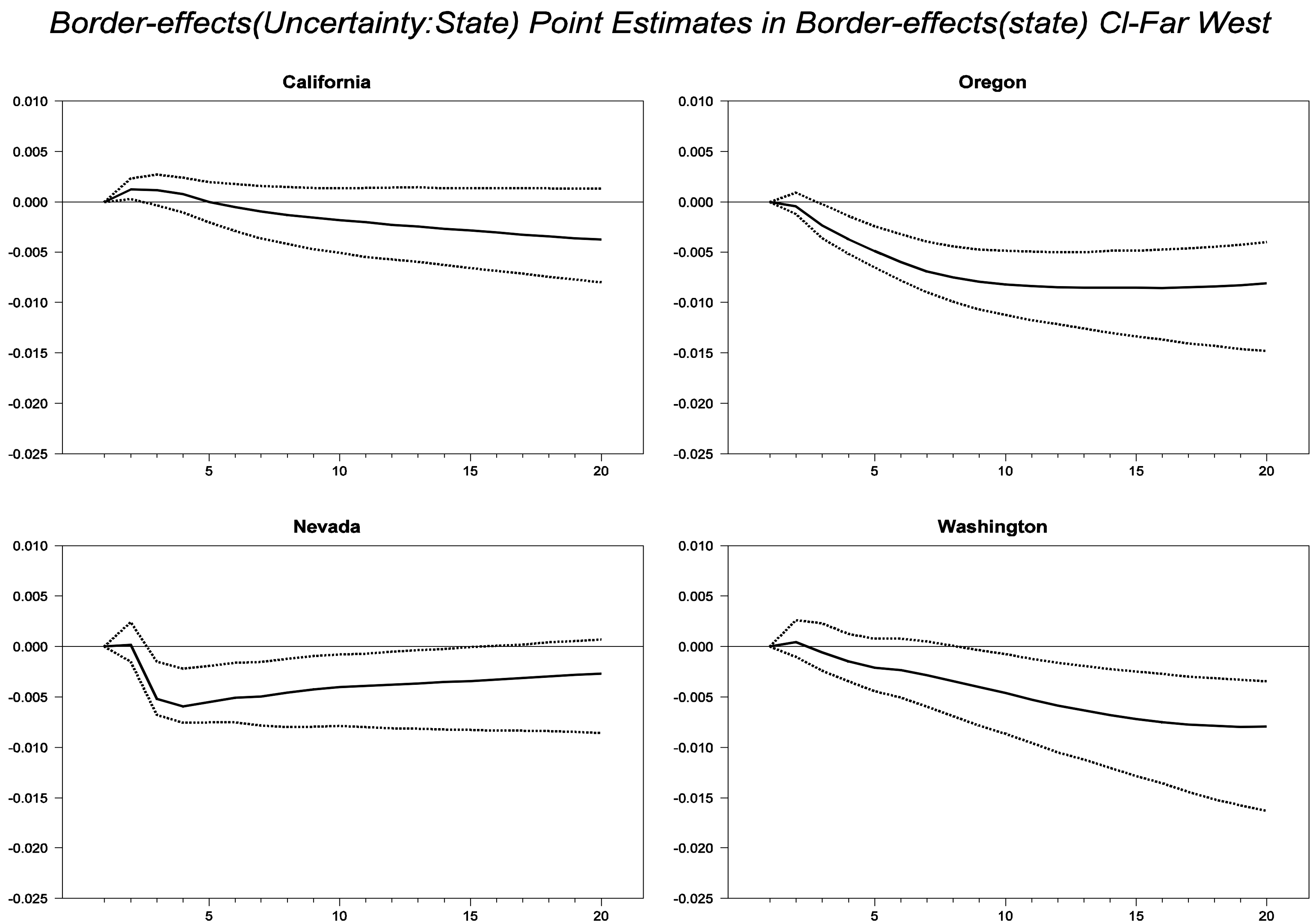


Figure 4.20.8 — Border-Effects VAR (Uncertainty: State) in Border-Effects VAR (State) Confidence Interval– Far West

4.4.1 Eight BEA Regions Case
4.4.1.1 Lastrapes-Type Restricted VAR Model

We obtain the point estimates from Lastrapes-type VAR using real GDP and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR using real personal income. Figure 4.21 and Figure 4.22 represent these results. As we can see in Figure 4.21, all point estimates fit inside well in the baseline model's confidence interval at all horizons except for national output and the 10-year~~s~~ Treasury bond rate. For national output, the point estimate hits the lower bounds approximately 2 quarters after the shock and remains outside the confidence intervals thereafter. For 10-year~~s~~ Treasury bond rate, the point estimate reamins outside the upper bounds approximately 2 quarters after the shock and stays inside confidence interval thereafter. However, as we can see in Figure 4.22, all eight regions of point estimates stays well inside the confidence intervals from the Lastrapes-type VAR using real personal income.

4.4.1.2 Border-Effects Restricted VAR Model

We can calculate the point estimates from the border-effects VAR using real GDP and then plot these point estimates along with the confidence intervals from the border-effects VAR using real PI. Figure 4.23 and Figure 4.24 represent these results. As we can see in Figure 4.23, all point estimates fit inside well in the baseline model's confidence interval at all horizons for all regions except for national output and the 10-year~~s~~ TB rate. For national output, the point estimate hits the lower bounds approximately 2 quarters after the shock and remains outside the confidence intervals thereafter and then it returns to inside the confidence interval 18 quarters after the shock. For the 10-year~~s~~ TB rate, the point estimate reamins outside the upper bounds approximately 2 quarters after the shock and stays inside confidence interval thereafter.

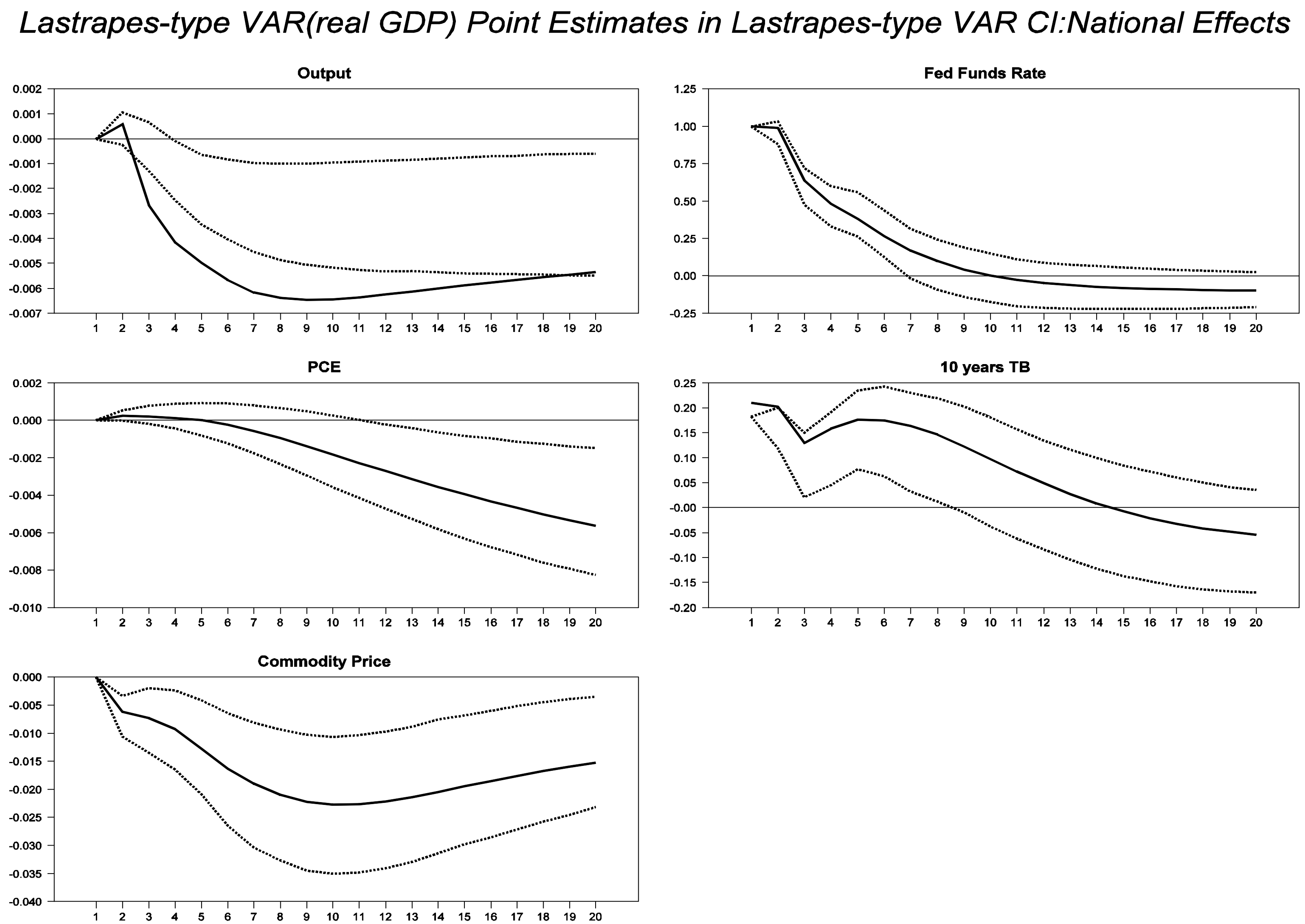


Figure 4.21 — Lastrapes-Type VAR (Real GDP) Point Estimates in Lastrapes-Type VAR Confidence Interval: National Effects

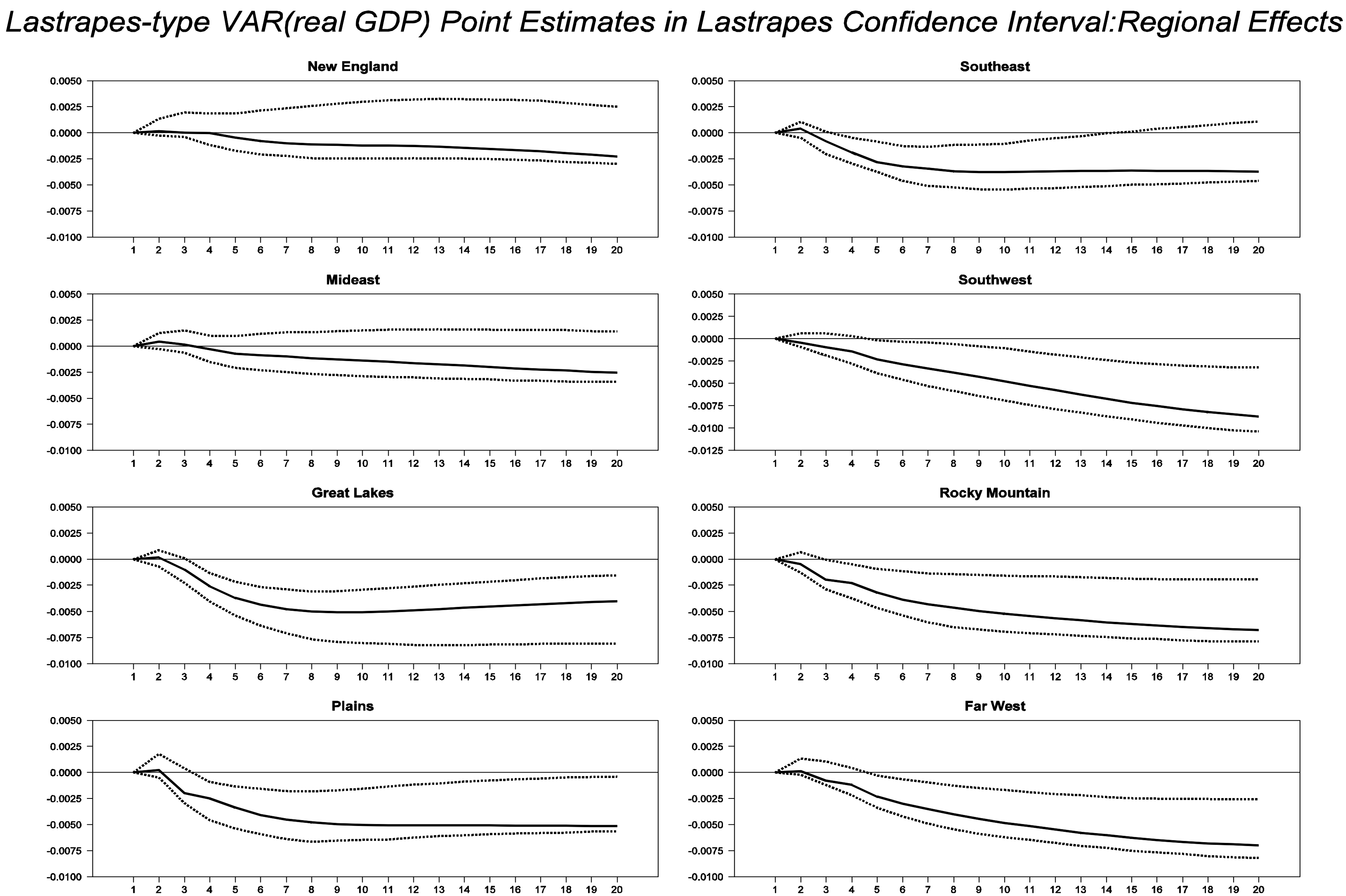


Figure 4.22 — Lastrapes-Type VAR (Real GDP) Point Estimates in Lastrapes-Type VAR Confidence Interval: Regional Effects

