THREE ESSAYS ON THE EFFECTS OF OIL PRICES ON STATE ECONOMIES

By

Wei Kang

A Dissertation Submitted to the Graduate School at Middle Tennessee State University

in Partial Fulfillment of the Requirement for the Degree

Doctor of Philosophy/Economics

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This dissertation is dedicated to my parents.

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ABSTRACT

This dissertation consists of three chapters that examine the effects of oil prices on state economies. The first chapter, "Asymmetric Effects of Oil Prices on State Economies," examines the impact of oil price changes on state-level income growth. I find strong evidence of asymmetry in the impacts of oil prices and that states vary considerably in terms of sensitivity to oil price shocks. Further analysis shows that states with a higher prevalence of manufacturing and higher coal production are more likely to be negatively affected by positive oil price shocks, while states with a high prevalence of petroleum and natural gas production tend to benefit from positive oil price shocks. The second chapter, "Regime-Switching Analysis of a State Economy's Response to An Oil Price Shock," analyzes the effects of oil price changes on state economies using a smooth transition autoregressive (STAR) approach. States are shown to present differences in both the tolerance and speed of response to an oil price shock. The differences are further explained by state-specific economic characteristics. The third chapter, "Multivariate Unobserved Component Analysis of State Employment with Oil Price Volatility," investigates whether and how oil price volatility affects state employment, with a focus on regional similarities and differences. Results show that oil price volatility has significant negative impacts on most states. Further, states with a higher prevalence of motor vehicle production are likely to experience larger job losses during periods of high oil price volatility.

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INTRODUCTION

The U.S. economy remains heavily dependent on imported oil. Oil is important for the U.S. economy for three main reasons. First, the U.S. consumes 25% of the world's oil supply, but it holds only 3% of the world's proven oil reserves. According to the U.S. Department of Energy, oil generates more than 40% of the total demand for energy and more than 99% of the fuel used in automobiles.[1] Second, the price of oil is volatile: more specifically, oil price fluctuations are largely determined by market forces outside of the U.S. economy and by political conflicts in the Middle East. Third, the demand for oil is very inelastic. Although the development of renewable and alternative fuels is on the rise, oil is still the most widely used source of energy for both industries and households. Thus, changes in the price of oil will have a significant impact on the U.S. economy. Typical responses of the economy to an upward oil price shock include a reduction in real GDP, an increase in inflation, higher unemployment, lower real wages, and higher short-term interest rates, among some of the most important impacts.

A large number of studies have examined the relationship between oil prices and aggregate macroeconomic activity, usually finding that oil price changes have significant effects on macroeconomic performance. However, the literature is focused nearly entirely on the relationship between oil prices and the economy at the national level, with very little attention paid to the effect of oil prices on state-level economic activity. This dissertation consists of three essays that examine the effects of oil prices on state

[1] U.S. Department of Energy, http://www.energy.gov/energysources/oil.htm

economies. The primary contribution of this dissertation is that it extends the oil price impact analysis to state economies.

The first essay examines whether oil prices exhibit asymmetric effects on state economies. I investigate various measures of oil price change to estimate the impact of oil price changes on state-level income growth. The results suggest that state economies respond to oil price changes differently due to their differing industrial structures. In addition, I investigate the determinants of sensitivity to oil price changes. The results indicate that states with a higher prevalence of manufacturing and higher coal production are more likely to be harmed by positive oil price changes, while states with petroleum and natural gas production tend to benefit more from positive oil price shocks.

My second essay continues to investigate the relationship between oil price changes and the growth rate of state economies by examining a state's tolerance and lag, or response delay, to an oil price change. Using a smooth transition autoregressive (STAR) regime-switching approach, I estimate a state's tolerance and delay of response to oil price changes. Results from the STAR models show that states with higher energy dependence tend to respond more quickly to oil price shocks than those less dependent on energy. State economies also present differences in the tolerance to an oil price shock and in the speed of adjustment from one regime to another, which can largely be explained by state-specific economic characteristics.

My final essay investigates whether and how oil price volatility affects dynamic movements in state employment, with a focus on regional similarities and differences. Oil

price volatility is extracted from a univariate GARCH process using daily oil price data. Multivariate unobserved component models are fitted to monthly observations of state employment in five U.S. regions. I find oil price volatility has significant negative impacts on employment for most states. Furthermore, states with a higher proportion of motor vehicle production in GDP are more susceptible to job losses when oil price becomes more volatile.

CHAPTER I

ASYMMETRIC EFFECTS OF OIL PRICES ON STATE ECONOMIES

1.1. INTRODUCTION

It is well established that changes in the price of oil have significant impacts on the United States economy. Many recessions during the past 35 years have been preceded by sharp oil price increases. Figure 1 depicts the relationship between oil price changes and economic recessions, with the recessions indicated by the shaded columns. Oil price spikes tend to be strongly related to political events. Table 1 shows a list of important political events and a timeline of recessions.[1] Figure 2 shows the correspondence of political events and oil price shocks. All these political events caused immediate significant increases in oil prices, and some of them led the U.S. economy into recession.

Though oil price spikes tend to precede economic slowdowns, an equivalent price decline seems to have little positive impact on the economy. Thus, the effects of oil price changes on the economy are thought to be asymmetric. According to the literature, the asymmetry can be explained by the transmission channels by which the unanticipated changes in oil prices affect economic activities (Balke et al. 2002). Fluctuations in oil prices cause uncertainty about future oil prices; as a result, consumers will postpone the purchase of durables, which is referred to as the uncertainty effect (Killian 2008b). However, when oil prices drop, consumers will not go out to buy another car. Moreover, increases in energy prices will cause a reallocation of capital and labor inputs away from energy-intense industries and will shift consumption toward more energy efficient durables. Asymmetry arises because these effects magnify the responses of

[1] The business cycle dates in Table 1 are from the National Bureau of Economic Research (NBER).

macroeconomic aggregates to oil price increases but restrict the corresponding responses when oil prices fall.

While many researchers have investigated the asymmetric relationship between oil prices and national economies, much less attention has been paid to state economies. Do state economies also exhibit an asymmetric response to oil price spikes? The objective of this paper is to examine how oil price shocks affect the 50 state economies. I use autoregressive distributed lag (ARDL) models to estimate the impact of oil price spikes on state private real incomes. I use four measures of the change in oil prices to capture potential asymmetry in the effects on real incomes, resulting in an oil price coefficient for each state. Then I use OLS models to identify factors that determine variation in the oil price coefficients among states. The paper shows that most but not all states show negative asymmetric impacts to oil price shocks. A few states, however, benefit from oil price increases. In addition, I show how the oil price coefficient is sensitive to the prevalence of manufacturing and the production of petroleum and its substitutes in a given state.

The paper is organized as follows: Section 2 offers a review of the literature, Section 3 introduces the ARDL models, Section 4 describes the data, Section 5 discusses the results, and Section 6 further investigates the factors that determine the response of state economies to an oil price shock.

1.2. LITERATURE REVIEW

Previous studies have used various approaches to examine the relationship between oil prices and aggregate economic activity. Backus et al. (2000) apply a DSGE model showing that oil accounts for much of the variation in the terms of trade over the past 25 years. Aguiar-Conraria and Wen (2007) find that standard models fail to explain the relationship between oil shocks and the deep recession in the mid-1970s in the United States. They propose a multiplier-accelerator mechanism in a general equilibrium model. Balke et al. (2008) assess how economic activity responds to oil price changes arising from diverse causes, such as supply shocks, domestic demand shocks, and demand shocks from outside the United States. They find that the effect of any particular oil price shock is largely determined by the source of the shock. Blanchard and Jordi (2007) compare the differences between oil price shocks in the 1970s and 2000s. They conclude that the mild effects of oil prices in the 2000s can be explained by four factors: luck, a smaller share of oil in output, more flexible labor markets, and improvements in monetary policy. Carruth, Hooker, and Oswald (1998) find evidence that the real price of energy has a strong and significant role in explaining fluctuations in unemployment, while the effect of the real interest rate is weaker and less significant. Cuñado et al. (2003) analyze the impact of oil prices on inflation and industrial production indexes for European countries; they find permanent effects on inflation and short-run asymmetric effects on the production growth rate.

The means by which oil price shocks are transmitted throughout the economy are diverse. Kilian (2008b) discusses transmission channels by which oil price changes affect consumption directly. First, oil price increases reduce discretionary income such that consumers have less to spend. Second, when oil prices increase, consumers tend to increase their precautionary savings, reflecting their uncertainty about the future. Third, households will delay or forgo the consumption of durables that are complementary in use of energy due to higher operating cost. Lee and Ni (2002) assess the oil price impact on demand and supply across industries. Their results indicate that a positive oil price shock mainly reduces oil supplies for industries in which oil is a large share of the cost, such as petroleum refining and industrial chemical production. Oil price increases will reduce the demand for output industries such as automobile production. Oil price shocks affect economic activity not only by raising production costs but also by increasing uncertainty and postponing purchases.

Responses of state-level economies to oil price shocks are also of interest. States with different industry structures are likely to be affected differently. Penn (2006), using four oil price measures to examine the impact of oil price shocks on the Eighth Federal Reserve District, finds that some states are more sensitive to oil price changes than others and measures of energy intensity do not help to predict the sensitivity.

In this study, I follow the approach in Penn (2006) to examine the effect of oil price changes on the economies of all 50 states; this approach is discussed later in the model section. The estimation results by state suggest regional heterogeneity in the influence of oil price changes, depending largely on the prevalence of manufacturing and oil production.

1.3. Model

Substantial evidence for the U.S. economy indicates that the relationship between oil prices and economic activity is asymmetric: oil price increases exert much more impact than do declining oil prices. To investigate oil price asymmetry, Hamilton (2003) introduces the concept of "net oil price change" to measure fluctuations in oil prices. The net oil price change for a given period is the amount by which the oil price exceeds its maximum value over the previous 12 months. The purpose of this approach is to isolate the component in the oil price that can be attributed to the exogenous driving forces, such as political events in the Middle East.

Following the approach used in Hamilton (2003) and Penn (2006), I use four measures of oil price change to estimate the effect of oil prices on state economies: "oil price change," "positive oil price change," "net oil price change over four quarters," and "net oil price change over eight quarters." The first measure, "oil price change," is simply the first difference of the natural logs of oil prices. In this paper, I use $\boldsymbol{o_t}$ to denote *oil price* and $\boldsymbol{\Delta o_t}$ for *oil price change*. Second, "positive oil price change" includes only the quarterly oil price changes greater than zero; negative changes are set to zero (1):

$$positive\ oil\ price_t = \begin{cases} \Delta o_t & if\ \Delta o_t > 0; \\ 0 & if\ \Delta o_t \leq 0 \end{cases} \tag{1}$$

Net oil price change is the positive price change from the previous peak over the past four and eight quarters, shown in equations (2) and (3), respectively.

$$net\ oil\ price(4)_t = max\{0, [o_t - \max(o_{t-1}, o_{t-2}, o_{t-3}, o_{t-4}]\} \tag{2}$$

$$net\ oil\ price(8)_t = max\{0, [o_t - \max(o_{t-1}, o_{t-2}, o_{t-3}, o_{t-4}, o_{t-5}, o_{t-6}, o_{t-7}, o_{t-8}]\} \tag{3}$$

All four measures are shown in Figure 3.

Following Penn (2006), I estimate (ARDL) models for each state using a model shown in equation (4). In this model, the growth of quarterly real earned income depends on its lag in the previous four quarters, oil price changes in the previous four quarters, and the change in the federal funds rate during the previous four quarters. Lagged earnings growth is expected to have a positive effect on current income growth, while oil price changes and the interest rate are expected to have negative effects. The estimated coefficients shown in the result tables are the sums of the coefficients for each of the four lagged independent variables.

$$\Delta y_t = \alpha + \sum_{i=1}^{4} \beta_i \Delta y_{t-i} + \sum_{i=1}^{4} \delta_i \Delta o_{t-i} + \sum_{i=1}^{4} \gamma_i \Delta ffr_{t-i} \tag{4}$$

$where \quad y_t = state\ income$

$o_t = oil\ price$

$ffr_t = federal\ funds\ rate$

1.4. DATA

As higher-frequency time series data are preferred over annual data for the purpose of studying the effect of energy price changes (Kilian 2008b), I use quarterly data for all 50 states from 1960:I to 2008:II. For the measure of oil prices, I use the oil and gasoline price index from the Bureau of Economic Analysis (BEA), deflated using the GDP deflator. The logarithm of oil price enters the model.

Since quarterly state-level data for GDP do not exist, a proxy that mimics the growth rate of gross state product (GSP) is needed. Private earnings, the sum of wage and salary disbursements, supplements to wages and salaries, and nonfarm proprietors' income accomplish this task reasonably well. I use the log difference of real private earnings as the state income variable. The federal funds rate is used in the model as a measure of the short-term interest rate. The federal funds rate change is the first difference of the quarterly federal funds rate.

Variable descriptions and descriptive statistics are shown in Table 2. The average quarterly growth rate of real earnings for U.S. over time is 0.81%; the average annual growth rate is 3.29%. Twenty-nine states have income growth higher than or equal to the U.S. average. Nevada, Arizona, and Florida show the highest income growth, while West Virginia, Ohio, and Michigan have the lowest income growth. Time series data from 1960:I to 2008:II are used to estimate the ARDL model for each of the 50 states as well as the United States.

1.5. RESULTS

I estimate ARDL models, as shown in equation (4), for each of the 50 states. Estimated oil price coefficients are shown in Table 3. Two features of this table are important. First, the evidence in favor of the asymmetry hypothesis is strong: only 13 states show significant coefficients using the symmetric oil price variable, while the vast majority of states show strong negative effects using the asymmetric measures of price change. Second, positive oil price shocks generate significant negative impacts on private earnings for most but not all states. The four states with positive oil price coefficients are Alaska, Louisiana, New Mexico, and Wyoming. In all four states, oil and gas production is a major industry. Alaska is the largest oil-producing state with nearly 40% of all U.S. oil output. I estimate that a 10% increase in net oil price change over the previous eight quarters will result in a 2.2% increase in Alaska's real income. The explanation for the other three states is similar, given that Louisiana, New Mexico, and Wyoming rank second, sixth, and third, respectively, in oil production per capita.[2] In addition, these four states rank high in energy spending for petroleum as a share of nominal GDP, which can be interpreted to mean their state economy is more positively dependent on oil than those with a lower ranking.

Table 4 ranks the states from negative to positive impact from a positive oil price shock. South Carolina has the most negative oil price coefficients among the 50 states, as shown in columns (2) and (3): a 10% positive oil price shock will reduce real earned income by more than 2%. The sensitivity of South Carolina to oil prices likely is due to

[2] Source: Energy Information Administration (EIA)

the important role of manufacturing in the state's economy. The production of transportation equipment, fabricated metals, and chemicals are all important and growing industries in South Carolina. Oil is important in two ways: 1) as a production input for the chemical industry and 2) as a determinant of demand for transportation equipment (vehicles) and indirectly for fabricated metals. Thus, positive oil price shocks both increase production costs and reduce demand, causing significant negative impacts on South Carolina's output. Other states that rank high for negative impacts include Maine, Kentucky, West Virginia, Michigan, North Carolina, Arkansas, Nebraska, Vermont, and Arizona. Maine is known for its shipbuilding industries, and its ports play a key role in national transportation. Energy intensity for Maine is high, indicating high dependence on oil.

Similar to South Carolina, Kentucky's primary manufacturing industries include transportation equipment, chemical products, and electrical equipment and machinery; the state ranks fourth among the 50 states in the number of automobiles and trucks assembled. An increase in the price of oil negatively impacts the Kentucky economy by both reducing demand for its products and increasing production costs. The impact of positive oil price shocks on Michigan is similar to Kentucky, given that Michigan is a top automobile producer. West Virginia is negatively affected by oil price changes due to concentrations of refineries and the distribution sector. West Virginia does not have pipelines that bring oil into the state; rather, petroleum products are delivered by barge and truck, more expensive modes of transportation. In addition, West Virginia has fewer product terminals and only one small refinery. These factors likely increase the sensitivity of the West Virginia economy to positive oil price shocks.

The oil price effects on state income are mainly determined by the role oil plays in a state's economy. The states can be divided into "oil producers," which are likely to benefit from oil price increases, and "non-oil producers," which might suffer during oil price increases. Among those non-oil producer states, those with industries that depend heavily on oil as an input will be harmed the most. In other words, states that rely on manufacturing of automobiles, textiles, chemicals, electrical equipment, and paper will be affected more by an oil shock. Oil price effects are different for each state due to specific characteristics of each state's economy. Oil price coefficients are not significant for some states, possibly because the effects are not visible in the short run.

Figure 4 shows how the 50 states are affected during oil price increases. States with a lighter color are more negatively impacted by an oil price shock. It is obvious that states in the middle portion of the United States should expect larger income decreases when oil prices rise. Energy intensity alone is not a good predictor of the sensitivity of state economies to oil price changes; states with higher energy intensity are not necessarily more sensitive to oil price changes.

1.6. FACTORS AFFECTING THE IMPACT OF OIL PRICE CHANGES ON STATE INCOMES

In this section, I estimate a model of the determinants of the oil price coefficients. Oil price coefficients are likely to vary due to factors such as energy dependence, intensity of energy use, and industrial structure. As discussed in Section 5, whether a state is an oil producer or an oil consumer determines the sign of the oil price coefficient. In addition, the intensity of energy use, industrial structure, and productions of alternative energy sources may also explain the differences between the coefficients.

Using data from the Bureau of Economic Analysis (BEA) and the Energy Information Administration (EIA), I calculate petroleum expenditure per capita, production of petroleum, coal and natural gas per capita, and the percent of the manufacturing, construction, and transportation sectors in GDP. [3] The per capita petroleum production measures the degree of dependence on oil resources as a source of income and output for a particular state. Incomes in oil-producing states are expected to respond positively to positive oil price shocks. On the other hand, states producing petroleum substitutes, such as coal and natural gas, are likely to be affected less by fluctuations in oil price. In addition, the prevalence of manufacturing, construction, and transportation as shares of GDP tells us about a state's economic structure. If a state has a high presence of these energy-intensive industries, it will more likely experience a decline in real income for a given oil price shock when compared with states that have smaller shares of GDP in these industries.

[3] Energy expenditure and production data are from EIA; other data are from BEA.