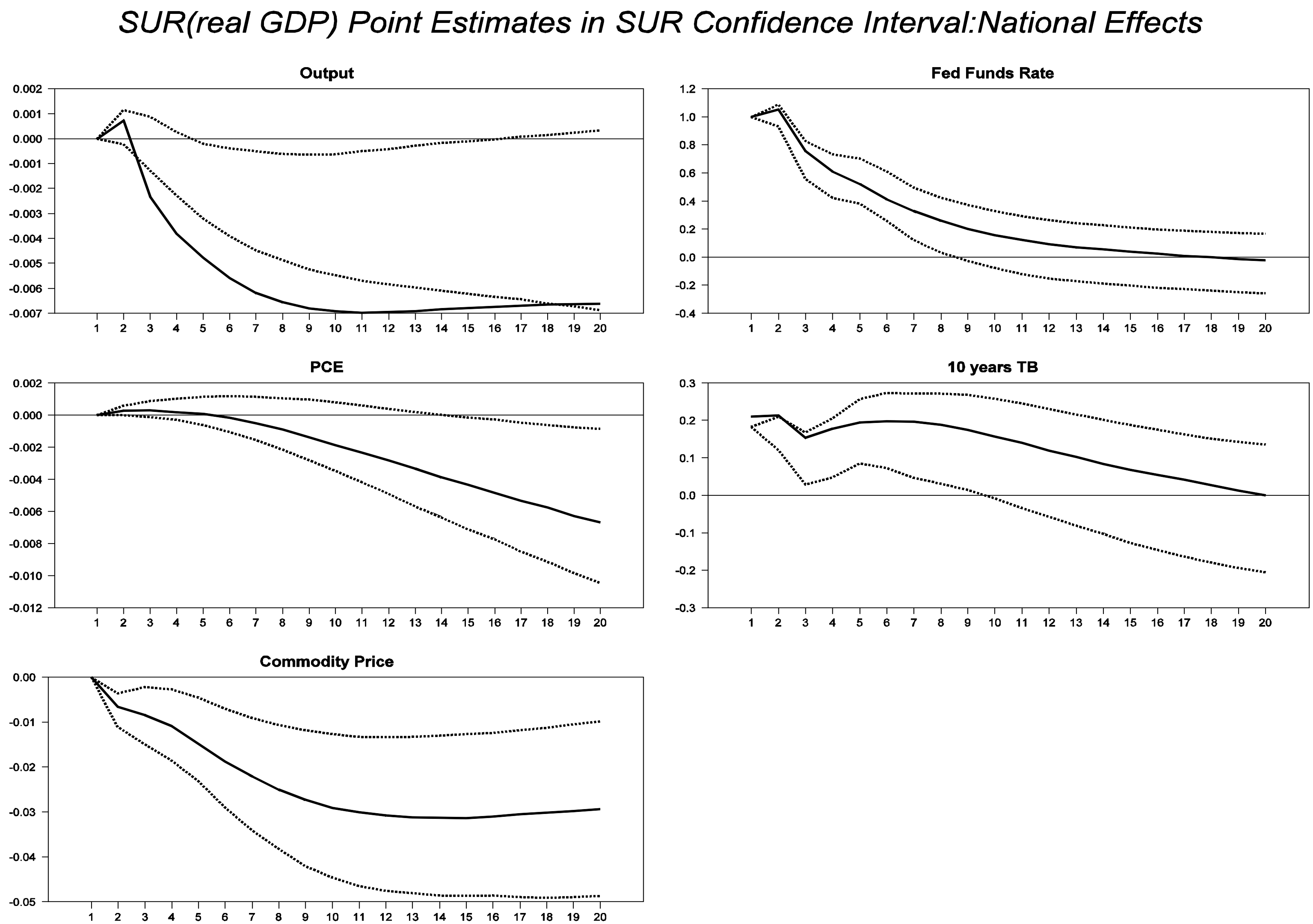


Figure 4.23 — Border-Effects VAR (Real GDP) Point Estimates in Border-Effects VAR Confidence Interval: National Effects

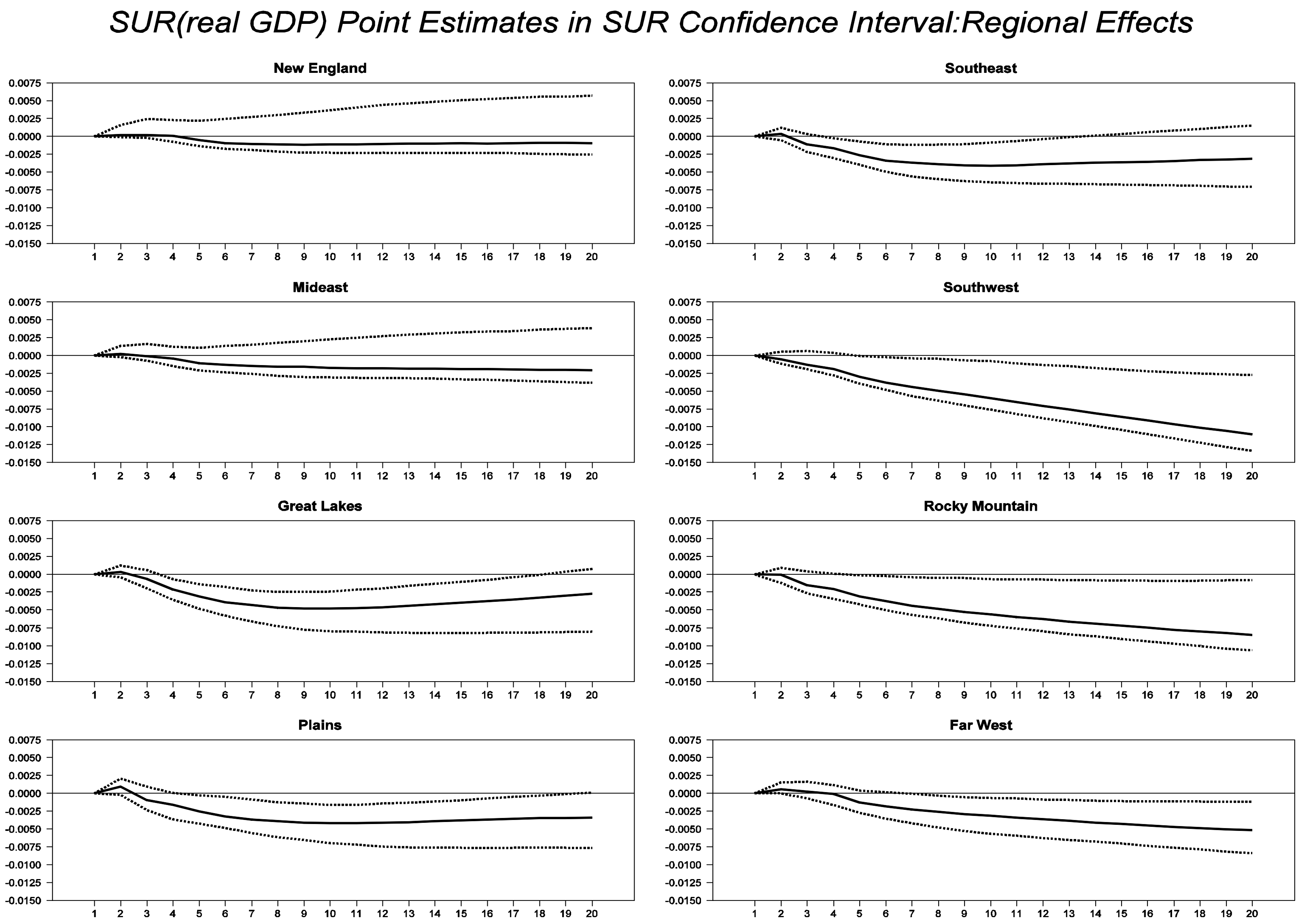


Figure 4.24 — Border-Effects VAR (Real GDP) Point Estimates in Border-Effects VAR Confidence Interval: Regional Effects

However, as we can see in Figure 4.24, all eight regions of point estimates stays well inside the confidence intervals from the border-effects VAR using real PI.

4.4.2 Forty Eight Contiguous States Case

4.4.2.1 Lastrapes-Type Restricted VAR Model

We calculate the point estimates from Lastrapes-type VAR (state) using real GDP and then plot these point estimates along with the confidence intervals from the Lastrapes-type VAR (state) using real personal income. Figure 4.25 and Figures 4.26.1 through 4.26.8 show these results. As we can see in Figure 4.25, all point estimates fit inside well in the baseline model's confidence interval at all horizons for all regions except for the national output and 10-years TB rate. For national output, the point estimate hits the lower bounds approximately 2 quarters after the shock and remains outside the confidence intervals thereafter and then it returns to inside the confidence interval 20 quarters after the shock. For the 10-years TB rate, the point estimate remains outside the upper bounds approximately 2 quarters after the shock and stays inside confidence interval thereafter. However, in Figures 4.26.1 through 4.26.8, most of all states' point estimates stay well inside the confidence intervals from the Lastrapes-type VAR (state) using real personal income.

4.4.2.2 Border-Effects Restricted VAR Model

We calculate the point estimates from border-effects VAR (state) using real GDP and then plot these point estimates along with the confidence intervals from the border-effects VAR (state) using real PI. Figure 4.27 and Figures 4.28.1 through 4.28.8 show these results. As we can see in Figure 4.27, all point estimates fit inside well in the baeline model's confidence interval at all horizons except for national output and the 10-years TB rate. For naional output, the point estimate hits the lower bounds approximately 2 quarters after the shock and remains outside the confidence intervals thereafter and then it returns to inside the confidence interval 14 quarters

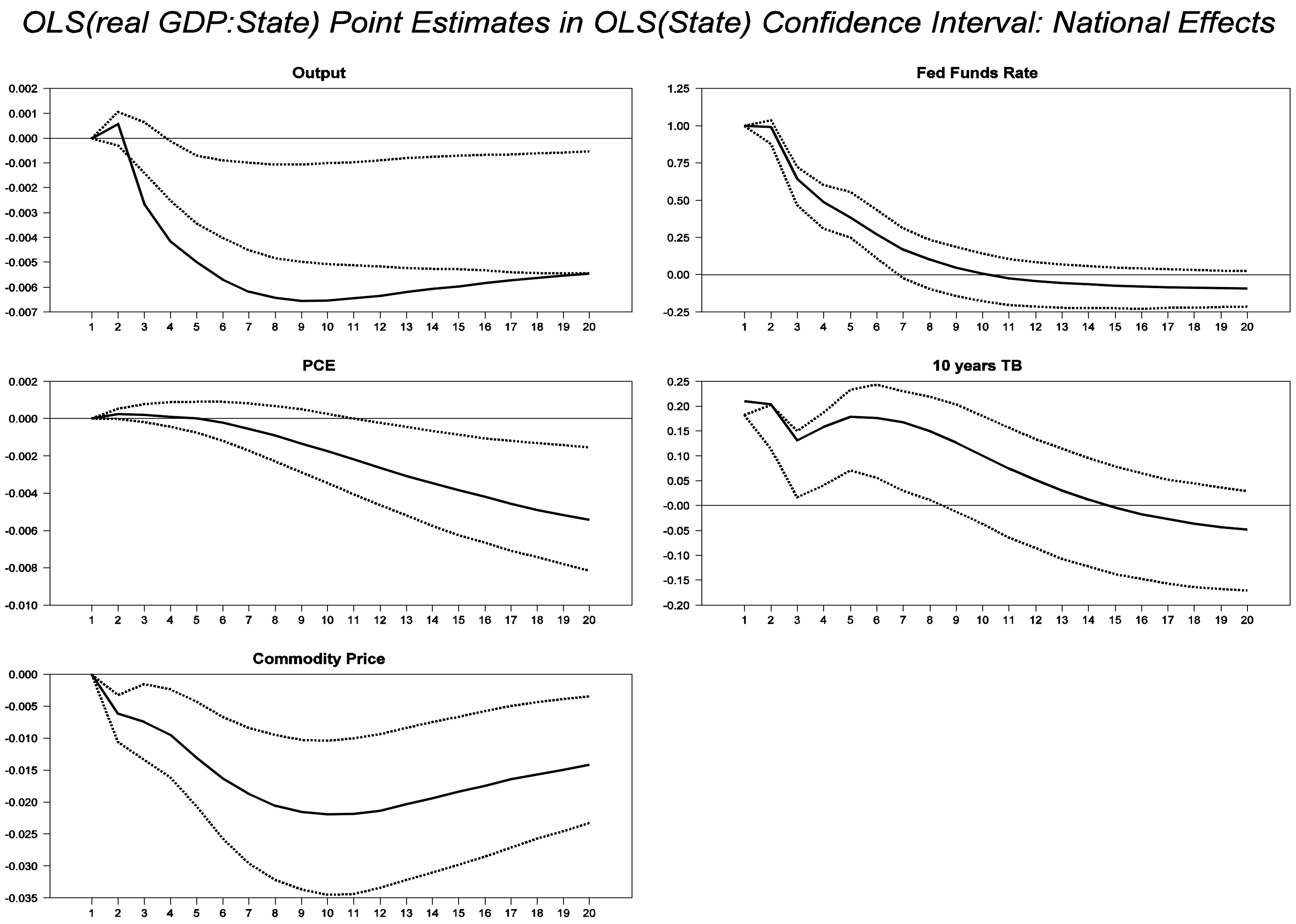


Figure 4.25 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval: National Effects