I use *c* to denote the oil price coefficient, which measures the effect of a positive oil price shock on a state's real income. The oil price coefficients are obtained from Table 4. The variables used to interpret *c* also need to be cross-sectional. The latest available year is 2008; Table 5 shows the basic statistics and description of the data used in this section. A simple OLS model is used to regress *c* on the potential explanatory variables including petroleum expenditure per capita, petroleum production per capita, per capita production of coal and natural gas, and percentage of manufacturing, construction and transportation as share of GDP.

As shown in Table 6, the model explains nearly 75% of the variation in the oil price coefficient. The *petroleum production*, *manufacturing, coal production,* and *natural gas production* variables are clearly the most important explanatory variables. The estimated sign for *petroleum production* is as expected: if a state has a very high level of petroleum production, the state will respond positively to a positive oil price shock. On the other hand, the states with a higher percentage of manufacturing in GDP are negatively affected by positive oil price shocks. Manufacturing usually entails more intense energy consumption than other industries per unit of output; thus, manufacturing-intensive states will suffer more from positive oil price shocks than states with lower manufacturing intensity. Estimates for the two petroleum substitute production variables have opposite signs. The positive sign for *natural gas production* is as expected; an alternative energy source is likely to protect a state from the negative impacts of oil price increases. Furthermore, as shown in Table 7, the largest natural gas producing states are also important oil producing states. Unlike those natural gas producing states, coal producing states should expect to be more negatively impacted when oil prices rise. Both the mining and processing involve using giant machines, which makes petroleum an important input in the coal production process. Moreover, the coal mining industry is heavily dependent on transportation services: 35% of the price of coal goes to transportation.[4] As petroleum is an important input in both the mining and shipping process, increase in oil prices will add cost to the coal mining industry and reduce profits.

It is somewhat surprising that the prevalence of construction and transportation as a share of GDP are not significant predictors. One reason might be that these variables are correlated with other explanatory variables; a higher percent of manufacturing is associated with more energy expenditure and needs more transportation for product delivery. Per capita petroleum expenditure is also not a significant determinant for the impact of oil prices. Table 8 shows the rank of state petroleum expenditures per capita: the states with the highest per capita expenditure are the largest oil-producing states. Thus, the positive and negative influences might offset each other.

We may conclude that, of the factors examined, the prevalence of manufacturing in a state's economy is an important determinant of the sensitivity of a given state to a positive oil price shock. In other words, if a state's economy relies more on manufacturing, the state will be negatively impacted by rising oil prices. Moreover, whether a state is an oil producer also affects the impact of positive oil price changes; oil-producing states are more likely to benefit from an oil price increase. In addition, states with higher natural gas production can also expect to benefit from positive oil price

[4] Source: Energy Information Administration (EIA), Coal Transportation Rate Database.

changes, while coal producers will be more negatively influenced by rising oil prices. Finally, there is no evidence that the petroleum expenditure and the relative size of the construction and transportation sectors have significant power explaining the impact of oil price shocks.

1.7. CONCLUSION

In this paper, I examine the sensitivity of state economic activity to oil price shocks. The asymmetric relationship between oil prices and economic activity that has been documented for the United States is confirmed for most but not all states. Using ARDL models, I explore the relationship between oil price changes and the growth of real income at the state level. The estimation results show 1) strong evidence of asymmetry in the impact of oil prices on state income and 2) different levels of sensitivity to oil price changes among the states. Except for the oil-producing states, a 1% rise in the price of oil causes real income to decline by 0.1% within four quarters for the median state. For the oil and gas producing states of Alaska, Louisiana, New Mexico, and Wyoming, the oil price coefficient is positive, indicating a direct relationship between oil price shocks and real income. Upon further investigation, I find that manufacturing prevalence and the production of petroleum and its substitutes explain nearly 75% of the variance in oil price coefficients across states. More specifically, states with high shares of manufacturing in GDP and more coal production will suffer more when oil prices rise, while oil and natural gas producing states tend to grow when oil prices rise.

The implication of the findings of this paper is that when oil prices spike, most states will experience a decline in real income; the median state will experience a decline of 0.1% per 1% rise in oil prices. To a large extent, the sensitivity to oil price changes depends on the prevalence of manufacturing. The result of this study should be of interest to policymakers, as oil price spikes will continue to occur in the future. Even though oil prices declined significantly as a result of the 1997 recession, political events in North Africa have generated another price spike. In addition, as the economies of the world are recovering from the recession, more oil price shocks are likely. The states most affected by oil shocks should pay more attention to reducing their dependence on oil by means such as by enacting tax incentives for hybrid and fuel-cell vehicles and developing renewable and alternative fuels.

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Table 1: Major Events Associated with Oil Price Increase and Recession Dates

Business cycle dates (quarterly)		
Peak	**Through**	**Events**
1960.II	1961.I	
1969. IV	1970. IV	
1973. IV	1975. I	October War and Oil Embargo 1973
1980. I	1980. III	Iranian Revolution 1979
1981. III	1982. IV	Iran-Iraq War 1980
1990. III	1991. I	Gulf War 1990
2001. I	2001. IV	Afghan War 2001
2007. IV		

Table 2: Descriptive Statistics

Variables	Mean	Std. Dev	Description
Oil Price	0.0038	0 0520	Log dıfference of deflated quarterly oıl price
Positive Oil Price	0.0193	0 0354	Positive oil price change
Net Oil Price (4)	0.0123	0.0318	Net oil price change over the past four quarters
Net Oil Price (8)	0.0096	0.0290	Net oil price change over the past eight quarters
Federal Fund Rate	-0.0011	0 9842	First difference of quarterly federal fund rate
State Income			**Log difference of real private earnings for the U.S .and each state**
United States	0.0081	0.0102	
Alabama	0.0082	0.0117	
Alaska	0.0102	0.0366	
Arizona	0.0133	0.0161	
Arkansas	0.0091	0.0137	
California	0.0092	0.0120	
Colorado	0.0116	0.0135	
Connecticut	0.0074	0.0136	
Delaware	0.0082	0 0176	
Florida	0.0122	0.0139	
Georgia	0.0110	0.0127	
Hawaii	0.0094	0.0140	
Idaho	0.0097	0.0160	
Illinois	0.0059	0.0118	
Indiana	0.0061	0.0151	
Iowa	0.0062	0.0122	
Kansas	0.0075	0.0119	
Kentucky	0.0080	0.0146	
Louisiana	0.0078	0.0361	
Maine	0.0071	0.0150	
Maryland	0.0091	0.0104	
Massachusetts	0.0076	0.0131	
Michigan	0.0054	0.0219	
Minnesota	0.0086	0.0119	
Mississippi	0.0083	0.0151	
Missouri	0.0064	0.0113	
Montana	0.0070	0.0150	
Nebraska	0.0072	0.0115	
Nevada	0.0153	0.0189	
New Hampshire	0.0102	0.0172	
New Jersey	0.0072	0.0122	
New Mexico	0.0089	0.0120	
New York	0.0060	0.0184	
North Carolina	0.0099	0.0137	
North Dakota	0.0079	0.0154	
Ohio	0.0050	0.0136	
Oklahoma	0.0086	0.0136	
Oregon	0.0088	0.0142	
Pennsylvania	0.0056	0.0106	
Rhode Island	0.0062	0.0144	
South Carolina	0.0096	0.0142	
South Dakota	0.0081	0.0150	
Tennessee	0.0094	0.0120	
Texas	0.0116	0.0111	
Utah	0.0109	0.0131	
Vermont	0.0082	0.0141	
Virginia	0.0108	0.0122	
Washington	0.0098	0.0170	
West Virginia	0.0045	0.0271	
Wisconsin	0.0068	0.0115	
Wyoming	0.0084	0.0208	

Note: Descriptive statistics for variables are over the period from 1961:I to 2008:II. Oil prices and state incomes are deflated real values. See Section 2 for the calculation of the four oil price measures

Table 3: Oil Price Coefficients

State	(1) Oil Price Change		(2) Positive oil price change		(3) Net oil price change(4)		(4) Net oil price change(8)	
United States	-0.0089		-0 0639	**	-0.0586	*	-0 0933	**
Alabama	-0 0351		-0 1167	***	-0.0810	*	-0 0776	
Alaska	0.1331	*	0.1422		0.1933	*	0.2215	**
Arizona	-0.0339		-0.1369	***	-0.1330	**	-0.1838	***
Arkansas	-0.0657	*	-0.1527	***	-0.1427	***	-0.1618	***
California	-0.0302		-0.0724	*	-0.0796	**	-0.1330	***
Colorado	-0.0225		-0.0651		-0.0629		-0 1147	**
Connecticut	-0.0244		-0.0833	*	-0.0940	*	-0.1409	**
Delaware	-0.0649		-0.1540	***	-0 1042		-0.1320	*
Florida	-0 0269		-0.0917	**	-0 0782	*	-0.1083	**
Georgia	-0.0283		-0.1313	***	-0.1003	**	-0.1251	**
Hawaii	-0.0532		-0.0742	*	-0.0860	*	-0.1232	**
Idaho	-0.0367		-0.0823		-0 0636		-0.0942	
Illinois	-0.0355		-0.0917	**	-0.1201	***	-0.1758	***
Indiana	-0.0398		-0.1333	***	-0 1239	**	-0.1341	*
Iowa	-0.0646	**	-0.1136	***	-0.1289	***	-0.1733	***
Kansas	0.0059		-0.0538		-0.0525		-0 0740	
Kentucky	-0.0914	**	-0.1883	***	-0.1779	***	-0 2071	***
Louisiana	0.1773	*	0.0981		0 2863		0.2954	*
Maine	-0 0898	**	-0.1745	***	-0.1854	***	-0.2143	***
Maryland	-0.0197		-0.0812	**	-0.0748	**	-0.1194	***
Massachusetts	-0.0532	*	-0.0784	**	-0.0891	**	-0.1476	***
Michigan	-0.0119		-0.1884	**	-0.1644	*	-0.1437	
Minnesota	-0.0643	**	-0.1271	***	-0.1411	***	-0.1981	***
Mississippi	-0.0079		-0.1172	**	-0.0560		-0 0304	
Missouri	-0.0390		-0.1286	***	-0.1385	***	-0.1625	***
Montana	-0.0050		-0 0463		-0.0283		-0.0579	
Nebraska	-0.0558	*	-0 1375	***	-0.1586	***	-0.2084	***
Nevada	-0.0394		-0.1015		-0.0927		-0.1313	
New Hampshire	-0.0421		-0.1344		-0.1637	**	-0.2144	***
New Jersey	-0.0464		-0.1152	***	-0.1450	***	-0.2133	***
New Mexico	0.0501		0.0018		0.0182		0.0147	
New York	-0.0202		-0.0615		-0.0764		-0.1278	*
North Carolina	-0.0584	*	-0.1604	***	-0.1384	***	-0.1552	**
North Dakota	-0.0353		-0.0667		-0.0906		-0.0938	
Ohio	-0.0250		-0.1269	***	-0.1189	**	-0.1374	**
Oklahoma	0.0377		-0.0038		0 0020		-0.0186	
Oregon	-0.0284		-0.1039	**	-0.1052	**	-0.1528	***
Pennsylvania	-0.0337		-0 0827	**	-0 0830	**	-0.1227	**
Rhode Island	-0.0182		-0 0845	*	-0.0863		-0.1178	*
South Carolina	-0.0809	**	-0.2069	***	-0.2086	***	-0.2333	***
South Dakota	-0.0603		-0.1180	**	-0.1279	**	-0.1692	***
Tennessee	-0.0517	*	-0.1526	***	-0.1332	***	-0.1433	**
Texas	0.0250		-0.0143		-0.0057		-0.0374	
Utah	-0.0007		-0.0482		-0.0303		-0.0546	
Vermont	-0 0672	*	-0.1440	***	-0.1416	**	-0.1755	**
Virginia	-0.0230		-0 0898	**	-0.0649		-0.1157	**
Washington	-0.0292		-0.0985	*	-0.0897		-0.1121	
West Virginia	-0.0596		-0.1675	*	-0 1956	**	-0.2428	**
Wisconsin	-0.0378		-0.1063	***	-0 1086	***	-0.1336	***
Wyoming	0.0470		0 0356		0.0338		0.0158	

Note: Coefficients in this table are the sum of the coefficients for four lagged values of oil price *** denotes the 1% significance level; ** denotes the 5% significance level; * denotes the 10% significance level.

Table 4: Rank of Sensitivity to Oil Price Shock by State

Rank	(1) Oil Price Change			(2) Positive Oil Price Change			(3) Net Oil Price Change (4)			(4) Net Oil Price Change (8)		
1	Kentucky	-0.0914	**	South Carolina	-0.2069	***	South Carolina	-0.2086	***	West Virginia	-0.2428	**
2	Maine	-0.0898	**	Michigan	-0.1884	**	West Virginia	-0.1956	**	South Carolina	-0 2333	***
3	South Carolina	-0.0809	**	Kentucky	-0.1883	***	Maine	-0.1854	***	New Hampshire	-0.2144	***
4	Vermont	-0.0672	*	Maine	-0.1745	***	Kentucky	-0.1779	***	Maine	-0.2143	***
5	Arkansas	-0.0657	*	West Virginia	-0.1675	*	Michigan	-0.1644	*	New Jersey	-0 2133	***
6	Delaware	-0.0649		North Carolina	-0.1604	***	New Hampshire	-0.1637	**	Nebraska	-0.2084	***
7	Iowa	-0.0646	**	Delaware	-0.1540	***	Nebraska	-0.1586	***	Kentucky	-0.2071	***
8	Minnesota	-0.0643	**	Arkansas	-0.1527	***	New Jersey	-0.1450	***	Minnesota	-0.1981	***
9	South Dakota	-0.0603		Tennessee	-0.1526	***	Arkansas	-0.1427	***	Arizona	-0.1838	***
10	West Virginia	-0.0596		Vermont	-0.1440	***	Vermont	-0.1416	**	Illinois	-0.1758	***
11	North Carolina	-0.0584	*	Nebraska	-0.1375	***	Minnesota	-0.1411	***	Vermont	-0.1755	**
12	Nebraska	-0.0558	*	Arizona	-0.1369	***	Missouri	-0.1385	***	Iowa	-0.1733	***
13	Massachusetts	-0.0532	*	New Hampshire	-0.1344		North Carolina	-0 1384	***	South Dakota	-0.1692	***
14	Hawaii	-0.0532		Indiana	-0.1333	***	Tennessee	-0.1332	***	Missouri	-0.1625	***
15	Tennessee	-0.0517	*	Georgia	-0.1313	***	Arizona	-0.1330	**	Arkansas	-0.1618	***
16	New Jersey	-0.0464		Missouri	-0.1286	***	Iowa	-0.1289	***	North Carolina	-0.1552	**
17	New Hampshire	-0.0421		Minnesota	-0.1271	***	South Dakota	-0.1279	**	Oregon	-0.1528	***
18	Indiana	-0.0398		Ohio	-0.1269	***	Indiana	-0.1239	**	Massachusetts	-0.1476	***
19	Nevada	-0.0394		South Dakota	-0.1180	**	Illinois	-0.1201	***	Michigan	-0.1437	
20	Missouri	-0.0390		Mississippi	-0.1172	**	Ohio	-0.1189	**	Tennessee	-0.1433	**
21	Wisconsin	-0 0378		Alabama	-0.1167	***	Wisconsin	-0.1086	***	Connecticut	-0.1409	**
22	Idaho	-0.0367		New Jersey	-0.1152	***	Oregon	-0.1052	**	Ohio	-0 1374	**
23	Illinois	-0.0355		Iowa	-0.1136	***	Delaware	-0.1042		Indiana	-0.1341	*
24	North Dakota	-0.0353		Wisconsin	-0.1063	***	Georgia	-0.1003	**	Wisconsin	-0.1336	***
25	Alabama	-0.0351		Oregon	-0.1039	**	Connecticut	-0.0940	*	California	-0.1330	***
26	Arizona	-0.0339		Nevada	-0 1015		Nevada	-0.0927		Delaware	-0.1320	*
27	Pennsylvania	-0 0337		Washington	-0.0985	*	North Dakota	-0.0906		Nevada	-0.1313	
28	California	-0.0302		Illinois	-0.0917	**	Washington	-0.0897		New York	-0.1278	*
29	Washington	-0.0292		Florida	-0.0917	**	Massachusetts	-0.0891	**	Georgia	-0.1251	**
30	Oregon	-0.0284		Virginia	-0.0898	**	Rhode Island	-0.0863		Hawaii	-0.1232	**
31	Georgia	-0.0283		Rhode Island	-0.0845	*	Hawaii	-0.0860	*	Pennsylvania	-0.1227	**
32	Florida	-0.0269		Connecticut	-0.0833	*	Pennsylvania	-0.0830	**	Maryland	-0.1194	***
33	Ohio	-0.0250		Pennsylvania	-0.0827	**	Alabama	-0.0810	*	Rhode Island	-0.1178	*
34	Connecticut	-0.0244	*	Idaho	-0.0823		California	-0.0796	**	Virginia	-0.1157	**
35	Virginia	-0.0230		Maryland	-0.0812	**	Florida	-0.0782	*	Colorado	-0.1147	**
36	Colorado	-0.0225		Massachusetts	-0.0784	**	New York	-0.0764		Washington	-0.1121	
37	New York	-0.0202		Hawaii	-0.0742	*	Maryland	-0.0748	**	Florida	-0.1083	**
38	Maryland	-0.0197		California	-0.0724	*	Virginia	-0.0649		Idaho	-0 0942	
39	Rhode Island	-0.0182		North Dakota	-0.0667		Idaho	-0.0636		North Dakota	-0.0938	
40	Michigan	-0.0119		Colorado	-0 0651		Colorado	-0.0629		Alabama	-0.0776	
41	Mississippi	-0.0079		New York	-0.0615		Mississippi	-0.0560		Kansas	-0.0740	
42	Montana	-0.0050		Kansas	-0.0538		Kansas	-0.0525		Montana	-0.0579	
43	Utah	-0.0007		Utah	-0.0482		Utah	-0.0303		Utah	-0.0546	
44	Kansas	0.0059		Montana	-0.0463		Montana	-0.0283		Texas	-0.0374	
45	Texas	0.0250		Texas	-0.0143		Texas	-0.0057		Mississippi	-0.0304	
46	Oklahoma	0 0377		Oklahoma	-0.0038		Oklahoma	0.0020		Oklahoma	-0.0186	
47	Wyoming	0 0470		New Mexico	0.0018		New Mexico	0.0182		New Mexico	0.0147	
48	New Mexico	0.0501		Wyoming	0 0356		Wyoming	0.0338		Wyoming	0 0158	
49	Alaska	0.1331		Louisiana	0 0981		Alaska	0.1933	*	Alaska	0.2215	**
50	Louisiana	0.1773	*	Alaska	0.1422		Louisiana	0.2863		Louisiana	0.2954	*

Note: States are ranked based on the oil price coefficients from the worst affected from an upward oil shock. Coefficients in this table are the sum of the coefficients for four lagged values of oil price. *** denotes the 1% significance level; ** denotes the 5% significance level; * denotes the 10 significance level.

Table 5: Descriptive Statistics of Affecting Factors

Variables	Mean	Std. Dev.	Description
Poil	-0.0925	0.0595	Effect of positive oil price change
Petroleum Expenditure	3.2805	1.3037	Per capita petroleum expenditure
Petroleum Production	0.0941	0.3221	Per capita petroleum production
Manufacturing	14.2269	6.0400	Percent of manufacturing as share of GDP
Construction	4.8608	1.2092	Percent of construction as share of GDP
Transportation	3.8144	1.7725	Percent of transportation as share of GDP
Coal Production	0.4139	2.1567	Per capita coal production
Natural Gas Production	0.1838	0.6716	Per capita natural gas production

Table 6: Estimation of Factors Affecting the Effect of Positive Oil Price Change

Variable	Estimate	Std. Error	t-value	p-value
Constant	-0.0491	0.0372	-1.3200	0.1937
Petroleum Expenditure	-0.0107	0.0094	-1.1300	0.2653
Petroleum Production	0.1148	0.0354	3.2400	0.0023
Manufacturing	-0.0019	0.0009	-2.2000	0.0333
Construction	0.0012	0.0042	0.3000	0.7679
Transportation	-0.0024	0.0043	-0.5700	0.5717
Coal Production	-0.0338	0.0079	-4.2800	0.0001
Natural Gas Production	0.1362	0.0266	5.1300	<.0001
R-square	0.7497			

Table 7: Rank of Energy Production Per Capita (Million Btu)

Rank	State	Petroleum	Rank	State	Natural Gas	Rank	State	Coal
1	Alaska	2,106.1130	1	Wyoming	4,633.1689	1	Wyoming	15,173.9649
2	Louisiana	580.5929	2	New Mexico	808.3752	2	West Virginia	2,132.5597
3	Wyoming	576.1350	3	Louisiana	748.6989	3	Montana	820.4610
4	North Dakota	567.6475	4	Alaska	650.2060	4	Kentucky	682.8235
5	Montana	189.0025	5	Oklahoma	584.6521	5	North Dakota	603.9762
6	New Mexico	173.4163	6	Texas	336.9776	6	New Mexico	239.4936
7	Texas	106.6907	7	Colorado	303.5182	7	Utah	206.8486
8	Oklahoma	101.9688	8	Utah	170.1143	8	Colorado	144.8110
9	Kansas	82.0684	9	Arkansas	158.1235	9	Pennsylvania	126.6871
10	Utah	46.7811	10	Kansas	153.4363	10	Indiana	125.7051
11	Mississippi	43.5996	11	West Virginia	153.1964	11	Alabama	108.3572
12	California	37.8457	12	North Dakota	121.7952	12	Virginia	79.9575
13	Colorado	28.2689	13	Montana	120.6361	13	Illinois	59.0302
14	Arkansas	12.2946	14	Alabama	92.5690	14	Ohio	55.3799
15	South Dakota	12.2344	15	Mississippi	39.3009	15	Alaska	33.4837
16	Alabama	9.4060	16	Michigan	28.3869	16	Arizona	26.7715
17	Nebraska	7.7920	17	Kentucky	28.3265	17	Texas	21.2100
18	West Virginia	5.0907	18	Virginia	17.1044	18	Louisiana	12.3021
19	Illinois	4.2555	19	Pennsylvania	16.5189	19	Maryland	11.5923
20	Michigan	3.6084	20	California	9.0620	20	Mississippi	9.7976
21	Kentucky	3.5777	21	Ohio	7.6554	21	Tennessee	9.4682
22	Ohio	2.8753	22	New York	2.6391	22	Oklahoma	8.1918
23	Indiana	1.6868	23	South Dakota	2.0509	23	Kansas	1.8371
24	Pennsylvania	1.6667	24	Nebraska	1.7486	24	Missouri	0.9088
25	Nevada	0.9668	25	Tennessee	0.7810	25	Arkansas	0.5398
26	Florida	0.6158	26	Indiana	0.7454			
27	Tennessee	0.3197	27	Oregon	0.2104			
28	New York	0.1150	28	Florida	0.1381			
29	Missouri	0.0964	29	Illinois	0.0988			
30	Arizona	0.0465	30	Arizona	0.0826			
31	Virginia	0.0053	31	Maryland	0.0051			
			32	Nevada	0.0015			

Note: States with zero energy production are excluded. Data source: Energy Information Administration (EIA).

Table 8: Petroleum Expenditure per Capita

Rank	State	Nominal Dollars (Million)	Rank	State	Nominal Dollars (Million)
1	Alaska	9,202	26	Virginia	2,942
2	Wyoming	7,762	27	Missouri	2,874
3	Louisiana	5,472	28	Tennessee	2,864
4	North Dakota	5,323	29	Delaware	2,809
5	Texas	4,657	30	Washington	2,789
6	Hawaii	4,016	31	Connecticut	2,686
7	Maine	4,005	32	Ohio	2,642
8	Montana	3,914	33	Wisconsin	2,632
9	South Dakota	3,593	34	North Carolina	2,628
10	Iowa	3,566	35	Pennsylvania	2,615
11	West Virginia	3,561	36	Idaho	2,595
12	Oklahoma	3,541	37	Nevada	2,584
13	Vermont	3,506	38	Oregon	2,540
14	Kentucky	3,498	39	Utah	2,540
15	Kansas	3,333	40	Massachusetts	2,524
16	Minnesota	3,289	41	Georgia	2,522
17	Mississippi	3,286	42	Colorado	2,505
18	Arkansas	3,274	43	Illinois	2,449
19	New Jersey	3,266	44	Maryland	2,389
20	Nebraska	3,192	45	California	2,364
21	New Mexico	3,189	46	Florida	2,319
22	New Hampshire	3,131	47	Rhode Island	2,286
23	Alabama	3,053	48	Michigan	2,279
24	Indiana	2,977	49	Arizona	2,185
25	South Carolina	2,943	50	New York	1,914

Source: U.S. Energy Information Administration, http://www.eia.doe.gov/

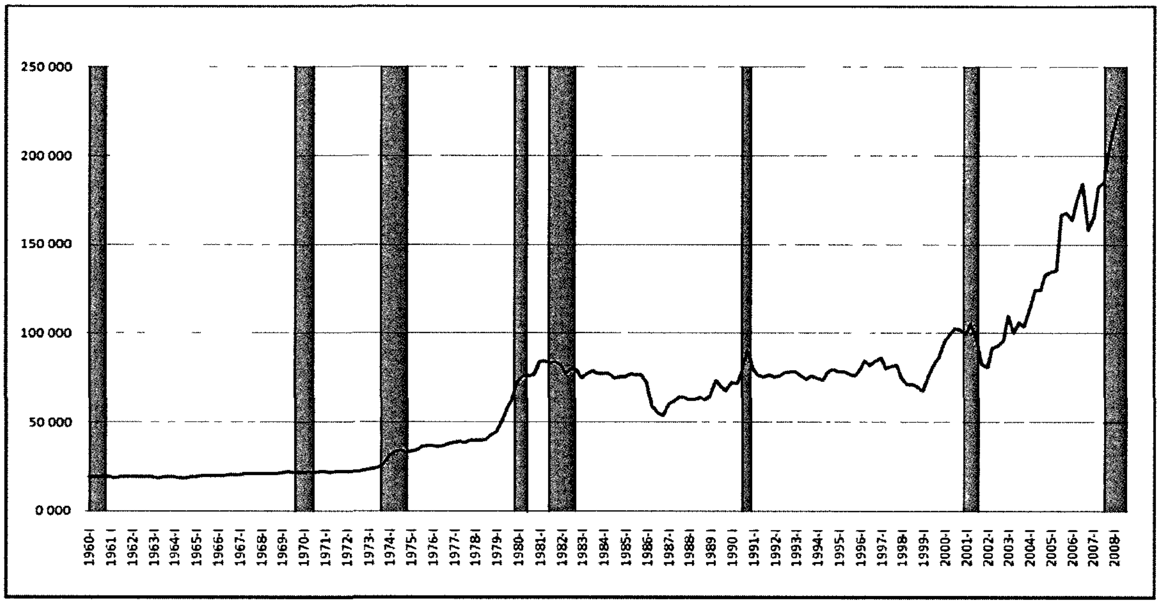


Figure 1: Price Index for Gasoline and Oil

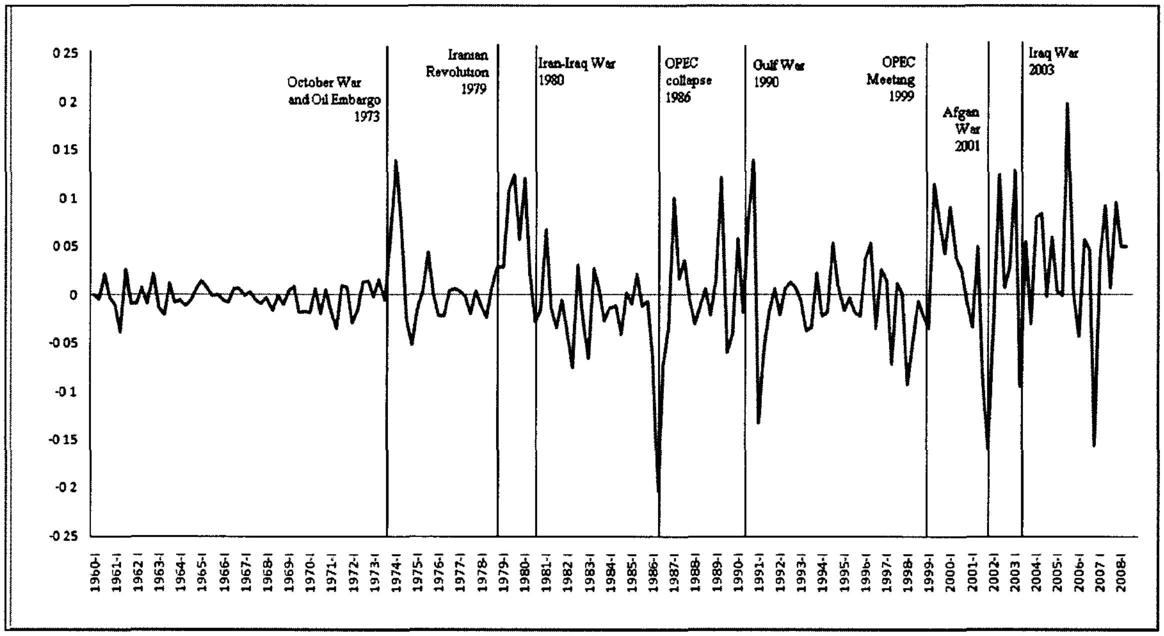


Figure 2: Oil Price Quarter-to-Quarter Change

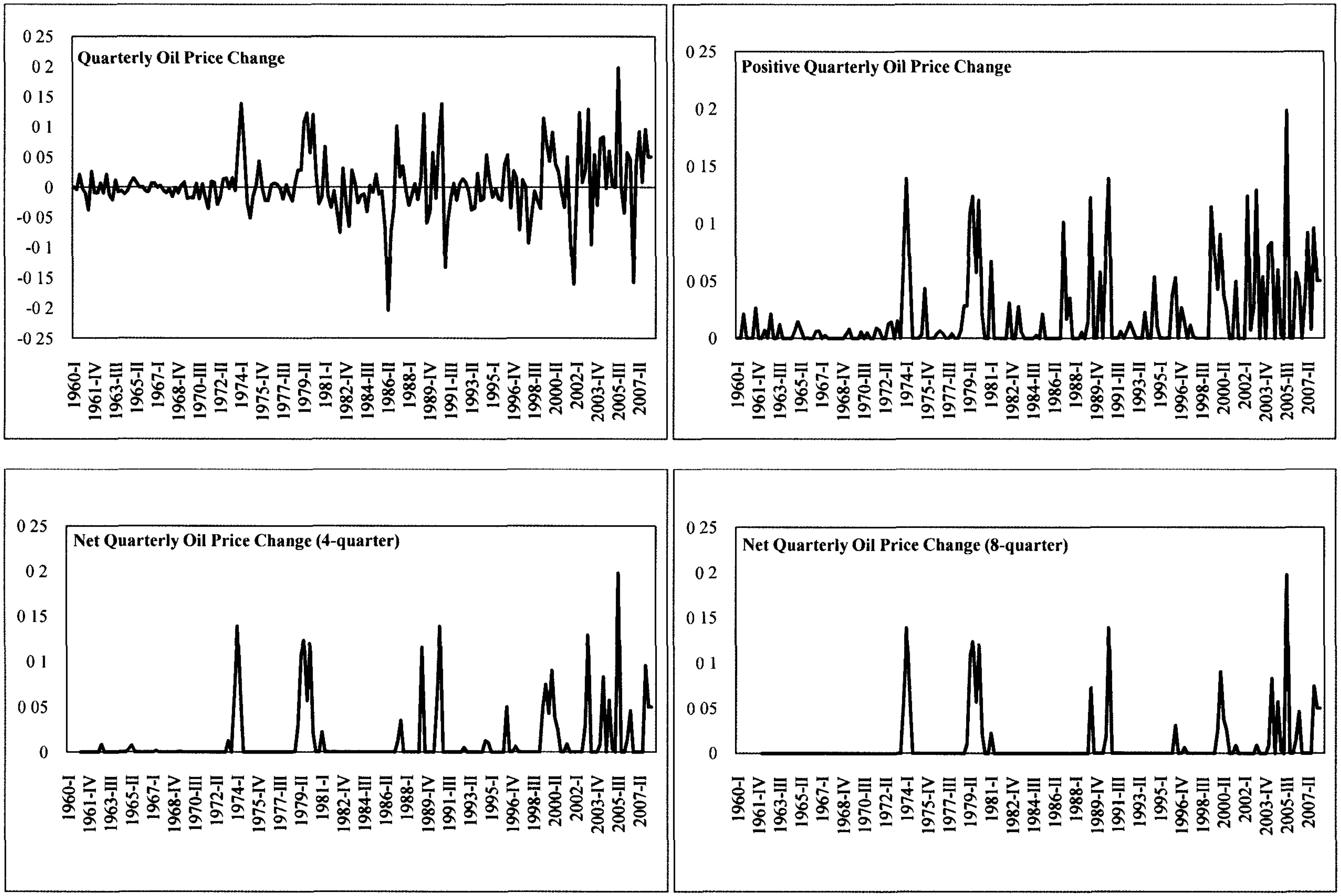
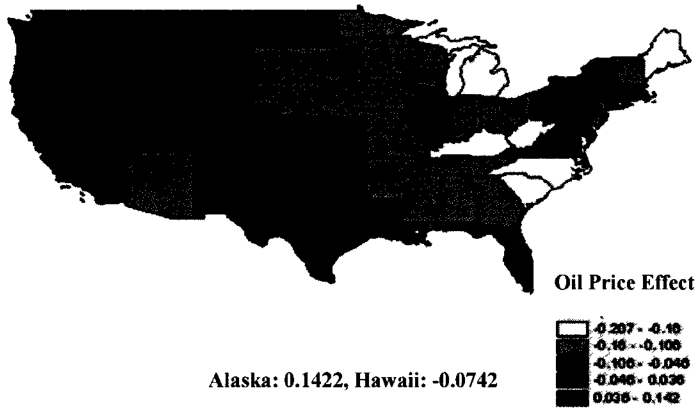
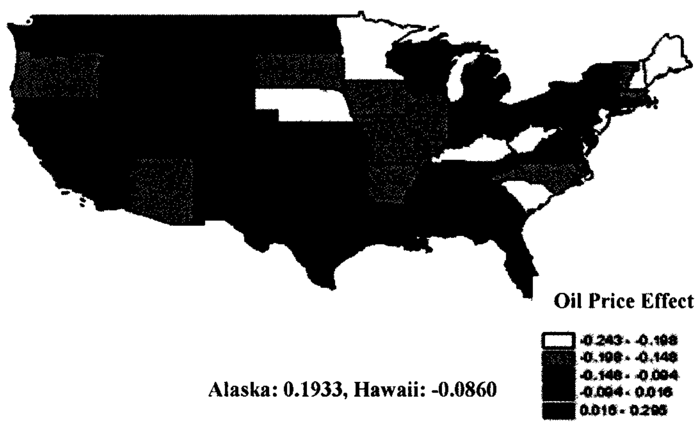


Figure 3: Four Measures of Oil Price Changes

(I) States Affected by Positive Oil Price Change



(II) States Affected by Net Oil Price Change (4)



(III) States Affected by Net Oil Price Change (8)

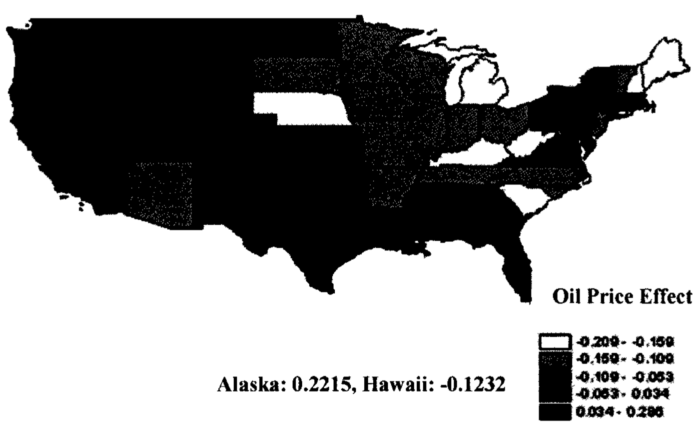


Figure 4: Impact of Oil Price Changes on States

CHAPTER II

REGIME-SWITCHING ANALYSIS OF A STATE ECONOMY'S RESPONSE TO AN OIL PRICE SHOCK

2.1. INTRODUCTION

It is generally acknowledged that oil price shocks have asymmetric impacts on the economy. An increase in the price of oil is usually followed by a recession, while a major decline in oil prices does not lead to a comparable economic expansion. The study of asymmetric effects of oil price changes can be traced back to Mork (1989), and there are many studies offering different theoretical and empirical analyses regarding the asymmetry or the nonlinear relationship between oil price and the economy (Lee et al. 1995, Cuñado et al. 2003, Hamilton 2003, Penn 2006, and Kilian 2008).