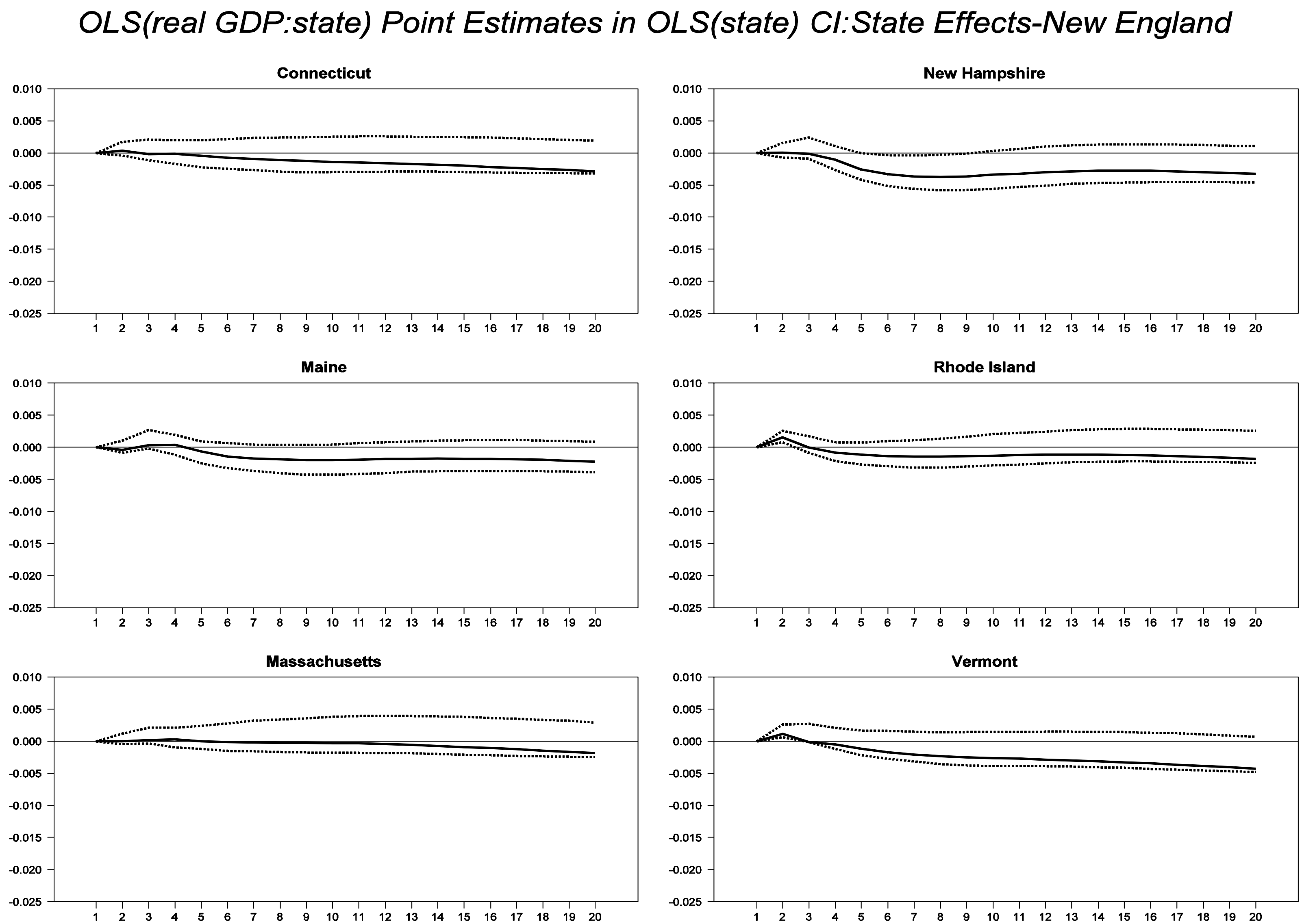


Figure 4.26.1 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval – New England

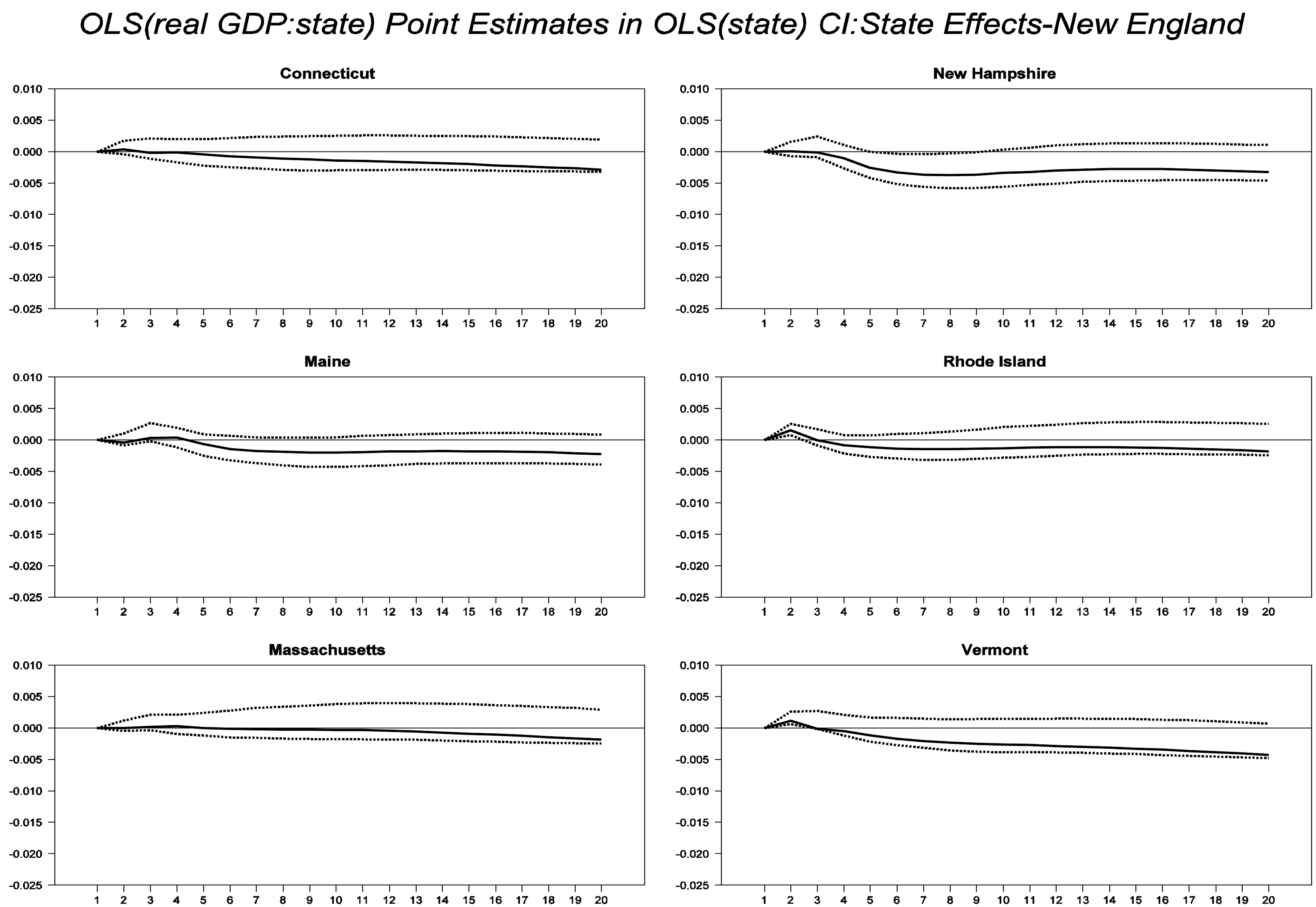


Figure 4.26.2 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Mideast

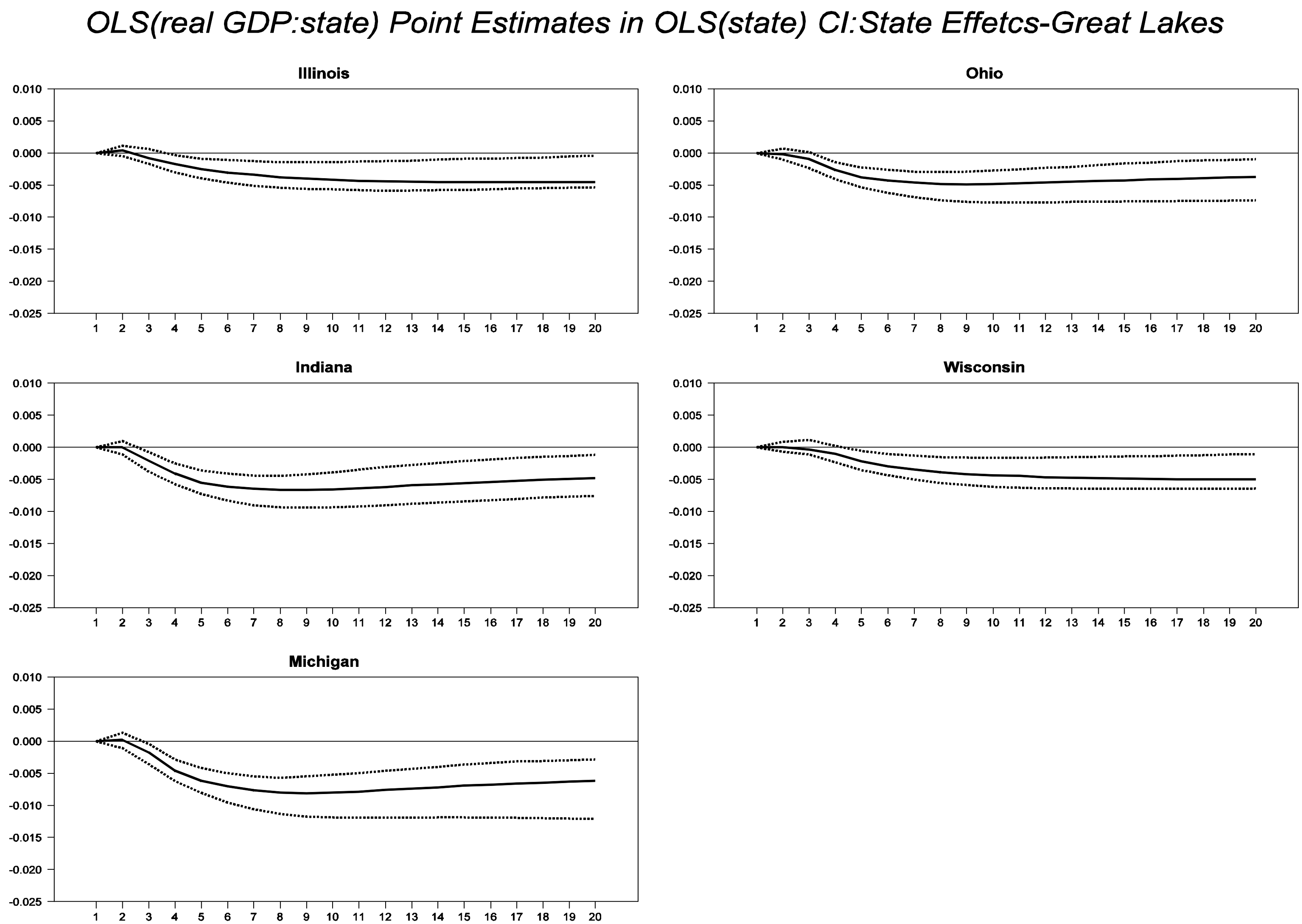


Figure 4.26.3 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Great Lakes

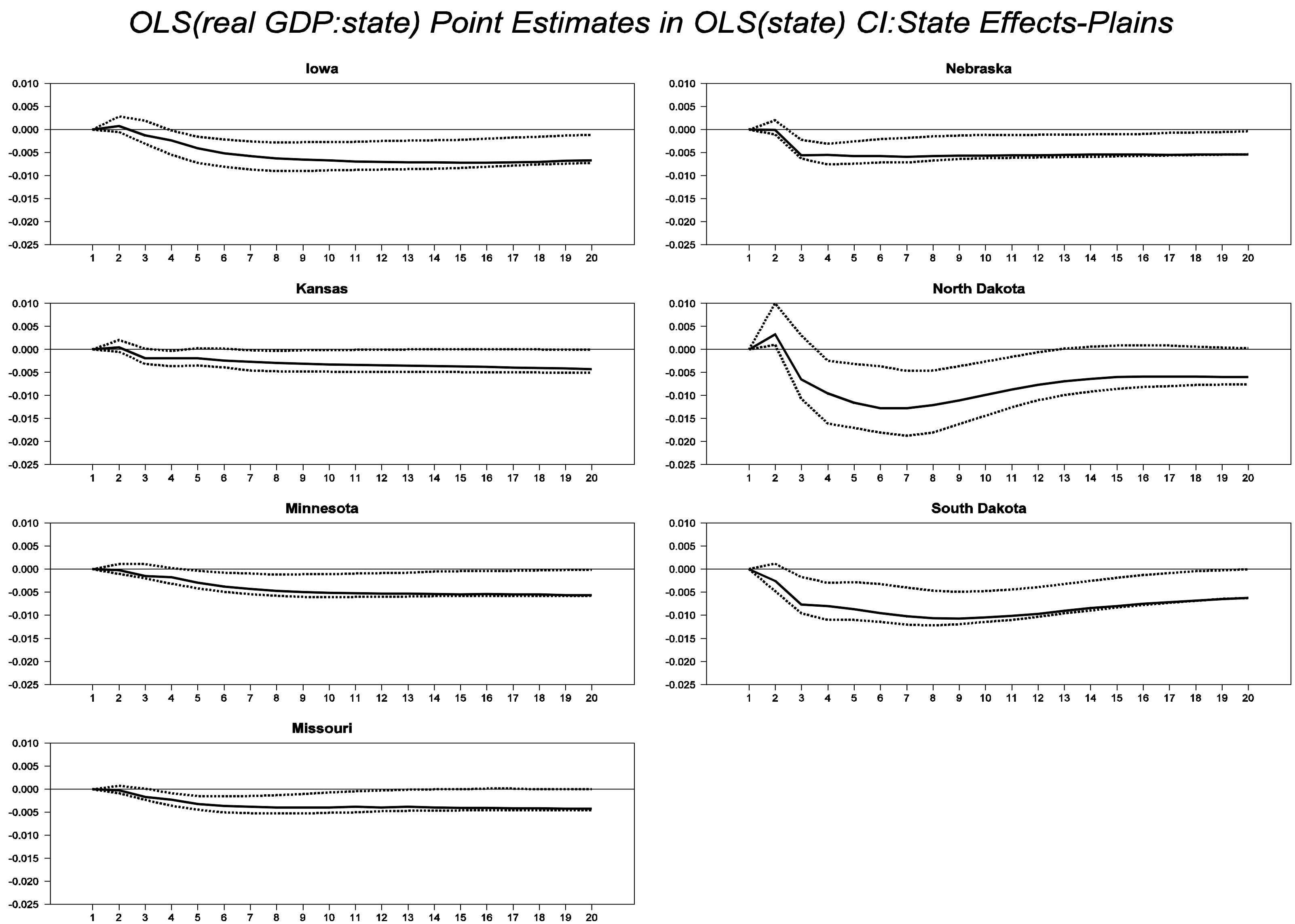


Figure 4.26.4 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Plains

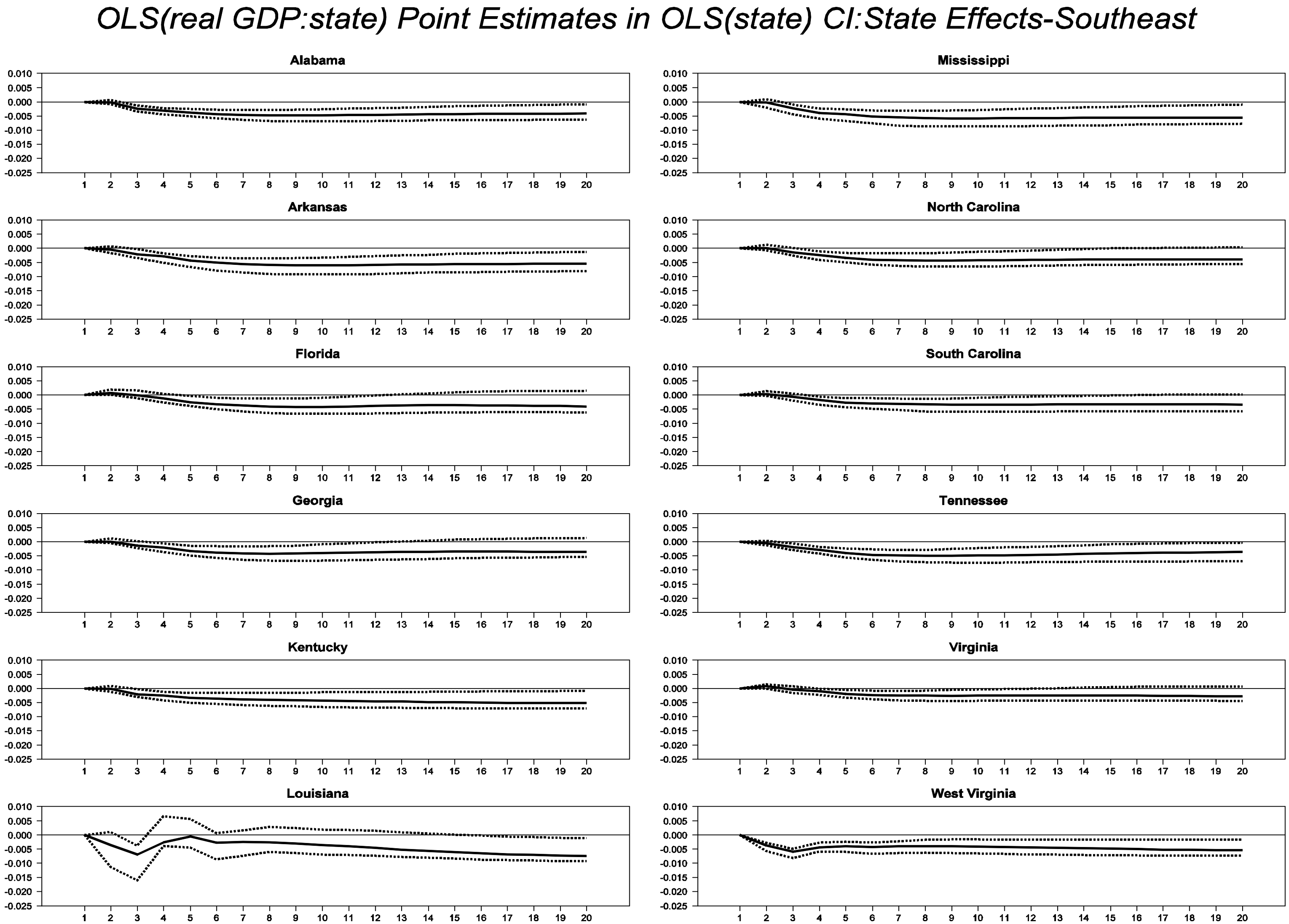


Figure 4.26.5 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Southeast

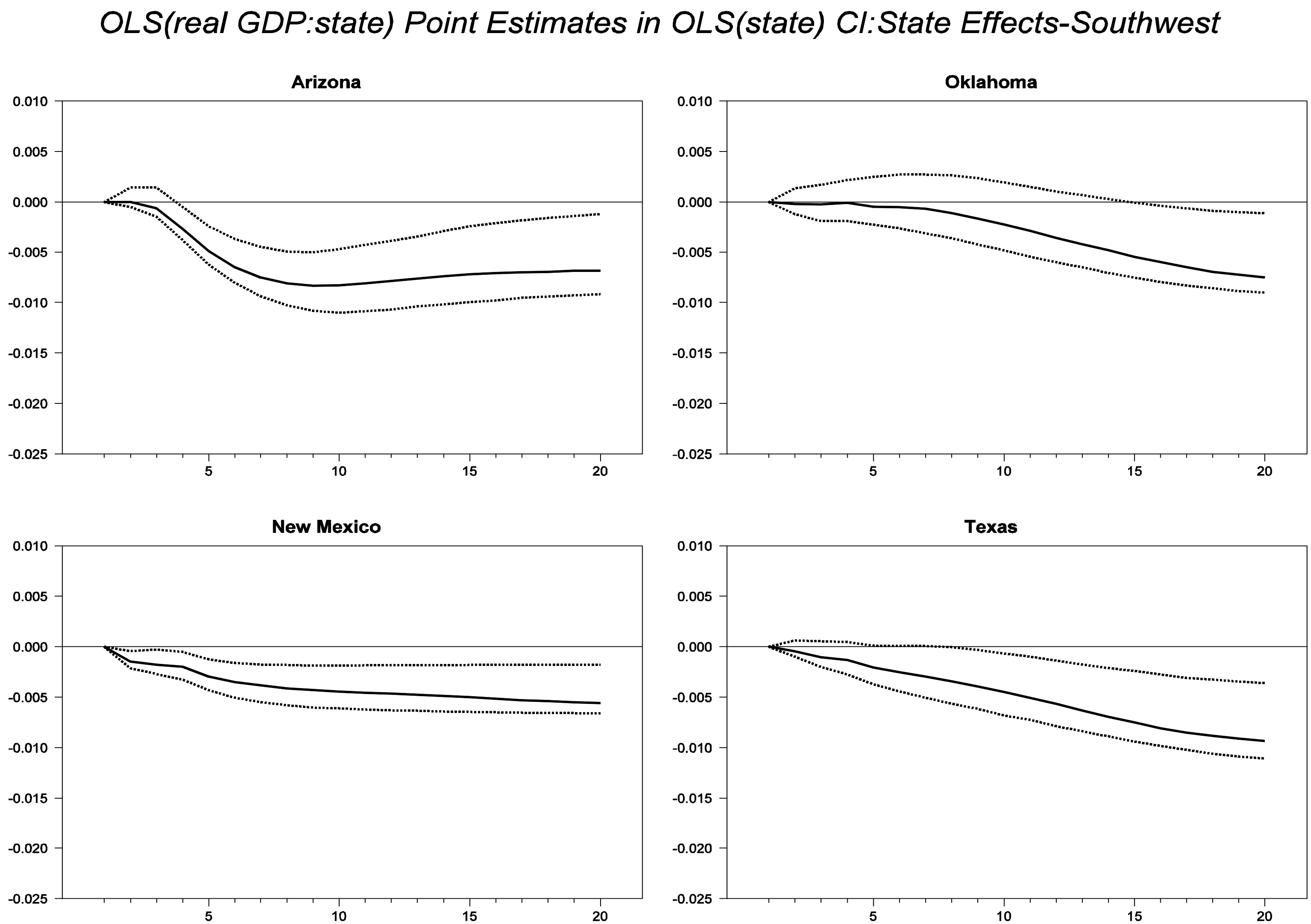


Figure 4.26.6 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Southwest

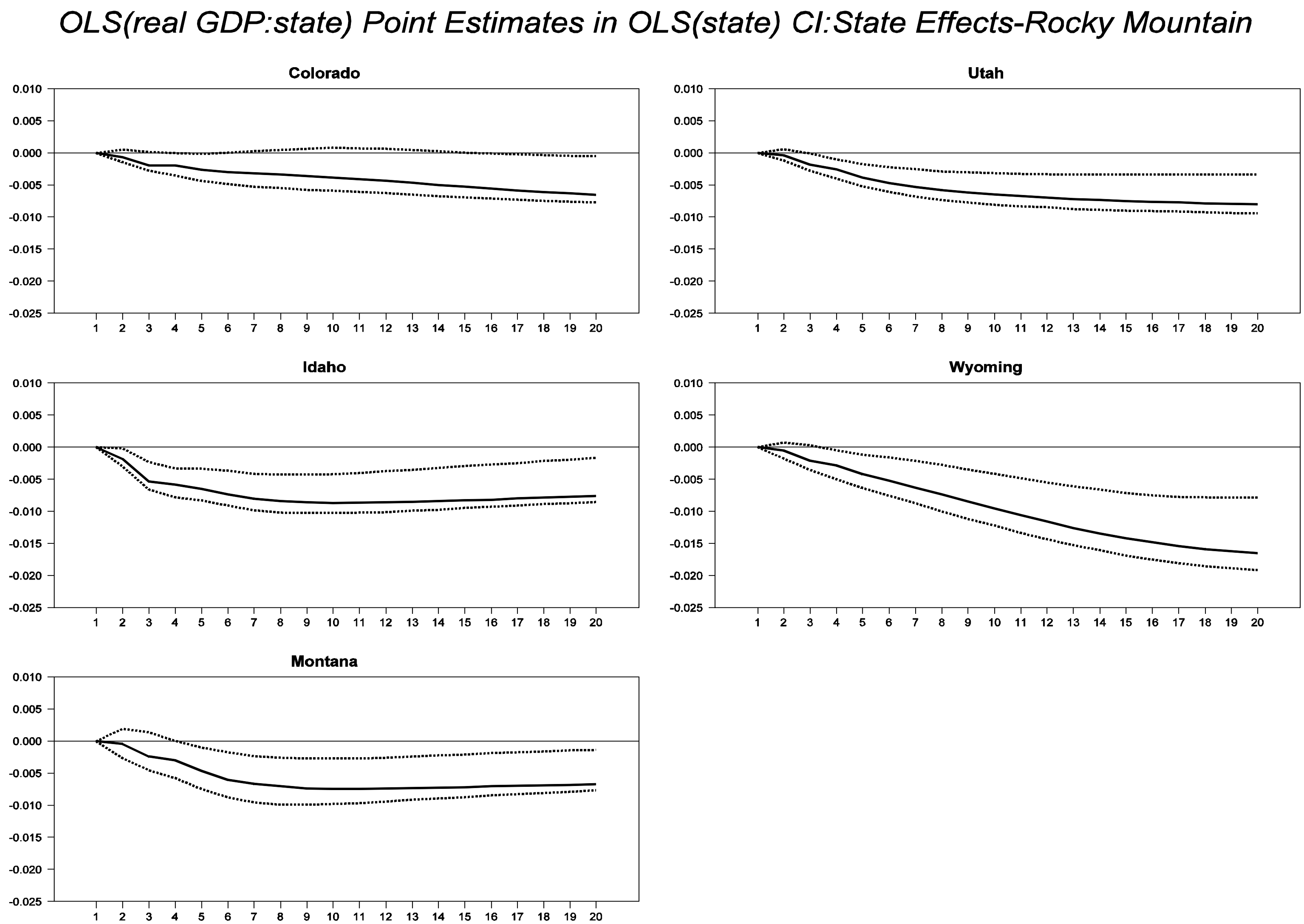


Figure 4.26.7 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Rocky Mountain

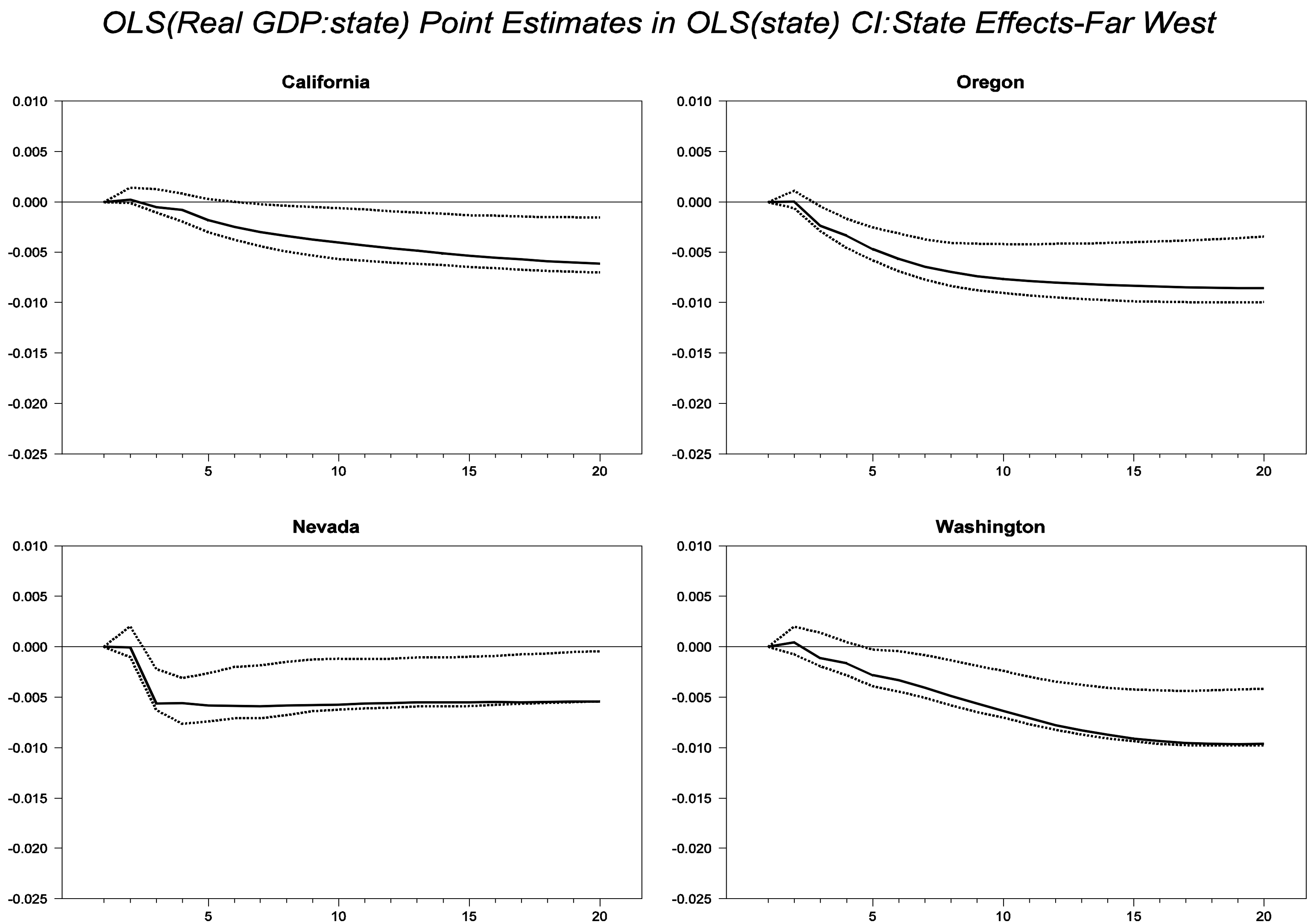


Figure 4.26.8 — Lastrapes-Type VAR (Real GDP: State) in Lastrapes-Type VAR (State) Confidence Interval– Far West

after the shock. For the 10-years TB rate, the point estimate remains outside the upper bounds approximately 2 quarters after the shock and stays inside confidence interval thereafter. However, in Figures 4.28.1 through 4.28.8, all states' point estimates stay well inside the confidence intervals from the Lastrapes-type VAR (state) using real personal income.

4.5 Conclusion