A recent study by Huang (2008) enriches the existing literature by examining how a positive oil price shock affects the tolerance and the speed of response of 21 economies. The 21 countries are different in the degree of economic development, energy dependence, and efficiency of energy use. For each country, Huang (2008) employs multivariate threshold models to estimate the threshold level (c) and the delay periods of response (d) to an oil shock. Huang (2008) then identifies the possible explanatory variables affecting c and d and produces three main findings. First, a country that is more advanced in economic development (measured by real per capita GDP) tends to have greater tolerance to a positive oil price change, because a more developed country requires a lower ratio of energy use in its industry. Second, a country with a lower ratio of energy use, a smaller percent of energy imports, and a more advanced economy is likely to have a longer delay in periods of response after an oil price shock. Last, the length of the delay of response increases as an economy develops.

Inspired by Huang (2008), this paper studies the tolerance and the speed of adjustment of state economies to the impact of oil price changes. Huang (2008) states that the level of economic development is the most important factor affecting the threshold level and the speed of response of an economy for a given oil shock. There exists imbalance in the degree of economic development among the states, which is expected to result in differences in the tolerance and the delay time of response of a state economy to an oil price shock. Furthermore, due to industrial diversity, states differ in terms of energy dependence and the efficiency of energy use. For instance, states that rely more on manufacturing and transportation industries are more sensitive to oil price changes and thus are likely to respond more quickly.

It has been established by many studies that a nonlinear relationship exists between oil prices and the economy. However, most existing studies simply use positive oil price changes to examine the impact of oil price changes, assuming that negative oil price changes have no effect on the economy. This paper estimates a regime-switching model for each state in order to show how oil price shocks affect the growth rate of a state economy. Regime-switching models are one type of nonlinear regression model. This methodology has been increasingly discussed and used in recent years to model the nonlinearities or asymmetries in time series. Regime-switching models have been applied to a wide range of research on such topics as business cycles (Teräsvirta and Anderson 1992), stock market (Liu et al. 2005), and real estate (Füss, Stein, and Zietz 2010), inflation (Amisano and Fagan 2010).

This study uses regime-switching models to investigate the tolerance and delay of the response of state economic activity to oil price shocks. In particular, I use a smooth transition autoregressive (STAR) model, which allows a more gradual transition between regimes. Compared with the threshold autoregressive (TAR) model, which assumes instantaneous regime switching, the STAR model is more data driven. In addition, the STAR model does not make any ad hoc assumptions regarding the speed of regime switching or the number of regimes.

The threshold values estimated in the STAR model will reflect a state's tolerance to oil shocks. When an oil price change is below a certain threshold, it has a certain effect on the economy; when the oil price change exceeds the threshold, the effect gradually switches to another regime, and the oil price shock affects the state economy to a different degree. The fitted threshold value is likely to vary by state according to a state's level of economic development and its degree of dependence on oil. The lag length of the threshold variable is also estimated in order to determine how fast a state responds to an oil price change. Studies suggest that state economies will show different responses to an oil price shock, with the more developed and less oil-dependent states expected to require more time to adjust to oil price changes.

The remainder of the paper is organized as follows. Section 2 presents the regime-switching model and the estimation methodology. Section 3 describes the data, and Section 4 discusses the results of the nonlinear estimation process. Section 5 concludes.

2.2. MODEL

During decades of development, regime-switching models have evolved into different forms. For example, a form used in Huang (2006) is a two-regime TAR model, which assumes that the model switches instantaneously once an oil price shock passes a threshold value. When the oil price change is below the threshold, it has little influence on the economy; once the oil price change exceeds the threshold, it becomes an essential factor that drives economic activity.

The TAR model ignores cases in which there are more than two regimes and cases in which the transition between regimes occurs smoothly. By contrast, this study employs a more general regime-switching model that removes these restrictions. The smooth transition autoregressive (STAR) model is used to investigate the response of state economies to an oil price shock. Based on the assumption that state economies may follow different dynamic processes, the STAR model is more general and therefore open to more possibilities.

The standard STAR model contains both linear and nonlinear terms:

$$
\begin{aligned}
y_t &= (\alpha^1 + \sum_{i=1}^{p} \beta_i^1 y_{t-i} + \sum_{k=1}^{K}\sum_{j=1}^{q} \delta_{k,j}^1 x_{k,t-i}) \\
&+ (\alpha^2 + \sum_{i=1}^{p} \beta_i^2 y_{t-i} + \sum_{k=1}^{K}\sum_{j=1}^{q} \delta_{k,j}^2 x_{k,t-i})\, G(\cdot) + \varepsilon_t \qquad \mathit{for}\ t = 1 \ldots T
\end{aligned}
\tag{1}
$$

where y_t = state income

x_t = exogenous variables including oil price (o_t), interest rate (r_t) and stock price (s_t)

$\varepsilon_t \sim i.i.d.$

$G(\cdot) =$ the transition function.

Superscript *1* denotes the coefficients of the linear part of the model, while the superscript *2* denotes the coefficients of the nonlinear part. The linear part of the model, the terms just to the right of the equality, takes the form of an autoregressive distributed lag (ARDL) model.

Thus, how a state's economy responds to an oil price shock is thought to depend on the lagged values of the endogenous variable and exogenous variables including the price of oil, interest rates, and stock prices. Interest rates reflect the influence of monetary policy, while stock prices reflect the increasingly important role of financial wealth in the economy. All the variables used in this study are in the form of growth rates.

The term $G(\cdot)$ is a transition function, governing the movement from one regime to another. Following Teräsvirta (2004), the general logistic transition function can be written as

$$G(\gamma, c, h_t) = \left(1 + \exp\left\{-\gamma \prod_{n=1}^{N} (h_t - c_k)\right\}\right)^{-1}, \quad \gamma > 0 \tag{2}$$

where γ is the adjustment parameter determining the speed of transition between regimes, N is the number of transition points, h_t is the transition variable, which in this study is oil price change o_{t-d}; d denotes the delay period of response to changes in oil price, and c_k is the threshold value indicating the level of the oil price change that marks the transition point. Equations (1) and (2) define the logistic smooth transition regressive (LSTR) model. When the transition variable changes, the value of the transition function moves smoothly between 0 and 1; γ controls the slope of the transition function and the location of the thresholds. The most common choices for the value of N are $N=1$ and $N=2$. If $N=1$, the transition occurs monotonically; if $N=2$, the transition path will be symmetric around the midpoint of $(c_1 + c_2)/2$ where the value of the transition function is minimized.

There are three types of models nested in the general logistic transition function in equation (2). First, when $\gamma = 0$, $G(\cdot) = 1/2$, so the STAR model in equation (2) becomes a linear model. Second, when $N=1$, the STAR model is termed an LSTR1 model (Teräsvirta 2004). In this case, the model transitions monotonically from one extreme regime to the other. An LSTR1 model can be used to capture asymmetric behavior in time series. When h_{t-d} moves from $-\infty$ to ∞, $G(\cdot)$ transits smoothly from 0 to 1. When $h_{t-d} = c$, $G(\cdot) = 1/2$. Third, when $N=2$, the STAR model becomes an LSTR2 model. The LSTR2 model can be used to model dynamic behavior when the process is similar at the outer edges of the transition variable. In this case, when the transition variable h_{t-d} is at $-\infty$ and ∞, the transition function $G(\cdot)=1$.

When $\gamma \to \infty$, the LSTR1 model approaches an instantaneous regime-switching model, while the LSTR2 model will result in a three-regime-switching regression model (Teräsvirta 2004). A STAR model nests the two-regime instantaneous TAR model as a special case: when $N=1$ and the value of γ is large, the model becomes a two-regime TAR model.

Since states differ from each other in the level of economic development and the degree of dependence on oil, they will likely experience differing tolerances and delays of adjustment to an oil price change. A regime-switching model allows the dynamic movement of a state economy to depend on the oil price variable. In this case, the behavior of a given state's economy to an oil price shock is divided into different regimes. An oil price shock is compared to one or two threshold values. The differences between the oil price change and the threshold values determine how a state economy will adjust to an oil price change. This threshold value c can be interpreted as the tolerance of an economy to an oil shock. The best-fitting lag length of the transition variable d will be estimated as the delay of response of a state's economy.

To estimate a STAR model, the first step is to test linearity, i.e., whether a model has just linear parts or both linear and nonlinear parts. However, the testing problem is complicated because the autoregressive lag order p, the delay variable d, and the threshold value c are not determined. Various methods exist in the literature to estimate these three parameters. For example, Franses and Van Dijk (2000) demonstrate an example in which they search for two oil price variable candidates with all possible lag lengths d as well as p and select the threshold variable that minimizes the Akaike Information Criterion (AIC). This method is most useful when the choices of p and d depend on each other (Enders 2003). However, it raises the difficulty of estimation when the threshold value c is not known.

As an alternative, Enders (2003) illustrates a technique in which the best-fitting autoregressive lag order p is selected first. He suggests that one should start by estimating a simple linear model in order to fix the data-generating lag process: that is, to choose the AR (p) process. Following Enders (2003), this study estimates a simple linear AR (p) model such that

$$y_t = \alpha + \sum_{i=1}^{p} \beta_i y_{t-i} + \eta_t \tag{3}$$

where α is a constant, β_i represents coefficients of the lags of state income, and η_t is the error term. Equation (3) is estimated in order to choose the lag order p. By searching over $p = 1,...p^*$,[1] one can choose the best-fitting p by examining the t-values of each coefficient, the F-test on a group of coefficients, or the minimum AIC and BIC (Bayesian Information Criterion).[2] After determining the best-fitting p, I estimate the model with only the linear part in equation (1) to test plausible combinations of the exogenous

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[1] p^* is the maximum possible value of p. Since quarterly data are used in this model, 8 is used as the maximum number of p, which allows the autoregressive impact for two years.

[2] Franses and Van Dijk (2000) proposed a way to determine p by minimizing the AIC. However, according to Teräsvirta (1994), experience indicates that the indication of the Bayesian BIC is more suitable than the AIC. Thus, when the AIC and BIC indicate different best-fitting lag lengths, this study chooses the one that is indicated by BIC.

variables and their lags, which are used as the initial setup in the linearity test discussed next.

This study follows Luukkonen, Saikkonen, and Teräsvirta (1988) and Teräsvirta (2004) to test linearity. To accomplish this, the transition function $G(\cdot)$ is replaced by a Taylor series approximation. The JMulTi software package incorporates this method. Teräsvirta (2004) suggests not omitting lags shorter than the maximum lag of the endogenous variable that is selected by the linear model for the reason that gaps in the lag structure may reduce the power of the linearity test. This linearity test will help to determine the transition variable as well as the type of STAR model.

Equation (1) and (2) can be rewritten in a simplified form such that

$$y_t = \phi' z_t + \theta' z_t G(\cdot) + \varepsilon_t, \qquad t = 1 \ldots T \tag{4}$$

where ϕ' and θ' are the sets of parameters for the linear part and the nonlinear part, respectively, and z_t is the set of the lagged endogenous variables and the exogenous variables. Based on this form, the linearity test can proceed by approximating the transition function in equation (2) with a third-order Taylor expansion around the null hypothesis $\gamma = 0$. The approximation yields the following auxiliary regression:

$$y_t = \rho'_0 z_t + \sum_{l=1}^{3} \rho'_l \tilde{z}_t h_t^l + \varepsilon_t^*, \qquad t = 1 \ldots T \tag{5}$$

where h_t is the transition variable raised to the power l, and $\varepsilon_t{}^*$ is the error term. As mentioned, in this study, the potential transition variables are restricted to oil price changes and their lags.[3]

The null hypothesis is $H_0 : \rho_1 = \rho_2 = \rho_3 = 0$, for testing for linearity. The *F-statistic* is used to determine the test result. The linearity test is conducted using all potential transition variables, one at a time; a strong candidate variable is one in which the null is rejected. If the null hypothesis is rejected for more than one transition variable, one should select the transition variable with the lowest *p-value* from the *F-test.* Thus, the selection of the transition variable is actually the test for the delay period of a state economy's response to an oil price change.

If linearity is rejected and the transition variable is determined, one can proceed to select the type of STAR model, either LSTR1 or LSTR2. The selection of the model type is also based on equation (5). Teräsvirta (1994) suggests the following tests in sequence:

1. $\mathrm{H}_{04} : \rho_3 = 0.$
2. $\mathrm{H}_{03} : \rho_2 = 0 \mid \rho_3 = 0.$
3. $\mathrm{H}_{02} : \rho_1 = 0 \mid \rho_2 = \rho_3 = 0.$

If the test of H_{03} yields the lowest p-value, it is an LSTR2 model; otherwise, it is an LSTR1 model.[4] Once the transition variable is selected and the model type is determined,

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[3] Since this study focuses on the state economy's response to oil price changes, only oil price changes and their lag are chosen as possible transition variables to be tested. In general cases, a plausible transition variable can be any endogenous or exogenous variable or its lags.

[4] The linearity test, model selection, and nonlinear estimation in this study are done using JMulTi.

the next stage is to estimate the parameters in the STAR model using conditional maximum likelihood.

2.3. DATA

Due to the lack of quarterly state output data, quarterly private earnings from the Bureau of Economic Analysis (BEA) are used as a proxy for state quarterly GDP. I use quarterly data from 1969:II to 2010:I, deflated by the PCE deflator from BEA. The BEA price index data for gasoline and oil is used as the oil price variable, deflated by the GDP deflator. The federal funds rate is used as the measure of the interest rate. The quarterly federal funds rate is calculated from monthly data obtained from the Federal Reserve. The stock price variable is obtained from monthly adjusted closing prices from Yahoo finance and then deflated by the CPI from the Bureau of Labor Statistics (BLS). All variables used in the models are log first differences except for interest rate, which is first difference.

I conduct the modeling process for each of the 50 states. The assumption is that states with a higher level of economic development and less dependence on oil are likely to exhibit stronger tolerance and longer response delays to an oil price shock. Descriptive statistics of the data used in the model are presented in Table 1. According to the table, Arizona, Colorado, Florida, Nevada, and Utah have higher state income growth rates on average. Alaska has much higher standard deviation in economic growth than other states. Both the highest and lowest growth rates occurred in Alaska.

2.4. RESULTS

2.4.1 LINEAR ANALYSIS

As mentioned in Section 2, for each state, I use the autoregressive distributed lag (ARDL) model in equation (1) to test for the best-fitting lag length for the endogenous variable and the potential combination of exogenous variables. All the lags, up to the maximum lag of the endogenous variables, are kept in this step in order to avoid reducing the power of the nonlinear test later on. I use the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) to evaluate the models. When AIC and BIC reach minima at different lag lengths, I follow the indication by BIC. I set the maximum lag of the endogenous and exogenous variables to eight and loop over with continuous lags of the endogenous variable and all possible combinations of the exogenous variable. For the other exogenous variables, I keep the lags that are significant in the estimation of the linear models. The results from the linear estimation are used as the starting point of the nonlinear analysis.

2.4.2 NONLINEAR ANALYSIS

Using the results from the linear estimation as the initial set-up of the model, I follow the sequential steps discussed in Section 2 to test the linearity and the type of the model for each state. Oil price variables up to eight lags are used in the test as the potential transition variables. The delay parameter d will also be determined at this stage as the best-fitting model is selected. The parameter d indicates how long it takes a state's economy to respond to an oil price shock. The test results are presented in Table 2.

The suprising test results show that only 20 out of the 50 states should be modeled with the LSTR1 model, which is usually used for modeling the asymmetry in economic dynamic behavior. Twenty-eight states fail to reject the linearity test in the first step, which implies the absence of an oil price threshold for these states. The test results indicate the LSTR2 model is the best choice for both Illinois and Virginia.

The lag lengths of the best-fitting transition variables indicate how fast a state responds to oil price changes. Table 2 shows that the delay of response varies from 0 to 8 quarters. For most states, it will take longer than one year for an oil price change to affect its economy, with three exceptions: Wyoming will respond immediately to an oil price shock, Alaska will respond in three quarters, and North Carolina will respond one year after an oil price shock. The other 19 states will be affected in five to eight months. The two states that respond most quickly, Alaska and Wyoming, are oil-producing states, and their economies would be influenced positively by oil price changes. North Carolina, also heavily dependent on oil, is the largest manufacturer of textiles, tobacco, and furniture in the United States; a major sector in its economy can easily be impacted by the effect of oil prices on production costs. By contrast, it takes much longer for an oil price shock to impact states that are less dependent on oil. For example, New York, known as the global center of finance and services, media, entertainment, and trade, ranks as the second-lowest in energy expenditures as share of GDP in 2008.[5] Oil is not a main factor that affects its major industries, and New York will not feel the full impact until two years after an oil price shock.

[5] State Energy Expenditure Ranking Data Source: Energy Information Administration (EIA), www.eia.doe.gov.

The two essential parameters in the STAR model are the slope parameter γ and the critical value of the transition variable c. Table 3 shows estimates of γ and c from the best-fitting LSTR1 models for the 20 states over the period 1969:II to 2010:I. More detailed estimation results of the 20 LTSR1 models are provided in Table A1 in the Appendix. The results show strong evidence of a significant asymmetric relationship between oil price changes and state incomes. The estimations of γ are significant for all states except Wyoming. The estimated threshold values of the transition variables c are significant for all states. The results reveal diversity in both of the two essential variables across states.

The slope parameter γ indicates the speed of adjustment from one regime to the other. The larger the value of γ, the faster will be the transition. When γ is very large such as for Colorado, Florida, North Carolina, Oregon, Washington, and Wyoming, the LSTR1 model approaches an instant-transition model, in which the switch between regimes happens instantaneously. Figures 1 to 3 plot the graphs of the transition functions $G(\cdot)$ against the transition variables, with states differentiated by different normal regimes.[6] The slope of the curves reflects the speed of adjustment between regimes. The transitions for Arkansas and New York are smoother than for the others. Oregon, Wyoming, and several other states with large γ values have very steep transition curves. These figures also tell whether a state will follow the linear or the nonlinear adjustment under normal conditions. For most states, the nonlinear part of the model is typical.