Robustness of results is a major concern in empirical economics. In particular, small changes in the specification of a model can sometimes lead to different results. For that reason, robustness analysis is an important part of the empirical literature. This chapter presents the results of various sensitivity analyses regarding the specification of the model and the use of an alternative definition of national output. We consider three types of robustness checks for the estimates of the regional effects of monetary policy.

In the robustness tests, the basic structure of the model is the same as in the previous chapters. For the first robustness test we include two fiscal variables in the national block: Ramey's military expenditure variable and Romer and Romer's tax variable. For the second robustness test, we include a measure of aggregate economic uncertainty. For the third robustness test, we replace real national personal income as the measure of national economy activity with real GDP. To test the robustness of the baseline results, we check and see if the impulse response functions are significantly different from those in the baseline models. This comparison indicates that the results are robust to the changes considered in this chapter.

SUR(real GDP:State) Point Estimates in SUR(State) Confidence Interval: National Effects

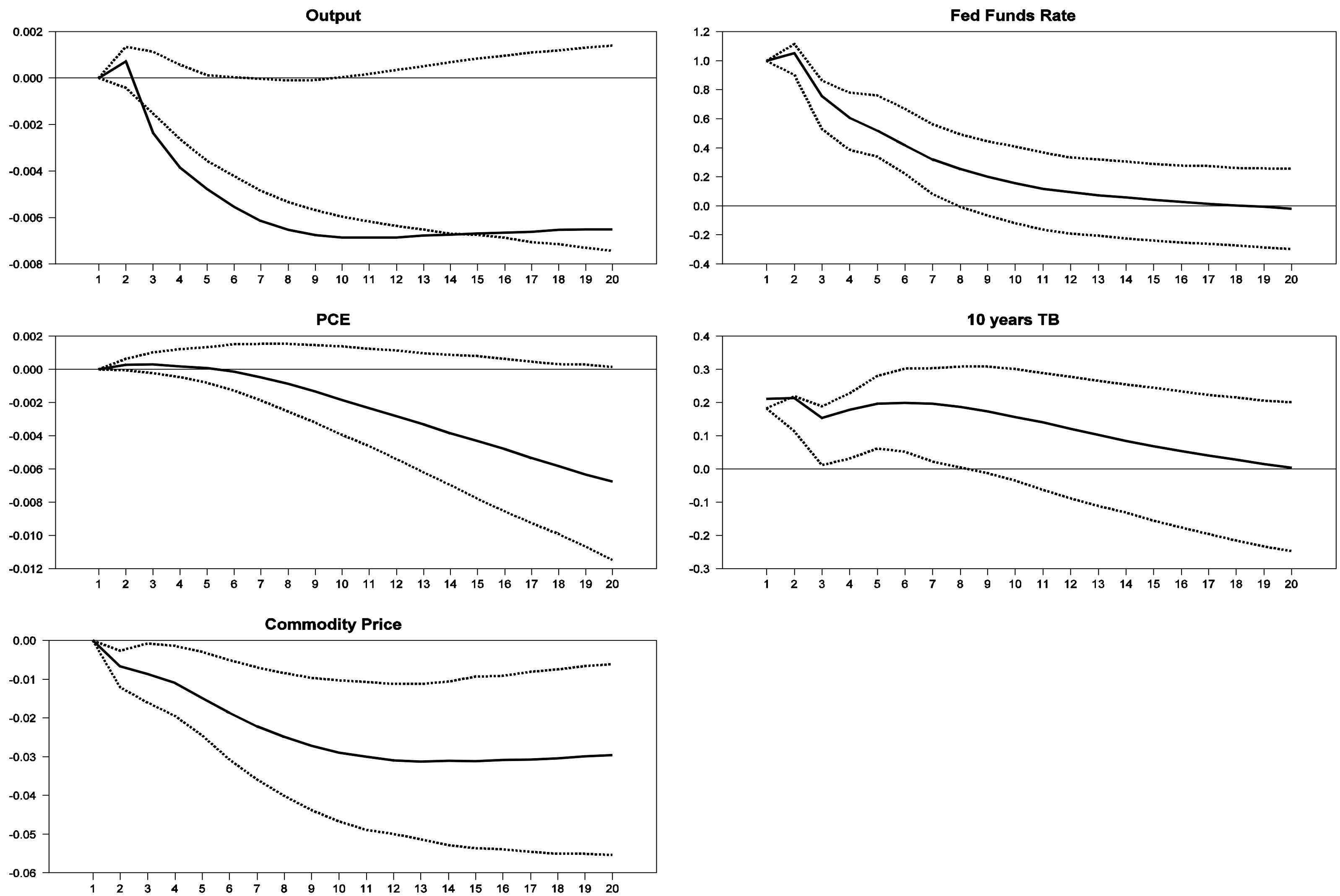


Figure 4.27 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval: National Effects

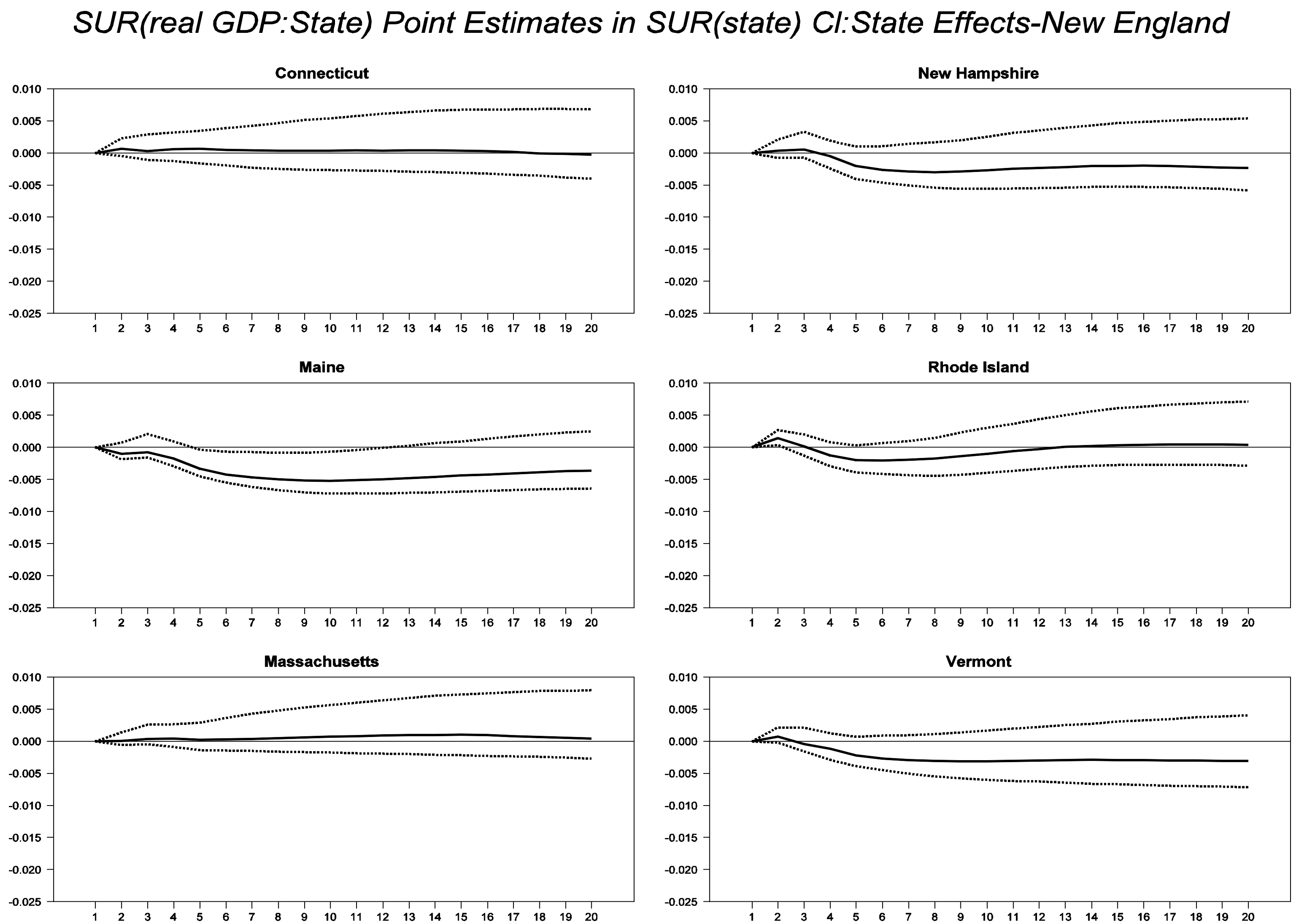
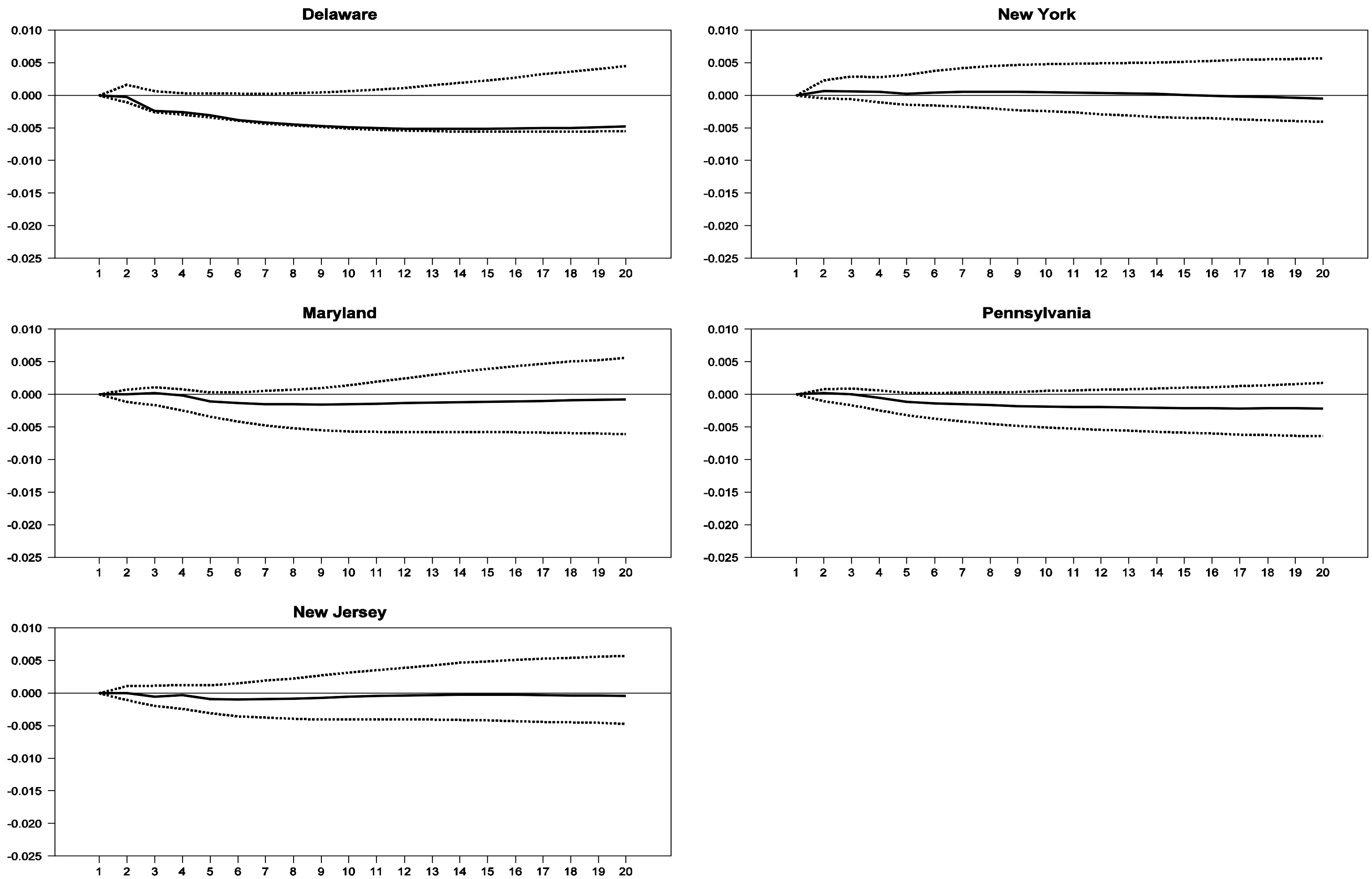