[6] Figures 1 to 3 show the graphs of the transition function $G(\cdot)$ against the transition variable c for the LSTR1 models. Figure 1 plots nine states with the linear part as the normal regime, Figure 2 plots eight states with the nonlinear part as the normal regime, and Figure 3 plots the three states with unclear normal regime.

The critical value c indicates the oil price growth rate where the transition occurs. For each of the 20 states, the model switches from the linear regime to the nonlinear regime at the threshold. For example, the Louisiana economy will make the shift when the quarterly growth of oil prices reaches 0.0739. Among the 20 states, 12 exhibit positive thresholds. Alaska has the highest critical value, 0.0859, which means Alaska's economy has a higher tolerance for oil price shocks than the other state economies. Alaska ranks second in crude oil production among the states. The oil and gas industry dominates Alaska's economy and is the main revenue source of the state. The state will directly gain more revenue when oil prices go up. Since the demand for energy is relatively inelastic, oil price changes always have a positive effect on Alaska's economy, unless oil price increases are extremely high and affect the demand side.

Kansas, by contrast, has a much lower threshold at 0.0181. Kansas is a major manufacturer of aircraft and automobiles; its major industries are more sensitive to oil price fluctuations. Even small increases in oil prices will add to the production cost and have an impact on its economy.

Eight states exhibit negative threshold values. Arkansas has the lowest transition point at -0.2273, which is close to the minimum value of oil price change. The Arkansas figure in Figure 2 shows that most of the observations fall into the nonlinear regime; thus, the dynamic behavior of the Arkansas economy mostly stays in this regime. Unless there is a severe decline in oil price, the impact of oil price on the Arkansas economy will be driven by both the linear and the nonlinear part of the model.

Table 4 provides a comparison between the estimated oil price effects from OLS models and LSTR1 models.[7] Most of the oil price variables are significant in the LSTR1 models as indicated in Table A1; however, most of the OLS models fail to show significant oil price effects. The estimates from the OLS models are biased in that the OLS models fail to incorporate the nonlinearity in the data. Estimates from the LSTR1 models show that the threshold value *c* divides each state into two regimes, and the typical regime indicates the one that contains more observations.

It is difficult to summarize a rule on oil price effects; typical regimes and transition values are determined in Table 4. However, it is possible to explain the numbers for a given state. Take Alaska, for example. If oil prices rise 1% per quarter, typically the quarterly real earnings growth rate in Alaska will increase 0.128%. Nevertheless, in a rare situation, once the growth rate in oil price exceeds 0.0859, a 10% quarterly increase in oil price will cause Alaska's state real earnings to decline 9.19%. As mentioned, the oil and gas industry dominates the state's economy, with more than 80% of the state's revenue coming from petroleum extraction. Except for the energy industry, the Alaska economy relies on seafood processing and exporting, and its tourism and services sector is also growing. Normally, oil price increases will transform into more revenue in oil products directly, from which the state's economy benefits. However, if oil price increases very sharply,[8] it will affect the other industries by adding costs; this might

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[7] The estimates of the impact of oil prices from the threshold models in Table 4 are the sums of the oil price coefficients, excluding the insignificant ones. When g=0, the estimate is the sum of the coefficients in the linear part of the model; when g=1, the estimate is the sum of the coefficients from both the linear and nonlinear parts of the model. Table A1 presents more detailed estimation of coefficients in the LSTR1 models.

[8] The threshold oil price growth rate value for Alaska (0.0859) is very high compared with the historical average of 0.0044.

also harm the oil production sector because the benefits will be offset once the demand declines. In the case of Alaska, the signs of oil price effects are different in the two regimes. For some states, oil price effects have the same sign in both regimes but at different levels. Louisiana is also one of the largest oil-producing states. Unlike Alaska, Louisiana can always benefit from an oil price rise. Under normal conditions (g=0), a 1% quarterly increase in oil price will raise the state's private earnings by 0.027%; if the growth rate of oil price exceeds 0.0739, a 10% positive oil price increase will cause the state's earnings to rise much more. For Kansas, Missouri, and North Carolina, it is not clear which regime is more common, because the observations are dispersed evenly between the two regimes. A 1% increase in oil price growth will increase earnings in North Carolina by 0.05%; however, a 10% increase will reduce the state's earnings by 1.24%. The major industries in North Carolina are agriculture and manufacturing. As the ninth-wealthiest state in the nation,[9] North Carolina has a certain level of tolerance to positive oil price shocks, such that the state's economy will not be harmed unless oil price growth exceeds 0.0084. When oil price growth exceeds the threshold, the increase in production cost and cost of resource reallocation reinforce each other, resulting in a significant impact on the economy. However, when the oil price decreases, the decrease in production cost and the increase in reallocation cost offset each other, and the state will not benefit from it, either. The LSTR1 model captures the asymmetry in the effect of oil price changes on state incomes.

Table A2 presents the estimation results from the LSTR2 models for Illinois and Virginia. Figure 4 shows the cross plot of transition functions relative to the transition

[9] In terms of gross state product (data source: BEA).

variables for Illinois and Virginia. Each point reflects one observation. The response of state earnings to oil price shocks in these two states can be divided into three regimes: the lower part in the middle is the linear regime, and the upper parts are the nonlinear regimes. In the Illinois figure, most of the points fall into the linear regime, where g=0. For Virginia, most observations locate in the regimes on the left side and the middle; only a few points fall into the right-side regime. Both states have significant transition points and slopes. The speed of transition between regimes is relatively smooth compared with other states with two regimes. For Illinois, if the oil price growth level is between -0.0879 and 0.1352, the variation in the state's earnings will be ruled by the linear part of the model, otherwise both the linear and nonlinear parts of the model. A 10% increase in oil price will cause the state's private earnings to decrease by 1.12%; if the oil price declines by 10%, the model will shift to the left outer regime, and it will reduce the state's earnings by 1.92%.[10] Comparing the two states, an equivalent oil price hike harms Illinois more than Virginia, and the impact lasts longer, up to seven quarters. However, in the nonlinear part, Virginia responds positively to oil price changes in several previous periods, while the lagged effects of oil price changes may offset each other for Illinois.

Based on the figures and Tables 3, 4, A1, and A2, the dynamic behavior of an oil price shock on a state can be divided into regimes, such that there is a nonlinear relationship between oil price changes and state economy. Estimated delay parameters *d* are not the same across states, suggesting that state economies exhibit differences in the speed of response to an oil price shock. State economies with higher dependence on oil

[10] Similarly, the estimates for the impacts of oil prices are the sums of oil price coefficients from Table A2, excluding the insignificant ones.

tend to respond faster, regardless of whether the state is an oil producer or not. Further, values of the transition variable c are different across states. This indicates that the transition between regimes occurs at different values, indicating that states have different degrees of tolerance to oil price shocks. It is difficult to conclude which factors determine the transition values and oil price effects for all the states; however, both the transition values and the oil price effect estimates might be explained by investigating the state-specific industrial characteristics. States also differ in the speed of adjustment between regimes, which is indicated by the slope variable γ.

2.5. CONCLUSION

The notion that oil prices have an asymmetric effect on economic activity is well established for the U.S. and other nations. This study examined whether a similar nonlinear relationship exists at the state level. This study adopts smooth transition autoregressive (STAR) models proposed by Teräsvirta (2004). This study allows for three potential types of models: a linear model (with one regime), the LSTR1 model (with two regimes), and the LSTR2 model (with three regimes). Surprisingly, the results show that 28 states fail to reject a linear model. Among the other 22 states, 20 fit the LSTR1 model; Illinois and Virginia fit the LSTR2 model.

The estimation results show differences among states in both the tolerance and delay of response to an oil price shock. The delay of response is likely due to a state's dependence on oil. Those dependent tend to respond faster than others. States also present differences in the tolerance to an oil price shock, which is indicated by the different critical values of the transition variable. However, the explanation for the difference in the location variable c is not straightforward. The transition value and oil price effects might be explained by state-specific industrial characteristics. Some states have a really high estimation of the slope parameter, which indicates that an instantaneous threshold model may be appropriate for them.

This study offers insights into the estimation of the nonlinear relationship between oil prices and the state-level economy but also raises several questions for future research. First, why does the linearity test suggest linear models for some states? One possible explanation for the result might be that the effect of oil is offset by some factor that is omitted in this study. Second, this study shows the differences in critical values of the transition variables and the slope parameter, which still need more detailed explanation. Finding the reasons behind the observation is important. It helps to model the dynamic behavior of a state economy more precisely and helps the policymaker to make more efficient policies to adjust the economy. Last, since the STAR model helps to capture the adjustment process of a state economy to an oil price shock, it can also be applied in forecasting the performance of a state economy.

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Table 1: Descriptive Statistics for Variables, 1969:II to 2010:I

Variable	Definition	Mean	Median	Max	Min	Std. Dev.
State Income	Growth Rate of State Income in					
AL	Alabama	0.0161	0.0157	0.0604	-0.0385	0.0142
AK	Alaska	0.0192	0.0119	0.2319	-0.1417	0.0400
AZ	Arizona	0.0218	0.0217	0.0618	-0.0403	0.0171
AR	Arkansas	0.0169	0.0162	0.0622	-0.0442	0.0152
CA	California	0.0173	0.0180	0.0490	-0.0372	0.0143
CO	Colorado	0.0205	0.0211	0.0591	-0.0255	0.0168
CT	Connecticut	0.0152	0.0169	0.0540	-0.0561	0.0151
DE	Delaware	0.0158	0.0188	0.0804	-0.0620	0.0182
FL	Florida	0.0200	0.0199	0.0719	-0.0375	0.0161
GA	Georgia	0.0188	0.0210	0.0529	-0.0361	0.0140
HI	Hawaii	0.0169	0.0167	0.0563	-0.0254	0.0155
ID	Idaho	0.0182	0.0186	0.0568	-0.0365	0.0176
IL	Illinois	0.0139	0.0149	0.0446	-0.0444	0.0136
IN	Indiana	0.0138	0.0136	0.0543	-0.0566	0.0165
IA	Iowa	0.0145	0.0136	0.0496	-0.0279	0.0136
KS	Kansas	0.0162	0.0168	0.0656	-0.0430	0.0147
KY	Kentucky	0.0158	0.0151	0.1061	-0.0391	0.0165
LA	Louisiana	0.0159	0.0154	0.0683	-0.0325	0.0159
ME	Maine	0.0159	0.0143	0.0878	-0.0326	0.0172
MD	Maryland	0.0171	0.0185	0.0427	-0.0327	0.0125
MA	Massachusetts	0.0160	0.0165	0.0597	-0.0500	0.0151
MI	Michigan	0.0122	0.0125	0.0843	-0.0811	0.0220
MN	Minnesota	0.0166	0.0177	0.0543	-0.0431	0.0147
MS	Mississippi	0.0160	0.0162	0.0751	-0.0335	0.0139
MO	Missouri	0.0146	0.0150	0.0555	-0.0755	0.0137
MT	Montana	0.0162	0.0143	0.0742	-0.0314	0.0169
NE	Nebraska	0.0160	0.0157	0.0641	-0.0240	0.0133
NV	Nevada	0.0224	0.0238	0.0802	-0.0443	0.0205
NH	New Hampshire	0.0184	0.0189	0.0652	-0.0373	0.0187
NJ	New Jersey	0.0155	0.0168	0.0429	-0.0427	0.0138
NM	New Mexico	0.0185	0.0179	0.0663	-0.0330	0.0143
NY	New York	0.0141	0.0159	0.0744	-0.0954	0.0206
NC	North Carolina	0.0176	0.0188	0.0726	-0.0523	0.0156
ND	North Dakota	0.0175	0.0154	0.1094	-0.0245	0.0170
OH	Ohio	0.0128	0.0122	0.0518	-0.0358	0.0144
OK	Oklahoma	0.0166	0.0161	0.0767	-0.0413	0.0179
OR	Oregon	0.0169	0.0163	0.0529	-0.0361	0.0156
PA	Pennsylvania	0.0138	0.0137	0.0472	-0.0328	0.0117
RI	Rhode Island	0.0145	0.0147	0.0585	-0.0513	0.0161
SC	South Carolina	0.0171	0.0181	0.0604	-0.0454	0.0157
SD	South Dakota	0.0173	0.0171	0.0848	-0.0193	0.0147
TN	Tennessee	0.0173	0.0187	0.0553	-0.0370	0.0137
TX	Texas	0.0197	0.0183	0.0594	-0.0428	0.0153
UT	Utah	0.0206	0.0199	0.0539	-0.0248	0.0151
VT	Vermont	0.0160	0.0156	0.0533	-0.0379	0.0157
VA	Virginia	0.0192	0.0203	0.0550	-0.0254	0.0139
WA	Washington	0.0179	0.0182	0.0658	-0.0425	0.0182
WV	West Virginia	0.0131	0.0109	0.2041	-0.1243	0.0309
WI	Wisconsin	0.0151	0.0155	0.0464	-0.0361	0.0132
WY	Wyoming	0.0183	0.0186	0.0786	-0.0733	0.0253
o	Growth rate of gasoline price	0.0044	0.0030	0.1873	-0.4194	0.0680
r	Growth rate of federal funds rate	-0.0392	-0.0033	6.0167	-3.9900	1.0503
s	Growth rate of stock price	0.0037	0.0070	0.1708	-0.2949	0.0726

Table 2: Test of Linearity for State Incomes

State	Transition Variable	H_0	H_{04}	H_{03}	H_{02}	Suggested Model
AL						Linear
AK	o(t-3)*	0 006266	0 766200	0 045284	0 001219	LSTR1
AZ	o(t-8)*	0 016651	0 014542	0 077808	0 512750	LSTR1
AR	o(t-8)*	0 000037	0 152060	0 003566	0 000436	LSTR1
CA						Linear
CO	o(t-6)*	0 001868	0 227140	0 028262	0 004561	LSTR1
CT	o(t-7)*	0 000118	0 027919	0 042260	0 001150	LSTR1
DE	o(t-8)*	0 001251	0 006385	0 008841	0 486310	LSTR1
FL	o(t-8)*	0 000748	0 014840	0 062326	0 020223	LSTR1
GA						Linear
HI						Linear
ID						Linear
IL	o(t-8)*	0 000016	0 174250	0 000011	0 042187	LSTR2
IN						Linear
IA						Linear
KS	o(t-8)*	0 000885	0 075334	0 047084	0 004562	LSTR1
KY						Linear
LA	o(t-7)*	0 000372	0 001699	0 055345	0 159800	LSTR1
MA	o(t-8)*	0 000000	0 010215	0 000205	0 000102	LSTR1
MD						Linear
ME						Linear
MI	o(t-7)*	0 001224	0 013608	0 023815	0 143970	LSTR1
MN						Linear
MS						Linear
MO	o(t-8)*	0 000000	0 000374	0 118690	0 000005	LSTR1
MT	o(t-7)*	0 007057	0 049793	0 242770	0 017303	LSTR1
NE						Linear
NV						Linear
NH						Linear
NJ						Linear
NM						Linear
NY	o(t-8)*	0 000348	0 004095	0 025769	0 099488	LSTR1
NC	o(t-4)*	0 001679	0 051967	0 344580	0 000795	LSTR1
ND						Linear
OH						Linear
OK						Linear
OR	o(t-5)*	0 002087	0 004570	0 320280	0 036215	LSTR1
PA	o(t-8)*	0 000164	0 001049	0 377740	0 004425	LSTR1
RI						Linear
SC						Linear
SD						Linear
TN						Linear
TX						Linear
UT						Linear
VA	o(t-8)*	0 002213	0 367340	0 000389	0 091084	LSTR2
VT						Linear
WA	o(t-8)*	0 002818	0 393400	0 195420	0 000161	LSTR1
WV	o(t-8)*	0 000002	0 003813	0 034240	0 000099	LSTR1
WI						Linear
WY	o(t)*	0 003024	0 060054	0 054241	0 028055	LSTR1

Note Twenty two states fail to reject the F test in step one, which indicates linear models

Table 3: Estimates of LSTR1 Models for State Incomes

State	Transition Variable	gamma	c
AK	o(t-3)	46.8195***	0.0859***
AR	o(t-8)	2.0713***	-0.2273***
AZ	o(t-8)	289.7156*	-0.0603***
CO	o(t-6)	74714.5402*	0.0737***
CT	o(t-7)	29.2617***	-0.0409***
DE	o(t-8)	63.9307*	0.0402***
FL	o(t-8)	2264580.2961***	-0.0439***
KS	o(t-8)	110.0792**	0.0181*
LA	o(t-7)	132.3394***	0.0739***
MA	o(t-8)	71.5195***	-0.0545***
MI	o(t-7)	4839.1772***	0.0655***
MO	o(t-8)	107.0890***	0.0084*
MT	o(t-7)	145.5908**	0.0331***
NC	o(t-4)	207311.9619*	0.0084**
NY	o(t-8)	8.6135**	-0.0836**
OR	o(t-5)	2588410972.0000*	0.0687***
PA	o(t-8)	2286.6657*	0.0181***
WA	o(t-8)	5032462.5760***	-0.0482***
WV	o(t-8)	4692.3087**	0.0410***
WY	o(t)	109020882.0189	-0.0769***

Note. *** indicates 1% significance level; ** indicates 5% significance level; * indicates 10% significance level. Gammas indicate the slope of LSTR1 models, and c's indicate the transition points where the switching between regimes happens

Table 4: Impact of Oil Prices on State Income

		STAR Model			
State	**OLS**	**g=0**	**g=1**	**typical**	**c**
AK	0.1738	0.1280	-0.9187	g=0	0.0859
AR	0.0118	8.3453	0.2827	g=1	-0.2273
AZ	-0.0183	0.2116	-0.0269	g=1	-0.0603
CO	-0.0115	0.0000	-0.9852	g=0	0.0737
CT	0.0037	-0.1323	0.0219	g=1	-0.0409
DE	-0.0009	-0.0517	0.3283	g=0	0.0402
FL	0.0262	-0.1338	0.1041	g=1	-0.0439
KS	0.0150	0.1399	-0.1138	not clear	0.0181
LA	0.1243	0.0265	2.7718	g=0	0.0739
MA	-0.0296	-0.4734	-0.0380	g=1	-0.0545
MI	-0.0277	0.0422	1.7907	g=0	0.0655
MO	-0.0258	-0.0086	0.2416	not clear	0.0084
MT	0.0448	0.0000	0.1183	g=0	0.0331
NC	-0.0289	0.0579	-0.1241	not clear	0.0084
NY	-0.0826	1.6661	-0.2952	g=1	-0.0836
OR	-0.1084	-0.0707	0.3546	g=0	0.0687
PA	-0.0221	-0.0816	0.0450	g=0	0.0181
WA	0.0066	0.7562	-0.0495	g=1	-0.0482
WV	0.0672	0.0000	0.1583	g=0	0.0410
WY	0.1341	-0.7897	-0.1378	g=1	-0.0769