Figure 4.28.1 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– New England

SUR(real GDP:State) Point Estimates in SUR(state) CI:State Effects-Mideast



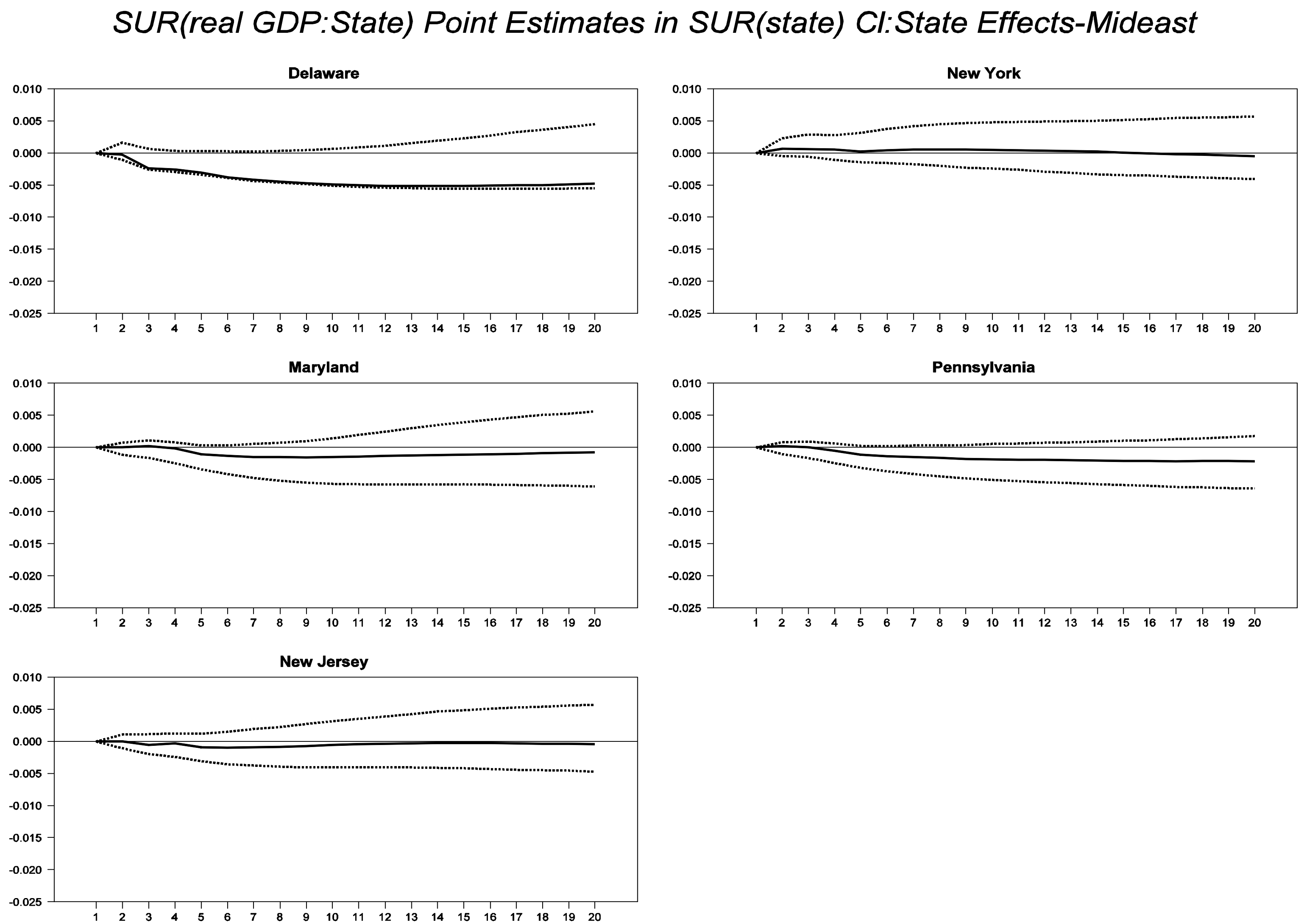


Figure 4.28.2 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Mideast

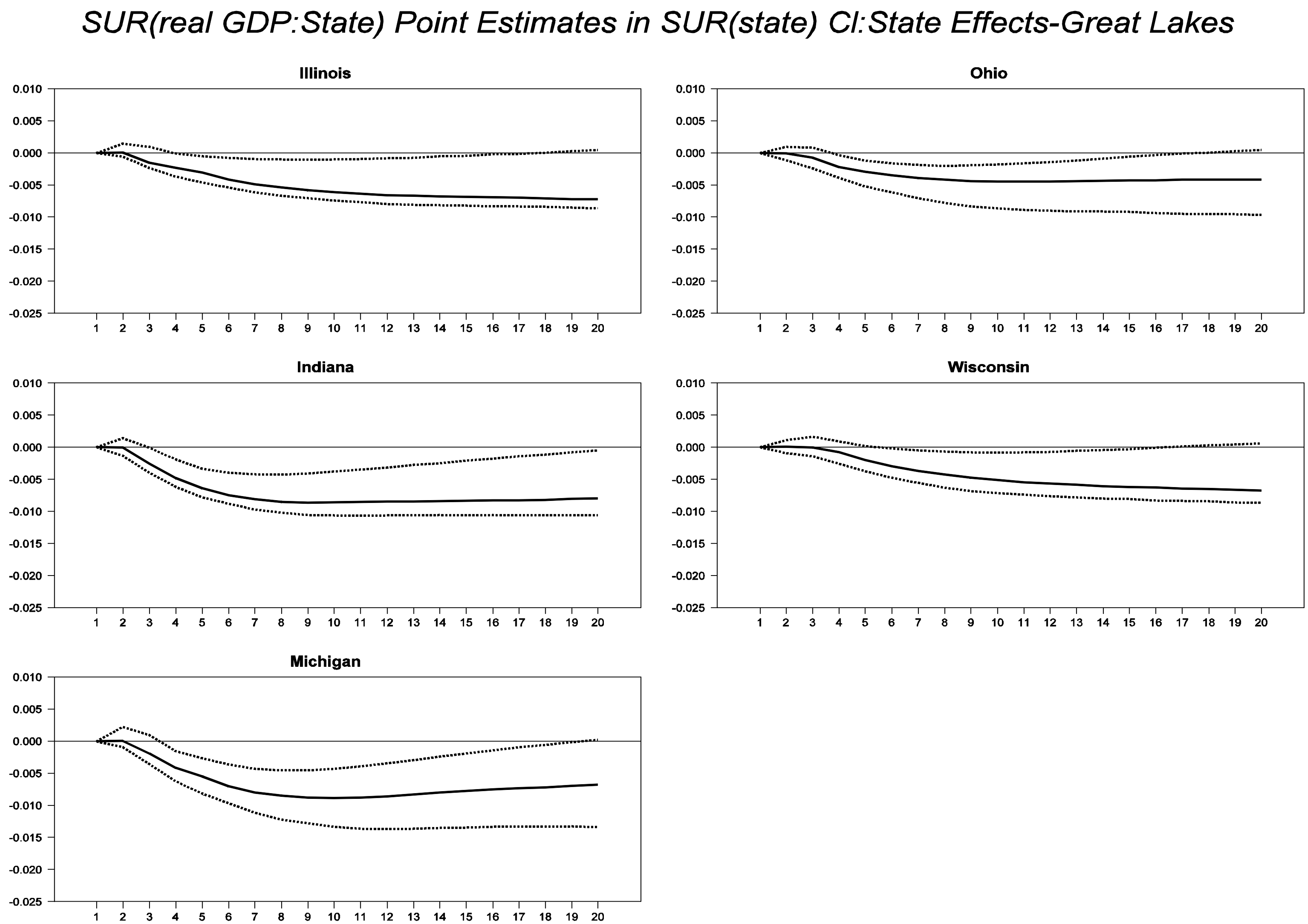


Figure 4.28.3 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Great Lakes

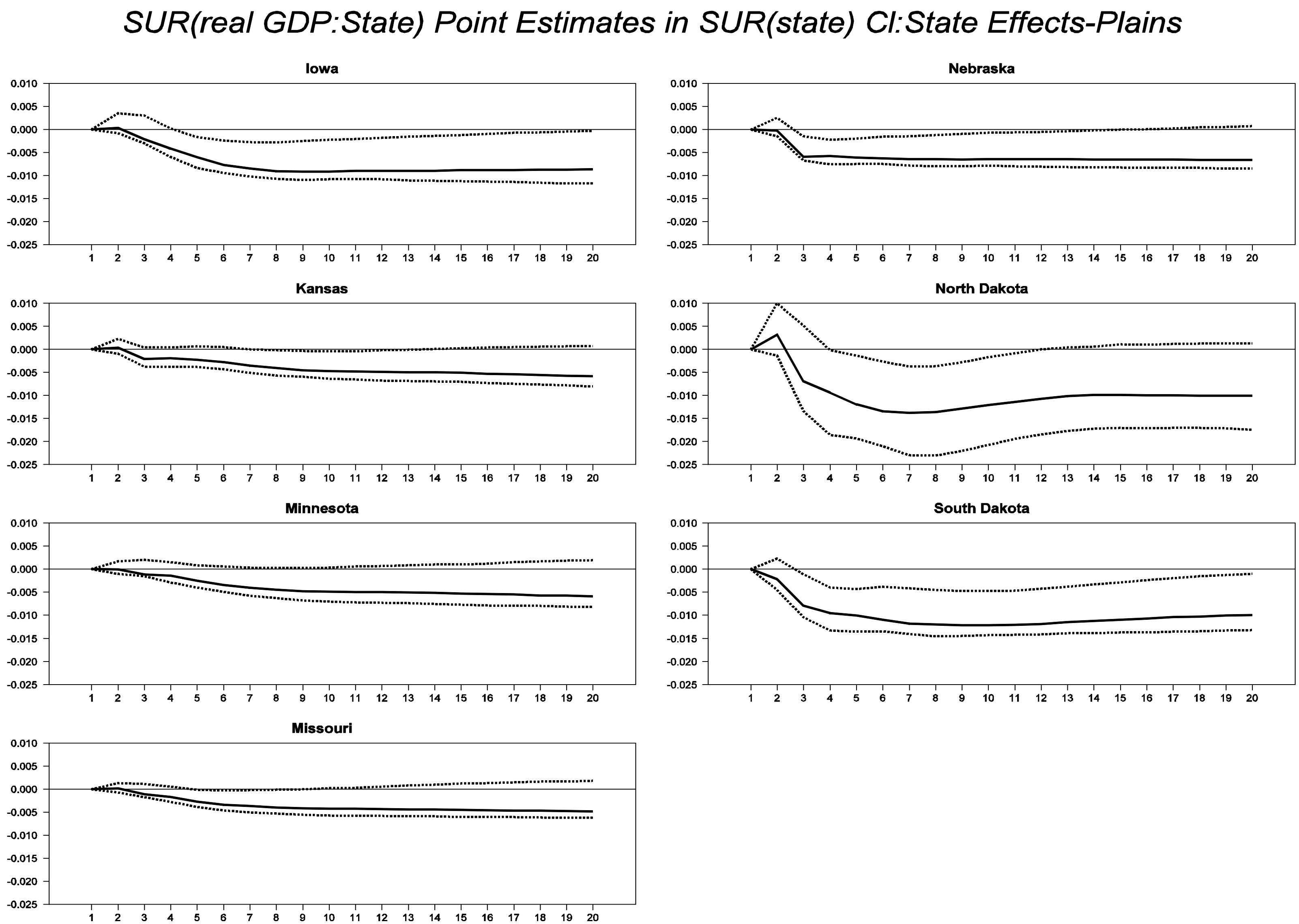


Figure 4.28.4 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Plains

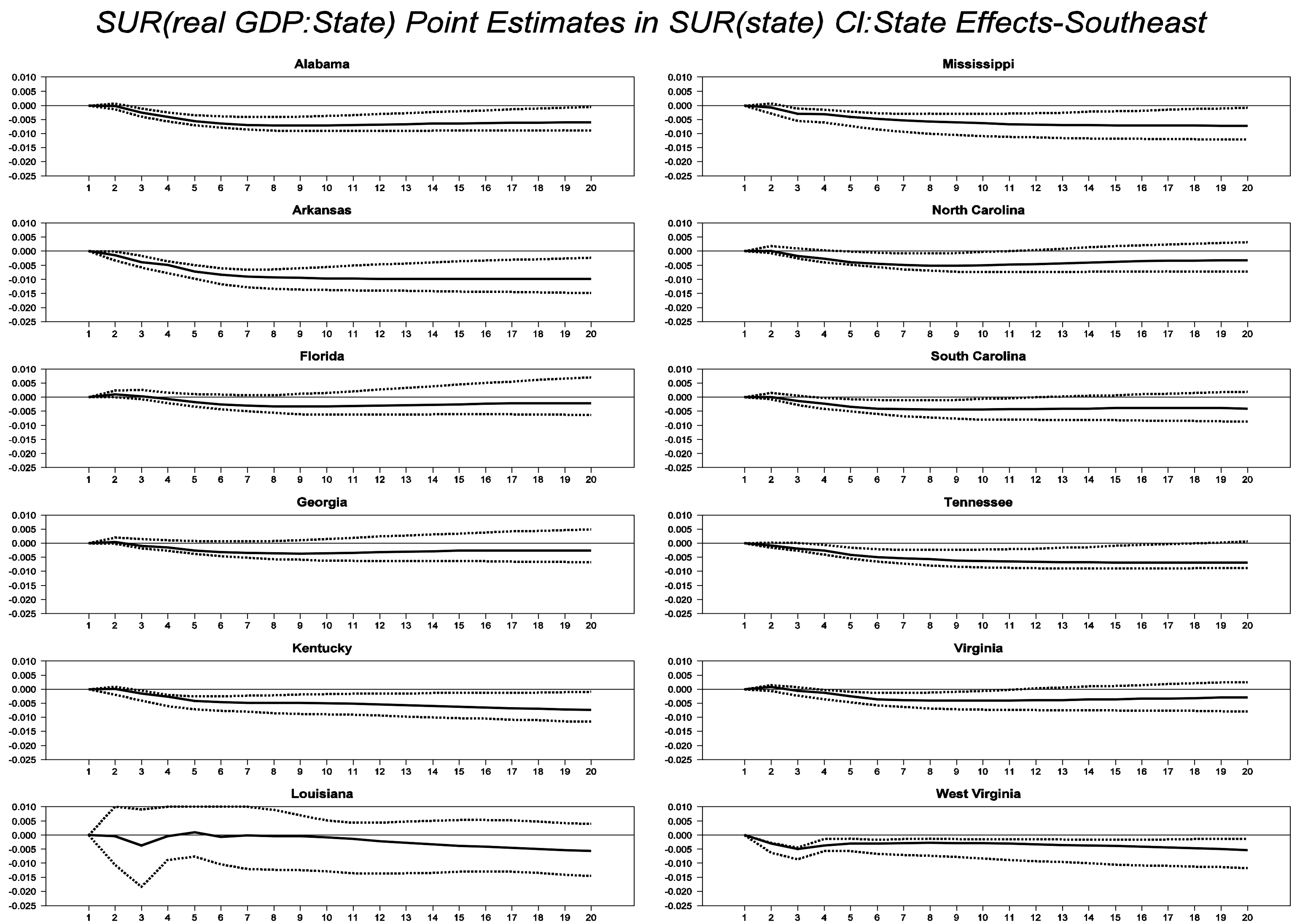


Figure 4.28.5 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Southeast

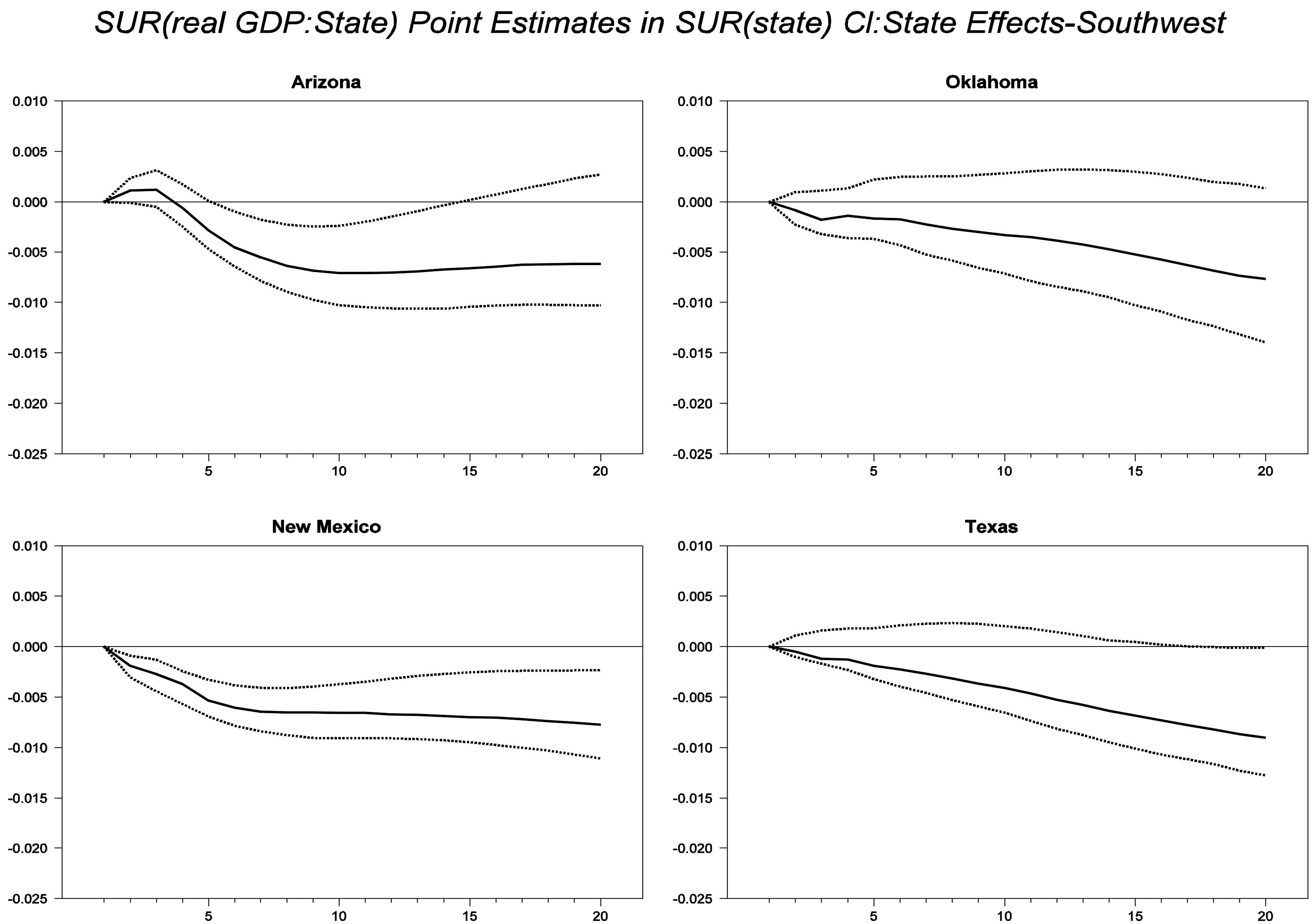


Figure 4.28.6 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Southwest

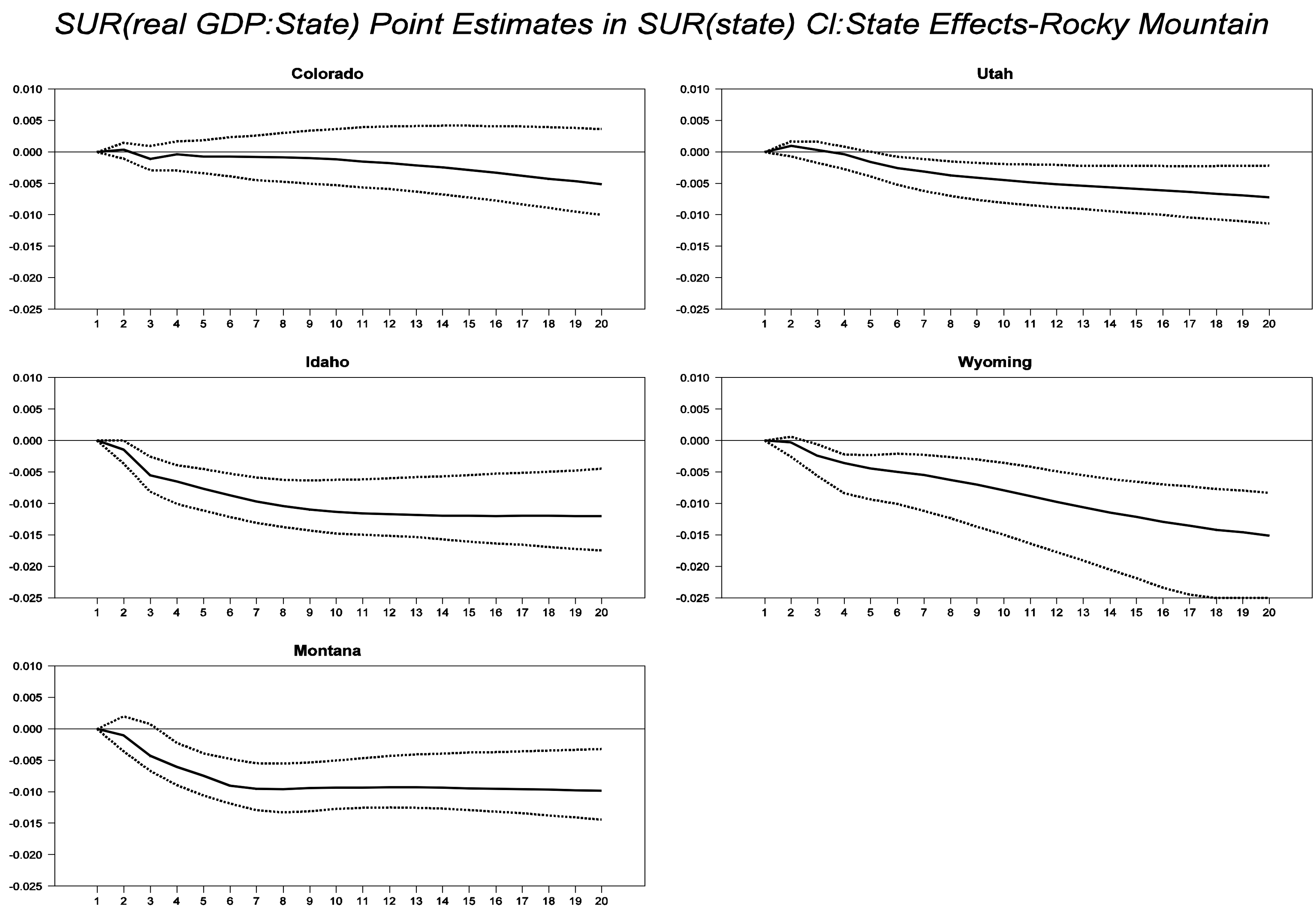


Figure 4.28.7 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Rocky Mountain

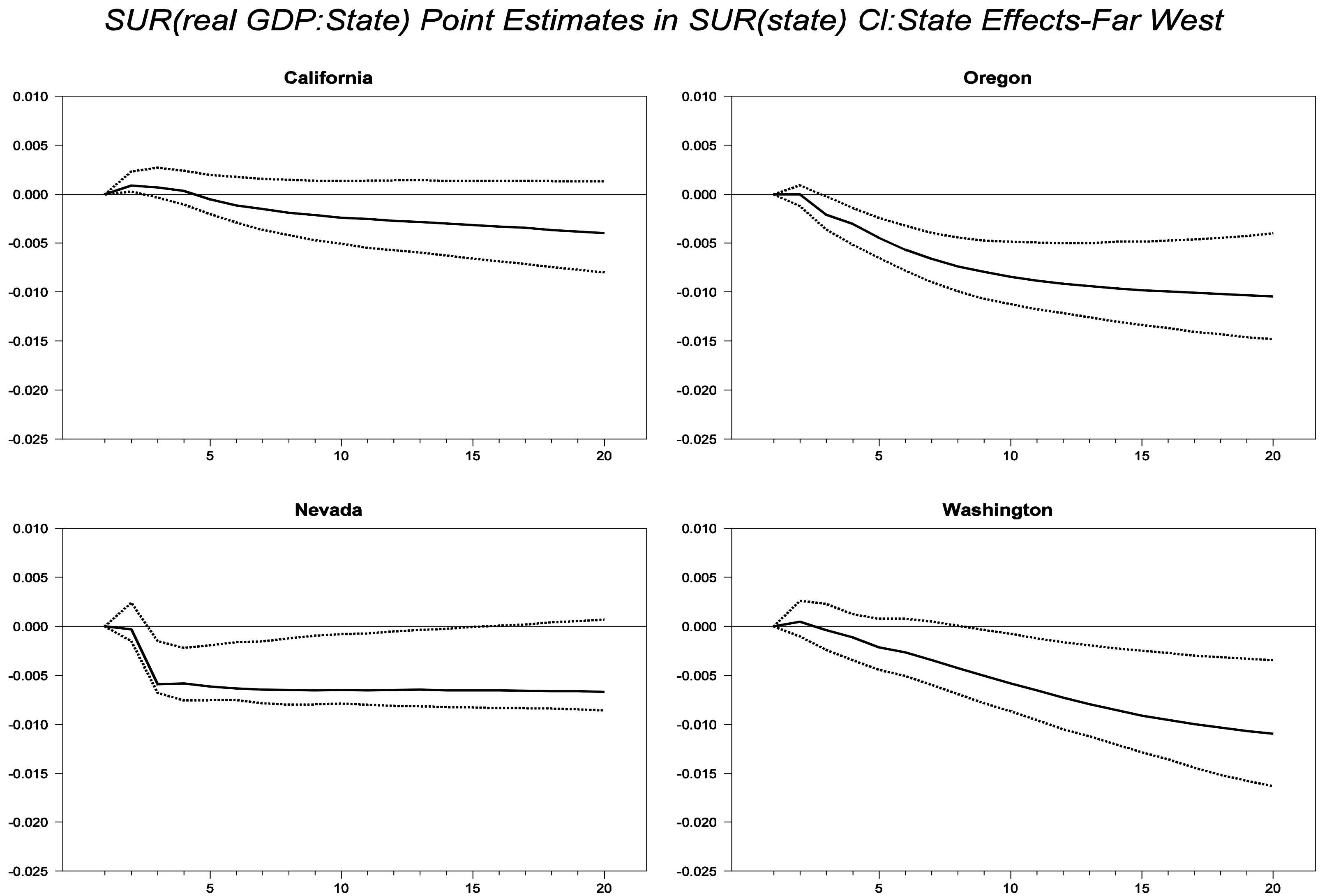


Figure 4.28.8 — Border-Effects VAR (Real GDP: State) in Border-Effects VAR (State) Confidence Interval– Far West

Chapter 5. Conclusion

We have compared two broad approaches to identifying monetary policy shocks that are used to estimate the regional and state-level effects of monetary policy. One approach that has been used in past literature, such as the one used by Owyang and Wall (2005, 2009), assumes that monetary policymakers respond directly to regional income shocks but do not respond directly to national income shocks. A second general approach assumes that monetary policymakers respond to shocks to national income but do not directly respond to region-specific income shocks. This assumption is based on descriptions of real world monetary policy formulation in which policymakers respond only to the national economy and regional information is just used to help gauge the state of the national economy. The second approach is based on a procedure developed by Lastrapes (2005) to study the effects of monetary policy on different industries. Within this second general approach, two restricted VARs are considered. In the first approach, it is assumed there is no direct contemporaneous or lagged feedback from one region to another; this approach is called the Lastrapes-type restricted VAR and ordinary least squares (OLS) is used for estimating the first type of restricted VAR. In the second approach, it is assumed there are border-effects in which there is lagged feedback among contiguous regions; this approach is called a border-effects restricted VAR and VARs based on this approach are estimated with SUR.

All three VAR models are estimated over a common sample period using the same model variables, and the same lag length. Estimates of the regional effects of monetary policy from the Owyang-Wall-type standard VAR, the Lastrapes-type restricted VAR, and the border-effects restricted VAR are compared. The monetary policy shocks are identified using a Choleski decomposition that differs across the three types of VARs only in the assumption about

how policymakers respond to income shocks and how regional economic activity affects other regions. In the Owyang-Wall-type standard VAR in which policy shocks are identified assuming that policymakers respond directly to region-specific policy shocks, personal income from each region is included but national income is not included in the VAR. In the two restricted VARs in which policy shocks are identified by assuming that policymakers respond directly to shocks to national personal income and not to region-specific income shocks, national income as well as income from each region is included.

The results show that the effects of monetary policy shocks on regional economic activity differ across the two broad approaches to identifying policy shocks. Therefore, assumptions about whether monetary policymakers respond directly to regional shocks seem to matter for estimating the regional effects of monetary policy. Even though the effects on regional personal income by themselves do not support one approach over the other, impulse response functions for contractionary shocks to monetary policy reveal insignificant effects on aggregate price and commodity prices for the Owyang-Wall-type VAR but significant negative effects on aggregate price and commodity prices for the restricted VARs. Since economic theory suggests negative effects of contractionary policy on prices, these contrasting results for the aggregate price level and commodity prices weigh in favor of the restricted VAR approaches.

Recent studies (Carlino (2007), Carlino and Sill (2001), and Crone (2006)) suggest that there are differences in business cycles across states and regions. Because there are large differences across states and regions our understanding of the effects of monetary policy can be enhanced by considering the richer state-level data. Hence, we used two Lastrapes-type restricted VAR approaches to examine whether monetary policy has symmetric effects across U.S. states.

The results using state-level data suggest are often similar to those from the Lastrapes-type restricted VAR, and comparisons of one states' response to monetary policy shocks show that each state's response is sometimes different from the response of the other states in that region and from the response of its region.

The robustness of the results from all three VAR models is checked by 1) including the fiscal policy variables, 2) including a measure of aggregate uncertainty, and 3) replacing national personal income with real GDP. In conclusion, the results are robust to these changes.

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Appendix: Definitions of Eight BEA Regions

Bureau of Economic Analysis Regions (50 States plus District of Columbia)

New England (NE)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Mideast (ME)	Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania
Great Lakes (GL)	Illinois, Indiana, Michigan, Ohio, Wisconsin
Plains (PL)	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
Southeast (SE)	Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia, Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee
Southwest (SW)	Arizona, New Mexico, Oklahoma, Texas
Rocky Mountain (RM)	Colorado, Idaho, Montana, Utah, Wyoming
Far West (FW)	Alaska, California, Hawaii, Nevada, Oregon, Washington

In the recent literature, they create the new BEA classification of 8 regions (see Carlino and DeFina (1998, 1999a, 1999b), Crone (2007), Owyang and Wall (2005, 2009) and Beckworth (2010)). Since Alaska and Hawaii do not share common borders with any other regions and District of Columbia is special region, they excluded those states and classified only 48 contiguous states into 8 regions.

New Definition: Bureau of Economic Analysis Regions (48 States)

New England (NE)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Mideast (ME)	Delaware, Maryland, New Jersey, New York, Pennsylvania
Great Lakes (GL)	Illinois, Indiana, Michigan, Ohio, Wisconsin
Plains (PL)	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota

Southeast (SE)	Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia, Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee
Southwest (SW)	Arizona, New Mexico, Oklahoma, Texas
Rocky Mountain (RM)	Colorado, Idaho, Montana, Utah, Wyoming
Far West (FW)	California, Nevada, Oregon, Washington

Crone (2005)'s Alternative Definition of Eight Regions

New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Mideast	Delaware, Maryland, New Jersey, New York, Pennsylvania
Great Lakes	Illinois, Indiana, Michigan, Ohio, Wisconsin, Minnesota, West Virginia
Plains	Iowa, Kansas, Missouri, Nebraska
Southeast	Florida, Georgia, North Carolina, South Carolina, Virginia, Alabama, Arkansas, Kentucky, Mississippi, Tennessee
Energy Belt	Colorado, Louisiana, New Mexico, Oklahoma, Texas, Wyoming, Utah
Mountains/Northern Plains	Idaho, Montana, South Dakota, North Dakota
West	Arizona, California, Nevada, Oregon, Washington

Vita

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