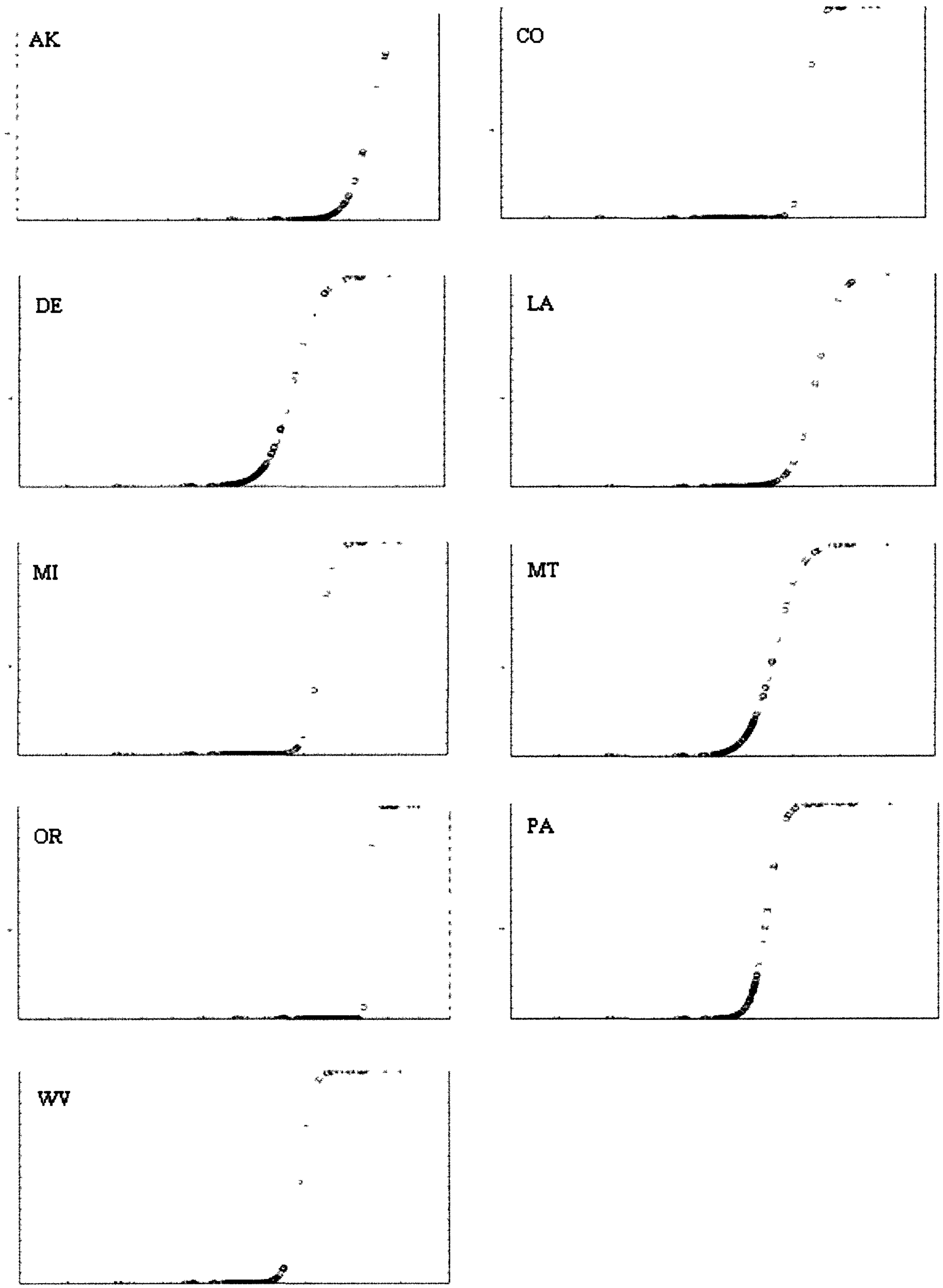

Figure 1: Cross-Plot of Transition Function (G) against Transition Variable (Normal: g=0)

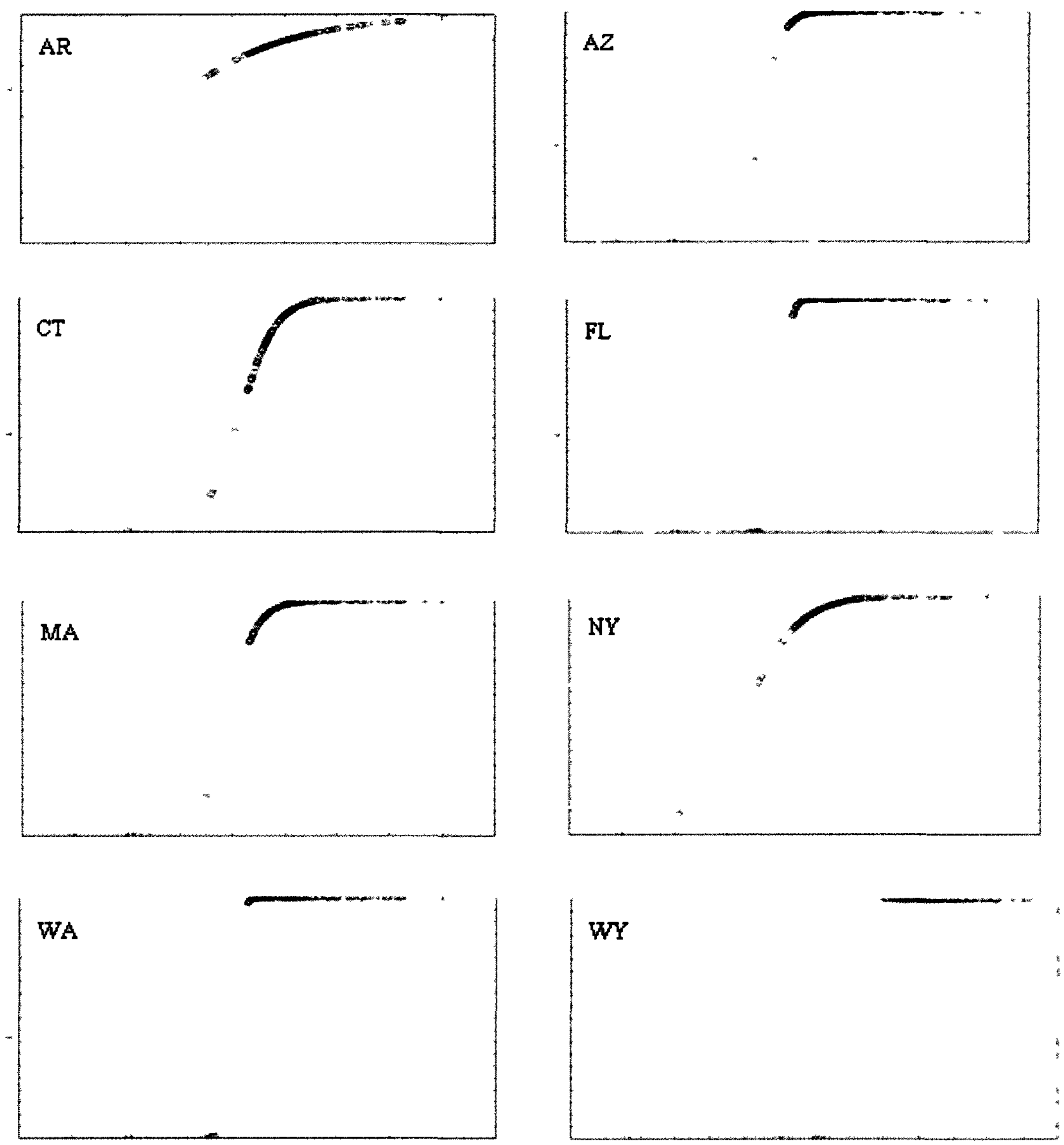

Figure 2: Cross-Plot of Transition Function (G) against Transition Variable (Normal: g=1)

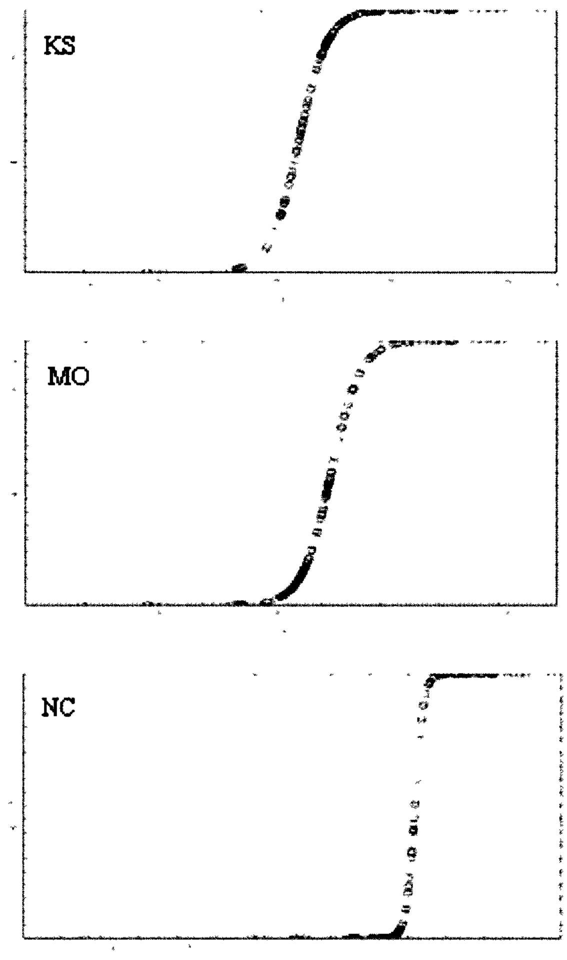

Figure 3: Cross-Plot of Transition Function (G) against Transition Variable (Normal: not clear)

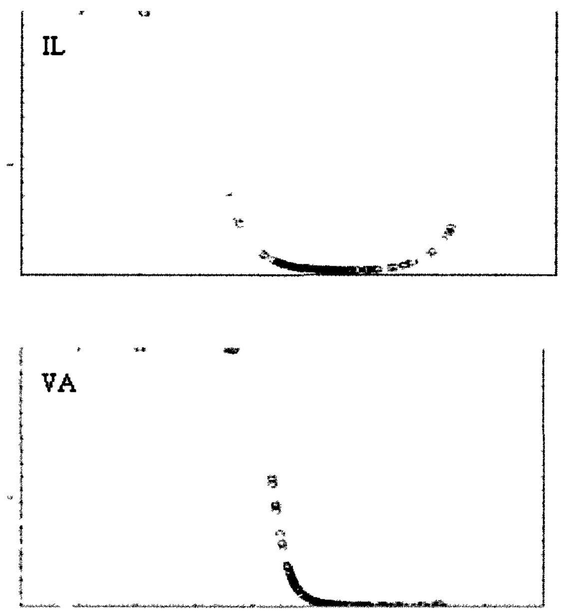

Figure 4: Cross-Plot of Transition Function (G) against Transition Variable, LSTR2 models

APPENDIX

Table A1: Estimates of LSTR1 Models for State Incomes (Part I:A)

State	AK	AR	AZ	CO	CT	DE	FL
Transition Variable	o(t-3)	o(t-8)	o(t-8)	o(t-6)	o(t-7)	o(t-8)	o(t-8)
				Linear Part			
Constant	0.0008	1.2952*	-0.0064		0.0085***	0.0030	0.0006
y(t-1)	0.3343***	-5.9474	-0.7242*			-0.3750***	-2.0029***
y(t-2)	-0.0714		0.4496***	0.4082***	1.5894***	0.1657*	-1.8175***
y(t-3)	0.2459**		1.3877**	0.3147***		0.2374**	1.1088***
y(t-4)		-1.3889				0.1552**	
y(t-5)							
y(t-6)						0.2697***	
y(t-7)		-4.1065		0.2172**	-1.1456***	0.2148***	
y(t-8)							
o	0.0422						0.2553***
o(t-1)	0.1096***	1.3046		0.0091	-0.1404**		
o(t-2)	-0.0724*	-1.2325		0.0080	0.1898**		
o(t-3)	0.0908*		0.2116*		-0.1817*		
o(t-4)		-1.4103		-0.0227		-0.0517*	
o(t-5)		2.0603*					
o(t-6)				-0.0164			
o(t-7)							
o(t-8)		6.2850*					-0.3891***
r							0.0004
r(t-1)	-0.0039*					0.0052***	
r(t-2)			0.0227**				-0.0231**
r(t-3)		0.5570					0.0237**
r(t-4)							
r(t-5)							
r(t-6)							-0.0493***
s					-0.1527**		
s(t-1)	0.0179		0.0293**	0.0537***		0.0562***	
s(t-2)		-0.5599					
s(t-3)							
s(t-4)					-0.1423*		
s(t-5)							
s(t-6)					-0.3664***		
s(t-7)							

Note: *** indicates 1% significance level; ** indicates 5% significance level; * indicates 10% significance level.

Table A1 : Estimates of LSTR1 Models for State Incomes (Part I:B)

State	AK	AR	AZ	CO	CT	DE	FL
Transition Variable	o(t-3)	o(t-8)	o(t-8)	o(t-6)	o(t-7)	o(t-8)	o(t-8)
				Nonlinear Part			
Constant	0.1123*	-1.3545**	0.0091	0.0564*		-0.0067	
y(t-1)	1.5658***	6.2953	1.0500**			0.9571***	2.3601***
y(t-2)				2.1961***	-1.5323***	-0.5274**	2.2373***
y(t-3)			-1.3275**	0.8108***		-0.5479**	-1.0318**
y(t-4)		1.8940			0.2267***		
y(t-5)						0.7542***	
y(t-6)				-1.5030***			
y(t-7)		4.3605		-2.1520***	1.4614***		
y(t-8)					-1.2152***		
o	-0.2310						-0.1933**
o(t-1)		-1.3624		-0.2301**	0.1803***	0.1138***	
o(t-2)		1.2995		-0.1392**	-0.2162**	0.1406**	
o(t-3)	-1.0467***		-0.2385**		0.1901*		
o(t-4)		1.4181		-0.2039***		0.1256**	
o(t-5)		-2.1000*					
o(t-6)				-0.4120*			
o(t-7)							
o(t-8)		-5.9626*					0.4312***
r					0.0036***	0.0081**	
r(t-1)						-0.0156***	
r(t-2)			-0.0256**	-0.0253***			0.0204*
r(t-3)		-0.0595					-0.0248**
r(t-4)							
r(t-5)							
r(t-6)							0.0488***
s					0.1975***		
s(t-1)				0.2441***			
s(t-2)		0.6376*					
s(t-3)							
s(t-4)					0.1824**		
s(t-6)					0.3764***		
s(t-7)							
gamma	46.8195***	2.0713***	289.7156*	74714.5402*	29.2617***	63.9307*	2264580.2961***
c	0.0859***	-0.2273***	-0.0603***	0.0737***	-0.0409***	0.0402***	-0.0439***
R-square	0.5497	0.4252	0.5573	0.5735	0.4486	0.4021	0.5500
AIC	-7.0398	-8.5833	-8.7704	-8.7350	-8.6757	-8.2604	-8.8455

Note: *** indicates 1% significance level, ** indicates 5% significance level; * indicates 10% significance level.

Table A1 : Estimates of LSTR1 Models for State Incomes (Part II:A)

State	KS	LA	MA	MI	MO	MT	NC
Transition Variable	o(t-8)	o(t-7)	o(t-8)	o(t-7)	o(t-8)	o(t-7)	o(t-4)
				Linear Part			
Constant	0.0433***	0.0085***	0.0210	0.0042*	0.0285***		0.0055*
y(t-1)	-0.6254***				-0.2801**		
y(t-2)		0.4746***	1.3912**				0.2617**
y(t-3)	0.2529***		-2.0125**	0.1702**			
y(t-4)			-1.3135**	0.2390***		0.3669***	0.2745***
y(t-5)						0.3683***	
y(t-6)			2.7198***				0.1577**
y(t-7)	-0.5592*			0.1453**		0.1659***	
y(t-8)			-0.0852				0.1171*
o			0.0068		-0.0751***		-0.0469*
o(t-1)	0.0263		-0.3991***				
o(t-2)	-0.0780*	0.0265*			-0.0513**		
o(t-3)							
o(t-4)				0.0422*			
o(t-5)			-0.3013**			0.0301	
o(t-6)	0.0128						
o(t-7)			0.2270***				
o(t-8)	0.2179***				0.1178***		0.1048***
r	0.0116***	0.0023**	-0.0137	0.0073***	0.0067***		0.0034***
r(t-1)							
r(t-2)		0.0019	0.0540***				
r(t-3)			-0.0232	0.0063***			0.0025**
r(t-4)		0.0019					-0.0016
r(t-5)				-0.0051***		-0.0048***	
r(t-6)							
s			-0.1067			-0.0500**	
s(t-1)							
s(t-2)	-0.0822**		-0.1023		-0.0679***		
s(t-3)			-0.2302***				0.0265*
s(t-4)				0.0343*			
s(t-5)						0.0382**	
s(t-6)							
s(t-7)							

Note: *** indicates 1% significance level; ** indicates 5% significance level; * indicates 10% significance level.

Table A1 : Estimates of LSTR1 Models for State Incomes (Part II:B)

State	KS	LA	MA	MI	MO	MT	NC
Transition Variable	o(t-8)	o(t-7)	o(t-8)	o(t-7)	o(t-8)	o(t-7)	o(t-4)
				Nonlinear Part			
Constant	-0.0395***	-0.0626*	-0.0147		-0.0441***	0.0103**	-0.0106**
y(t-1)	0.8356***	3.0618**	0.1808**	-4.1806***	0.3483**		
y(t-2)		-5.5253**	-1.2214**		0.6710***		-0.4125**
y(t-3)		2.3742*	2.0751**				0.4553***
y(t-4)		3.7964*	1.5490**	1.0625***			
y(t-5)		-3.4120*				-0.7665***	
y(t-6)		1.7723	-2.7051***	4.9173***			
y(t-7)	0.7854**	6.5253***		-1.3407***	0.5186***		
y(t-8)		-6.9393***		2.7111***			
o		0.6569**		0.5531***	0.1456***		0.0885**
o(t-1)		0.5954**	0.4071***				
o(t-2)	0.0741				0.1046***		-0.0555***
o(t-3)		0.8761**		0.3087**			
o(t-4)		0.9027**					0.0628
o(t-5)		-0.2858**	0.3098**				
o(t-6)				0.7177***		0.1183***	
o(t-7)	-0.0550**		-0.2815***	-0.7384***			-0.0473**
o(t-8)	-0.1987***			0.9074***			-0.1677***
r	-0.0097**		0.0157		-0.0069**		
r(t-1)		0.0094*		0.0215***			
r(t-2)		-0.0275**	-0.0553***	-0.0261***	-0.0041***	-0.0058***	
r(t-3)			0.0231	-0.0142**			
r(t-4)		-0.0290**					
r(t-5)		-0.0723**		-0.0385***		0.0074***	
r(t-6)							
s		-0.5140***	0.1339*	0.5616***	0.0744***	0.2033***	
s(t-1)				-0.5873***			0.0898***
s(t-2)	0.1119**	0.5710**	0.1337*	1.3023***	0.1399***		
s(t-3)		-0.4261*	0.2591***	0.5572***		0.1385***	
s(t-4)		-0.6552*					
s(t-6)				0.5496***			
s(t-7)							
gamma	110.0792**	132.3394***	71.5195***	4839.1772***	107.0890***	145.5908**	207311.9619*
c	0.0181*	0.0739***	-0.0545***	0.0655***	0.0084*	0.0331***	0.0084**
R-square	0.3789	0.5891	0.6037	0.5618	0.4387	0.3797	0.5681
AIC	-8.6442	-8.7656	-8.8560	-8.1891	-8.8982	-8.4119	-8.8575

Note: *** indicates 1% significance level; ** indicates 5% significance level; * indicates 10% significance level.

Table A1 : Estimates of LSTR1 Models for State Incomes (Part III:A)

State	NY	OR	PA	WA	WV	WY
Transition Variable	o(t-8)	o(t-5)	o(t-8)	o(t-8)	o(t-8)	o(t)
			Linear Part			
Constant	0.0050***	0.0050**	0.0150**	-0.1205***	0.0195***	0.0044**
y(t-1)	-0.6033	0.2841***	-0.2437**	0.2778***	-0.3502***	0.2350***
y(t-2)		0.1276		2.7966***	-0.0856	2.3259***
y(t-3)					-0.1375*	-2.0043***
y(t-4)		0.1722**	0.3462***			
y(t-5)				-1.0100**		
y(t-6)					0.1621*	
y(t-7)		0.1511**		7.0441***		
y(t-8)				-3.1381***		
o	0.0030			2.0843***	-0.0324	-0.1690**
o(t-1)	-0.4028	-0.0387**	-0.0380*	-1.0034***		0.5358***
o(t-2)	0.2487					
o(t-3)	0.4526	-0.0107				0.0366
o(t-4)	1.1216*					-1.1565***
o(t-5)	-0.0289					-0.0030
o(t-6)	0.8058	-0.0320*	-0.0436**			
o(t-7)	0.1847	-0.0320		0.2067**		
o(t-8)	0.5445*		0.0436	-0.5314**		
r		0.0031**	0.0052***	-0.2386***	0.0097**	
r(t-1)	0.0008				-0.0058*	0.0032**
r(t-2)			-0.0027*		0.0038	
r(t-3)						
r(t-4)		-0.0020**				
r(t-5)						
r(t-6)						
s	0.2305		-0.0251	-1.9905***		
s(t-1)				-0.7154***	-0.0618	-0.6188***
s(t-2)	-0.3120				-0.0640*	
s(t-3)	0.4207					
s(t-4)	0.2737					
s(t-5)						
s(t-6)						
s(t-7)	0.9359					

Note. *** indicates 1% significance level, ** indicates 5% significance level, * indicates 10% significance level

Table A1 : Estimates of LSTR1 Models for State Incomes (Part III:B)

State	NY	OR	PA	WA	WV	WY
Transition Variable	o(t-8)	o(t-5)	o(t-8)	o(t-8)	o(t-8)	o(t)
			Nonlinear Part			
Constant		-0.0339***	-0.0224***	0.1307***	-0.0163**	
y(t-1)	0.3938	-1.1035***				
y(t-2)				-2.7840***	1.1399***	-2.0948***
y(t-3)						2.1886***
y(t-4)			-0.1151		0.8986***	
y(t-5)				1.2660***		
y(t-6)						
y(t-7)		0.8991***		-7.0019***		
y(t-8)				3.0940***		
o				-2.1215***	0.1496	0.1094
o(t-1)	0.4217		0.0552**	1.0367***		-0.4876***
o(t-2)	-0.3209				0.1583***	
o(t-3)	-0.4565					
o(t-4)	-1.1430*					1.1395***
o(t-5)		0.2648***				
o(t-6)	-0.8142		0.0714**			
o(t-7)	-0.3244*	0.1605**		-0.2505**		
o(t-8)	-0.4939*		0.0815	0.5296**		
r		-0.0030	-0.0034	0.2407***	-0.0632***	
r(t-1)		0.0125***			0.0603***	
r(t-2)			-0.0054**		-0.0217***	
r(t-3)		-0.0048**				
r(t-4)						
r(t-5)						
r(t-6)						
s	-0.1792		0.0923***	1.9881***		
s(t-1)		0.2865***		0.7362***	0.1538	0.6920***
s(t-2)	0.3764*	-0.0841*				
s(t-3)	-0.4106					
s(t-4)	-0.2358					
s(t-6)						
s(t-7)	-0.9568					
gamma	8.6135**	2588410972*	2286.6657**	5032462.5760***	4692.3087**	109020882.0189
c	-0.0836**	0.0687***	0.0181**	-0.0482***	0.0410***	-0.0769***
R-square	0.5042	0.5802	0.4218	0.4835	0.4263	0.5165
AIC	-8.0559	-8.8702	-9.1633	-8.3494	-7.1812	-7.9760

Note: *** indicates 1% significance level; ** indicates 5% significance level; * indicates 10% significance level.

Table A2: Estimates of LSTR2 Models for State Incomes

Variable	IL	VA
	Linear Part	
Constant	0.0038***	0.0042***
y(t-1)	0.1582	-0.0727
y(t-2)		0.1000
y(t-3)		0.1603**
y(t-4)		0.2054***
o	-0.0328**	-0.0271*
o(t-1)		-0.0191
o(t-2)	0.0011	
o(t-3)	-0.0393	-0.0329*
o(t-4)		-0.0033
o(t-5)		-0.0070
o(t-6)	0.0122	-0.0357**
o(t-7)	-0.0792***	-0.0310
o(t-8)	-0.0112	0.0068
r		0.0021**
r(t-1)	0.0026***	
r(t-2)		-0.0032***
r(t-4)		0.0001
s		0.0260**
s(t-1)		0.0076
s(t-2)	0.0753***	0.0375**
s(t-3)		0.0451**
s(t-4)		0.0150
	Nonlinear Part	
Constant	0.0188**	
y(t-1)	-1.7937***	-0.2498
y(t-2)		1.0134***
y(t-3)		0.5427*
o(t-1)		-0.2494***
o(t-2)	-0.1370	
o(t-3)	0.4633***	0.2459***
o(t-4)		0.3132***
o(t-6)	-0.5471***	0.2432***
o(t-7)	0.1500*	0.1225**
o(t-8)	0.1240*	0.2112**
r(t-2)		0.0332***
r(t-4)		-0.0302***
s(t-2)	-0.1518***	-0.2265***
s(t-3)		0.1337***
s(t-4)		0.1008*
gamma	2.8278*	8.4491***
c1	-0.0879***	-0.0338***
c2	0.1352***	0.1657***
R-square	0.5079	0.6397
AIC	-9.0694	-9.1058
Variance of residual	0.0001	0.0001

Note: *** indicates 1% significance level, ** indicates 5% significance level, * indicates 10% significance level.

CHAPTER III

MULTIVARIATE UNOBSERVED COMPONENT ANALYSIS OF STATE EMPLOYMENT WITH OIL PRICE VOLATILITY

3.1. INTRODUCTION

Large fluctuations in oil prices have been a distinguishing characteristic of the U.S. economy since 1973. Most of the recent concern about oil prices is focused on their extreme volatility since 2008. In January 2008, the oil price touched $100 per barrel for the first time; the price of oil reached $147 per barrel in July and then dropped down to below $50 per barrel in December.[1] Figure 1 plots the daily crude oil price from April 4, 1983, to February 23, 2010. With the price of oil becoming more volatile, economists may refocus their attention on the impact of oil price volatility on economic activity. While literature exists on how the U.S. economy responds to changes in oil price volatility, there are virtually no studies investigating how oil price volatility affects state-level economic activity.

Does oil price volatility have a significant impact on state economies? What are the factors affecting the response of a state economy to changes in oil price volatility? Are these factors observable? If state economies behave differently to an oil price change, it is reasonable to expect that states with different oil dependences would respond differently to shocks in oil price volatility. This paper investigates the impact of oil price volatility on economic activity: in particular, employment.

It is important to identify all the factors, in addition to oil price volatility, that affect state employment. Due to the lack of relevant state-level data and theoretical guidance, factors that affect state employment may or may not be observable. However,

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[1] WTRG Economics, http://www.wtrg.com/prices.htm

the unobserved components embedded in the state labor market, in the form of trends, cycles, or seasonal factors, are shaped by regional economic phenomena. The analysis of this paper is based on multivariate time series models, in which these unobserved factors are identified and captured. Unobserved component models are able to capture the components that are not included in the regressors without imposing any unjustifiable assumptions and allow for more precise estimation for state-level economies.

Because of spillover effects, states are likely to affect their neighbors much more than states that are more distant. In order to capture regional similarities and differences, I select representative states, assign them to regions, and apply multivariate time series models to each region. The major contribution of this paper is that it identifies the impact of oil price volatility on state employment using unobserved component modeling. Furthermore, unlike other studies that analyze each state economy individually, this paper allows for interaction among states. The results show evidence that oil price volatility has a negative impact on employment for most of the investigated states; however, states are affected by oil price volatility to different degrees. Further analysis indicates that the impact of oil price volatility on state employment can be explained by state-specific economic characteristics.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 demonstrates the estimation of oil price volatility and the process of the multivariate unobserved components model. Section 4 describes the data, and Section 5 presents the results from the multivariate unobserved component models;

further analysis for the determinants of the impact of oil price volatility on state employment is also conducted in this section. Section 6 concludes.

3.2. LITERATURE REVIEW

A large number of studies have investigated the relationship between oil prices and macroeconomic performance. It is widely accepted that oil prices have a clear negative effect on output (Hooker 1996, Hamilton 2003, Rotermberg and Woodford 1996, etc). Davis and Haltiwanger (2001) find that oil shocks reduce employment the most in industries that are more capital intensive, are more energy intensive, and have greater product durability. Also, nine out of 10 economic recessions are preceded by oil price increases, but there is no clear evidence that oil price declines lead to an economic rebound. Many studies have modeled the asymmetric effect of oil prices (Mork 1989, Davis and Haltiwanger 2001, Hamilton 2003, etc). To solve the asymmetry puzzle, some economists argue that, in addition to changes in oil price levels, the volatility of oil prices should also be considered when explaining responses of the economy.

In principle, oil prices ought to be less volatile compared to other commodities because the demand side is usually stable and inelastic to price. However, the supply side is affected by many exogenous factors that can cause rapid fluctuations in oil prices. Guo and Kliesen (2005) noted that the 10 largest daily movements of the 12-month crude oil futures are associated with developments in OPEC or political disturbances in the Middle East. Oil price volatility can be attributed to supply and demand imbalances arising from unanticipated exogenous shocks to the U.S. economy, including political instabilities, OPEC price control, and surging demand from developing countries.

The key mechanism by which oil price volatility affects the economy is through a disruption in consumer spending and business investment. Consumers and firms make purchase and investment decisions based partially on their expectations about future oil prices (Bernanke 1983). Oil price instability and volatility raises uncertainty about future oil prices. Thus, faced with uncertainty, rational agents will delay consumption and investment, which will in turn affect employment negatively. Another channel through which the effect of oil price volatility is transmitted to the economy is through resource reallocation across sectors (Hamilton 2003). It is costly when labor shifts between adversely influenced sectors and less influenced sectors. When the oil price is more volatile, people tend to stay unemployed instead of moving to another sector. Furthermore, rising oil prices increase the risk of inflation (Ferderer 1996). Central banks tend to respond with contractionary policy, but central banks do not necessarily use expansionary policies in response to oil price declines.

Other studies have examined the effect of oil price volatility on the economy. Lee, Ni, and Ratti (1995) create an oil price shock variable by dividing oil price increases by the standard deviation of recent price volatility, so that the oil price shocks capture both the unanticipated factors and the conditional variance of oil price changes. They show that oil price shocks have a greater impact on real GNP in an environment where oil prices have been stable, rather than erratic. An explanation is that during periods of high oil price volatility, much of the change in oil prices will be considered transitory, containing little information about future prices. Rational agents will forgo or postpone their decision on the irreversible purchase of durables and reallocation of resources. In addition, increased uncertainty will offset the effect of a lower oil price on the economy and result in asymmetry.

Ferderer (1996) examines the impact of oil price volatility on industrial production. He focuses on three transmission channels: counterinflationary monetary policy, sectoral shocks,[2] and uncertainty. He finds that oil price volatility contains important independent information that helps to forecast output growth. Monetary policy plays an important role in the correlation of oil prices and output, but it cannot explain the asymmetry of the effect of oil prices. The sectoral shocks and uncertainty channel could account for part of the asymmetry effects.

Guo and Kliesen (2005) investigate the relationship between oil price volatility and several U.S. macroeconomic variables. The measure of the oil price volatility is constructed using daily crude oil future prices. Their results show that oil price volatility has a significant negative effect on economic growth. Moreover, the estimation is improved when both oil price volatility and oil price level changes are included in the regression, since both of the asymmetric and symmetric effects of oil price shocks on output are captured. Their study also confirms that Hamilton's (2003) nonlinear oil shock measure captures the overall effects of oil shocks.

[2] The sectoral shocks theory argues that oil price volatility increases aggregate unemployment. When oil price shocks become more variable, workers in adversely affected sectors will remain unemployed because they wait for conditions to improve in their sector rather than transfer to positively affected sectors.

While the relationship between oil price volatility and the national economy has been explored, to my knowledge, no literature exists that examines how oil price volatility affects state-level economies. This paper fills this gap by studying the relationship between oil price volatility and state employment with a focus on regional economic similarity and geographic spillovers. Employment is one of the most important economic indicators at the state level. It has been confirmed in the literature that oil price volatility has an adverse impact on output and employment is highly dependent on output growth. The hypothesis here is that the increase in oil price volatility decreases employment. This could be explained by the uncertainty and sectoral reallocation theory: in periods of high volatility, workers in adversely influenced sectors will remain unemployed, instead of moving to other sectors, until conditions get better. It is expected that state employment levels are affected differently by oil price volatility, since states possess different economic characteristics. In addition to oil price volatility, state employment also depends on other observable and unobservable factors. Due to the lack of relevant state-level data and theoretical guidance, multivariate unobserved components models (UCM) are employed to capture the components not included in the regressors. Moreover, contiguous or nearby states are likely to be correlated because of shared economic resources and interstate economic activity. States are divided into regions according to their geographic locations, and multivariate unobserved component models are estimated for each region.

3.3. Model

3.3.1 Modeling Oil Price Volatility

To measure oil price volatility, I follow the approach proposed by Kuper (2002). I construct a measure of volatility based on the conditional standard deviation obtained from a univariate generalized autoregressive conditional heteroskedasticity or GARCH process. This approach has been widely used in finance to measure the conditional volatility of a financial instrument within a specific time period.

The GARCH process is constructed for oil price return r_t, which is calculated as the first difference in the natural logarithm of oil price P_t.[3] Figure 2 plots the daily price returns of crude oil. As can be seen, daily oil price returns exhibit volatility clustering, a characteristic that is commonly associated with financial time series. Volatility clustering occurs when large changes tend to be followed by large changes and small changes tend to be followed by small changes.[4] These serially correlated changes can be captured by GARCH models.

Following Kuper (2002), I construct a univariate GARCH (p,q) model to capture oil price volatility. Let

$$r_t = c + \sum_{i=1}^{G} a_i r_{t-i} + \sum_{j=1}^{M} b_j \varepsilon_{t-j} + \varepsilon_t \tag{1}$$

[3] For the oil price data, I use the New York Mercantile Exchange (NYMEX) futures prices for crude oil measured in dollars per barrel. The data is available from the EIA (U.S. Energy Information Administration) website.

[4] The implication of volatility clustering is that today's large disturbance in volatility, of either sign, can persist and influence the volatility forecasts for several periods (Kuper 2002).

where c is a constant, a_i is a G-element autoregressive coefficient vector, b_j is an M-element moving average coefficient vector, and ε_t is a zero-mean random error term that is serially uncorrelated. The error process can be expressed as:

$$\varepsilon_t = z_t \sqrt{h_t} \tag{2}$$

where z_t is a white-noise process, and $\sqrt{h_t}$ is the conditional standard deviation. The GARCH (p,q) model for h_t is:

$$h_t = k + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \beta_j h_{t-j} \qquad \text{where } k > 0, \alpha_i \geq 0, \beta_j \geq 0$$
$$\text{and } \sum_{i=1}^{q} \alpha_i + \sum_{j=1}^{p} \beta_j < 1 \tag{3}$$

Next, the estimated GARCH models are evaluated using the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). Both the AIC and the BIC statistics suggest a GARCH (2,1) model. Detailed estimation results of the GARCH (2,1) process are presented in the Appendix. The conditional standard deviations ($\sqrt{h_{t,m,d}}$) can be derived from the GARCH (2,1) model, which is plotted in Figure 3 as the daily oil price volatilities. The monthly oil price volatility series ($vol_{t,m}$) is constructed from the daily conditional standard deviation through the following process.

$$vol_{t,m} = \left[\frac{1}{n} \sum_{d=1}^{n} h_{t,m,d} \right]^{\frac{1}{2}} \quad \text{where} \quad \begin{array}{c} t = \text{year} \\ m = \text{month} \\ d = \text{day} \\ n = \text{number of days in month m} \end{array} \qquad (4)$$

Figure 4 plots the monthly oil price volatility.

3.3.2 Multivariate Unobserved Component Models

The relationship between oil price volatility and employment is estimated using multivariate unobserved component models (UCM), which are also known as seemingly unrelated time series equation (SUTSE) models. SUTSE models have been applied to a broad range of economic studies. Lenten and Rulli (2006) use both univariate models and a multivariate model to explore the time-series property of life insurance demand and find evidence of common components. Fadiga and Wang (2009) adopt a multivariate state-space model to examine the price dynamics and relationship among U.S. regional housing markets. Their analysis shows the presence of common trends and common cycles that drive the regional markets and identifies several economic factors that significantly impact the common movements. SUTSE models have also been used to investigate the dynamics in macroeconomic aggregates including consumption, investment, output, unemployment, and capacity utilization (Mangeloja 2003, **Payaslıoğlu** 2009, and Scott 2000). Here, I apply SUTSE models to examine the time-series dynamics in state-level employment with an emphasis on the effects of oil price volatility.

Previous studies do not account for the underlying unobserved factors that drive state labor markets. Instead of imposing ad hoc and unjustifiable assumptions, the unobserved component models let the data speak as much as possible by capturing the underlying trend and cycle components. One advantage of the unobserved component approach is that the trend, cycle, and seasonal components are treated simultaneously, and nonstationary series can be modeled without transformations such as differencing. Moreover, in the absence of state-level data, the unobserved component approach allows approximating the data generating process as much as possible even without other observable variables. Multivariate time series models allow handling more than one time series simultaneously with consideration of unobserved interactions between state labor markets. The aim of this paper is to investigate whether and how oil price volatility affects the dynamic movement of state-level employment in different regions.

I investigate state economies in five regions: South, Northeast, East Central, West, and the oil-producing states. States fall into the same region because they are geographically contiguous except for the last region, which includes four important oil-producing states. The states investigated in this paper are presented in Table 1. Multivariate unobserved components models are applied to each region; the states within regions are linked to each other through the correlation of the disturbances that drive the unobserved components.

I follow Koopman et al. (2000) for the SUTSE approach. For each region, suppose there are *N* time series of state-level employment. The multivariate structural time series model can be set up in terms of trend, cycle, seasonal, explanatory variables, and irregular components:

$$y_t = \mu_t + \psi_t + \gamma_t + Dx_t + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \Sigma_\varepsilon), \; t = 1,...,T, \tag{5}$$

where $y_t = (y_{1t},...,y_{Nt})'$ is an $N \times 1$ vector of observations for state employment; μ_t represents the trend level; ψ_t is the cycle component; γ_t denotes the seasonal component, x_t represents the explanatory variable, which in this case is oil price volatility; D is the coefficient to be estimated; ε_t is the irregular; and Σ_ε is an $N \times N$ positive semidefinite covariance matrix of the irregular components. The irregular component is assumed to be a normally distributed random vector. In a multivariate model, each time series is modeled similar to a univariate model except that the disturbances may be correlated across series.

The long-term trends of state employment can be specified as a level with drift such that

$$\begin{aligned} \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t & \qquad \eta_t &\sim NID(0, \Sigma_\eta), \; t = 1,...,T, \\ \beta_t &= \beta_{t-1} + \varsigma_t & \qquad \varsigma_t &\sim NID(0, \Sigma_\varsigma), \; t = 1,...,T, \end{aligned} \tag{6}$$

where β_t is the vector of growth terms specified as a random walk, η_t is the disturbance of the trend, and Σ_η and Σ_ς are $N \times N$ covariance matrices. η_t, ς_t, and ε_t are multivariate normal disturbances that are mutually uncorrelated in all time periods. This trend process is called the local linear trend model (Luginbuhl and Koopman 2004).

When $\Sigma_{\varsigma} = 0$, that is, when the slope is fixed, μ_t reduces to a random walk plus drift. When $\Sigma_{\eta} = 0$ and Σ_{ς} is positive, one gets a smooth trend model, in which the trend is extracted from the integrated random walk.

The short-term movement in the time series can be captured with a similar cycle component:

$$\begin{bmatrix} \psi_t \\ \psi_t^* \end{bmatrix} = \left[\rho_{\psi} \begin{pmatrix} \cos \lambda_c & \sin \lambda_c \\ -\sin \lambda_c & \cos \lambda_c \end{pmatrix} \otimes \mathrm{I_N} \right] \begin{bmatrix} \psi_{t-1} \\ \psi_{t-1}^* \end{bmatrix} + \begin{bmatrix} \kappa_t \\ \kappa_t^* \end{bmatrix}, \qquad t = 1,\ldots,T \tag{7}$$

where ψ_t and ψ_t^* are $N \times 1$ vectors; and κ_t and κ_t^* are $N \times 1$ vectors of disturbances such that

$$E(\kappa_t \kappa_t') = E\left(\kappa_t^* \kappa_t^{*}{}'\right) = \Sigma_k, \qquad E(\kappa_t \kappa_t^{*}{}') = 0 \tag{8}$$

where Σ_{κ} is an $N \times 1$ covariance matrix. For a given cycle, the damping factor ρ_{ψ} and the frequency λ_c are the same for all series, and the disturbances can be correlated across series. Since this study uses unadjusted monthly data for employment, a seasonal component is also included in the model. All the unobserved components can be stochastic or deterministic, depending on whether they have variable or fixed effects on the time series.

The essential component in this study is the explanatory variable: oil price volatility. As mentioned, the effects of oil price volatility are transmitted into the economy through three main channels. First, high volatility increases uncertainty about future prices, which will in turn cause rational agents to postpone or cancel consumer spending and business investment. Second, costs of reallocation will cause labor to remain unemployed instead of transferring to another sector. Third, high oil prices increase the risk of inflation and lead to corresponding contractionary policy.

Since the primary purpose of this study is to examine the impact of oil price volatility on state employment, unrestricted multivariate unobserved component models are applied for each region. Stochastic trend, cycle, and seasonal components are incorporated in order to capture the movements in the data-generating process that are not explained by oil price volatility. The impact of oil price volatility is assumed fixed over time.

3.4. Data

I use daily crude oil future prices from the New York Mercantile Exchange (NYMEX) over the period 1983:04 to 2010:02 to construct monthly oil price volatility.[5] Monthly oil price volatility is extracted from a univariate GARCH process as described in Section 3. The advantage of using this data set is that the accuracy of the oil price volatility will be improved when using stochastic price series within each month at a higher frequency. Because changes in oil price volatility do not affect employment immediately, employment is likely to respond to changes in oil price volatility with a

[5] The daily oil price data is obtained from the U.S. Energy Information Administration (EIA).

delay. Taking the time delay into consideration, this study uses the three-month lagged oil price volatility in the regressions.

The data used in the multivariate structural time series models have a monthly frequency and cover the period from 1983:5 to 2010:1. Monthly state employment data is obtained from the U.S. Bureau of Labor Statistics (BLS). The definitions of variables are provided in Table 1, and Table 2 offers summary statistics for the variables. Table 2 reveals remarkable inequality in employment across regions and states. Among the states investigated in this paper, California has the largest employment, and North Dakota has the smallest.

3.5. Estimation Results

3.5.1 UCM Outcomes

Multivariate unobserved component models are estimated for each of five regions: South, Northeast, East Central, West, and Oil Producers. Trend, cycle, seasonal, and irregular components are incorporated in the models as well as oil price volatility as the explanatory variable. All the unobserved components are set to be stochastic for all the regions, and oil price volatility is set to have a fixed effect on state employment.

The results from the preferred models are reported in Table 3. Not all of the models are well determined. For example, the model has low explanatory power for Louisiana's employment. However, oil price volatility is a significant determinant for state employment in most of the 18 states, all but New Jersey, Illinois, Ohio, Louisiana, and Oklahoma. The estimation result is consistent with the expectation that oil price volatility has a negative impact on employment growth. Through interruption in consumption, investment, and the sectoral resource reallocation channels, higher oil price volatility will cause employment to decline. Among the investigated states, California is the most adversely affected by high oil price volatility in terms of the number of job losses: if oil price volatility rises 0.001, about 740 workers in California will lose their jobs. The main reason a larger number of job losses occurs in California is that this state has the largest employment among these states. Excluding the five states that are not significantly affected by oil price fluctuations, the one that is least affected is North Dakota. A 0.001 increase in oil price volatility will cause the employment in North Dakota to drop by 29. The explanation here is similar to the one for California: North Dakota has the lowest employment.

Because of trade flows, capital flows and migration, access to input and output markets, and government policy, adjacent states are likely to correlate in terms of economic activity. Ignoring these economic interactions might result in inadequate or biased model estimation. The advantage of using multivariate models is that these correlations are incorporated into the model. To show the advantage of multivariate UCM, Table 4 presents a comparison between multivariate and univariate UCMs for two regions: South and East Central. For each of the eight states in the two regions, the multivariate model explains a higher proportion of the variation in employment compared with the univariate model. For Alabama, for example, the multivariate model explains

38.12% of the variation, while the univariate model explains only 32.54%. Another issue is that the coefficients for the explanatory variable are overestimated in the univariate models, with the univariate UCM results showing much stronger negative effects of oil price volatility on state economies. The multivariate models are more realistic.

Heterogeneity in the impact of oil price volatility exists not only between regions but also within regions. For example, in the West region, the effect of oil price volatility varies from -0.1125 to -0.7395. The four states in the South region are affected similarly, compared with the other regions. Generally, states with larger populations will suffer from more job losses when the oil price is more volatile; however, there are some exceptions. In the Northeast region, New York has a much larger employment than Pennsylvania but will be less negatively affected by increases in oil price volatility. A similar situation is found for Alabama and Kentucky. The average employment in Alabama is slightly higher than that in Kentucky; nevertheless, a 0.001 increase in oil price volatility will result in 32 more job losses in Kentucky. Therefore, size of employment is not the only explanation for the impact of oil price volatility; there may be some other state-specific economic characteristics that determine how a state's employment is affected by oil price volatility. Theoretically, states with a higher dependence on oil and more oil-intense industries may be more affected by fluctuations in oil prices.

3.5.2 Determinants of the Effects of Oil Price Volatility on State Employment

To investigate the potential factors that might explain the impact of oil price volatility on state employment, I simulated the effect of a 100% increase in oil price volatility using the estimated coefficients from the UCMs. Using average oil price volatility and average state employment in 2009 as the base, the percentage change in employment by state is simulated and shown in Table 5. The table shows that Michigan is the most affected and New Jersey is the least affected.

I regressed the simulated employment impacts on seven state level economic characteristics using an OLS approach.[6] The six factors investigated are per capita petroleum expenditure, the share of petroleum production in GDP, and manufacturing, transportation, construction, and motor vehicle production as shares of GDP.[7] The estimation results are displayed in Table 6.

Only one variable has a significant effect on the impact of oil price volatility on state employment: motor vehicle production. When oil prices become more volatile, rational consumers, facing uncertainty about future oil prices, tend to postpone their purchase of durables and products that induce more expenditure on oil. Thus, vehicle production industries can be easily adversely impacted by oil price volatility. A state with a larger proportion of vehicle production in GDP should expect to be more negatively affected by high oil price volatility. Figure 5 shows a scatter plot of motor vehicle

[6] Since 18 states in total are investigated in this paper, only 18 observations enter the regression.

[7] The population growth is the change in annual population estimates from 2008 to 2009 obtained from the U.S. Census Bureau in 1,000s. Per capita petroleum expenditure is calculated from the 2008 petroleum expenditure data from the Energy Information Administration (EIA) in millions of U.S. dollars. The other industrial structure variables are the respective percentage as share of GDP for each industry.

production as a share of GDP against the simulated impact of a 100% increase in oil price volatility. In this figure, a clear left-leaning upward trend line can be drawn through those states with more than 2% motor vehicle production share of GDP, which implies a negative relationship between motor vehicle production and the effect of oil price volatility on state employment. However, this is not the case for the states with a lower proportion of motor vehicle production, denoted by the points along the bottom of the plot. States with a similarly low rate of motor vehicle production exhibit differences in the simulated percentage change in employment. Thus, the states can be divided into two groups by the rate of motor vehicle production as a share of GDP on this issue. Further analysis should be conducted with additional observations.

It is surprising that there is no evidence that the impact of oil price volatility is affected by oil dependence, the intensity of petroleum expenditure, and other industrial structure variables. A possible explanation for the insignificance of these variables is the small number of observations.

3.6. Conclusion

This paper examines the effect of oil price volatility on state-level employment in the United States. Selected states are divided into five regions according to their contiguity and economic similarity. Fitting a multivariate structural time series model to each region shows negative impacts of oil price volatility on state employment, with most states suffering significant reductions in employment when oil prices become more volatile.

This study extends the existing literature by paying attention to the regional similarities and differences in responses of state employment to changes in oil price volatility. Distinct heterogeneity exists between states, even within regions. Further investigation of the potential determinants of the impact of oil price volatility is conducted using state-specific economic variables, including per capita petroleum expenditure, the share of petroleum production in GDP, and the manufacturing, transportation, construction, and motor vehicle production shares of GDP. Only motor vehicle production is found to have significant explanatory power for the employment impact of oil price volatility. According to the OLS results, a state with a higher proportion of motor vehicle production in GDP should expect more job losses during periods of high oil price volatility.

Another special aspect of this paper is the estimation of oil price volatility. To solve the volatility-clustering problem, oil price volatility is extracted from a univariate GARCH process. Based on daily oil price data, this measure of oil price volatility is shown to capture the movements in oil prices more precisely.

The results of this paper suggest that oil price volatility has significant negative effects on most state labor markets, with variations in intensity. It is important for those regions that can be more adversely impacted by volatile oil prices to implement corresponding policies to protect labor markets and to stimulate employment. The findings of this study will also help to forecast future dynamic movements in employment. Further research can be conducted regarding the determinants of the impact of oil price volatility on state economies by incorporating more observations.

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APPENDIX

MODELING OIL PRICE VOLATILITY

As mentioned in the previous part of this paper, oil price return series exhibit volatility clustering, which suggests using the generalized autoregressive conditional heteroskedasticity (GARCH) models to obtain oil price volatilities. Before rushing into a GARCH model, I did some pro-estimation analysis. Figures A1 and A2 plot the ACF and the PACF for the oil price return series, which exhibit little correlation. However, significant correlation may still be present in the second-order moments. To check for this, the ACF for the squared oil price return series is plotted and displayed in Figure A3, which shows that there is some correlation in the variance process of the oil price return series. Moreover, the ACF appears to die out slowly, indicating the possibility of a variance process close to being nonstationary. In addition, the results from a Ljung-Box-Pierce Q-test for the oil price return show significant series correlation.[8] The Engles ARCH test result shows strong support of GARCH effects. [9]

A number of GARCH (p,q) models are estimated with different values of p and q. Detailed set-up of the GARCH (p,q) model is presented in the model section. These models are compared and evaluated based on the AIC and the BIC. Both the minimum AIC and the minimum BIC suggest $p=2$ and $q=1$. Estimation results from the GARCH (2,1) are shown in Table A1. Figure A4 plots the innovations from the conditional mean model, the corresponding conditional standard deviations, and the oil price returns. The

[8] Tested for up to 10, 15, and 20 lags of the ACF at the .05 level of significance. H=1 suggests rejection of the null hypothesis of no serial correlation.

[9] H=1 suggests rejection of the null that the time series is a random sequence of Gaussian disturbances.

innovations exhibit volatility clustering. Figure A5 plots the standard innovations.[10] The standard innovations appear to be stable without clustering. The ACF of the squared standardized innovations shows no correlation as shown in Figure A6. Compared to the ACF of the squared oil price returns, this figure shows that the model is sufficient to explain the heteroskedasticity of the data. Last, results from the Ljung-Box-Pierce Q-test allow us to accept the null hypothesis of no autocorrelation, which confirms the explanatory power of the GARCH (2,1) model.

[10] The standard innovation is obtained by dividing the innovation by the conditional standard deviation.

Table 1: Variable Definition

Variable Name	Definition
Employment	Total nonfarm employment, in millions
South:	
AL	Alabama
KY	Kentucky
NC	North Carolina
TN	Tennessee
Northeast:	
NJ	New Jersey
NY	New York
PA	Pennsylvania
East Central:	
IN	Indiana
IL	Illinois
MI	Michigan
OH	Ohio
West:	
CA	California
OR	Oregon
WA	Washington
Oil Producers:	
LA	Louisiana
ND	North Dakota
OK	Oklahoma
TX	Texas
Explanatory Variables:	
oilvol	Oil price volatility

Table 2: Data Statistics

Variable Name	Mean	Min	Max	Std.Dev.
Employment				
South:	2.3118			
AL	1.7588	1.3213	2.0267	0.1940
KY	1.6125	1.1193	1.8876	0.2180
NC	3.4557	2.3969	4.2105	0.4981
TN	2.4200	1.6974	2.8364	0.3249
Northeast:	5.7517			
NJ	3.7381	3.1384	4.1596	0.2507
NY	8.1937	7.2979	8.9215	0.3819
PA	5.3234	4.5108	5.8753	0.3662
East Central:	4.3497			
IN	2.6870	2.0275	3.0463	0.2927
IL	5.5083	4.5263	6.1248	0.4496
MI	4.1188	3.2054	4.7449	0.3691
OH	5.0848	4.0842	5.6948	0.4227
West:	5.6180			
CA	13.0598	9.8749	15.3482	1.4914
OR	1.4139	0.9636	1.7559	0.2364
WA	2.3805	1.5812	2.9934	0.4037
Oil Producers:	2.9333			
LA	1.7535	1.4594	1.9588	0.1595
ND	0.3040	0.2436	0.3749	0.0392
OK	1.3431	1.0848	1.6065	0.1577
TX	8.3329	6.1568	10.6812	1.3939
Explanatory Variables:				
oilvol	0.0224	0.0057	0.0843	0.0114

Table 3: Estimated Coefficients of Explanatory Variables

Variable or statistics	South			
	AL	KY	NC	TN
Oilvol	-0.0866(-1.9089)*	-0.1184(-2.6407)***	-0.1740(-1.8386)*	-0.1529(-2.3751)**
Std. error	0.0054	0.0050	0.0105	0.0075
R-square	0.3812	0.3630	0.4911	0.4005
Durbin-Watson test	2.0210	1.8664	1.9012	2.0507
Box-Ljung test	0.0113	0.0306	0.0817	0.3894
Heteroskedasticity	0.8236	1.0171	2.0222	1.2578
	Northeast			
	NJ	NY	PA	
Oilvol	-0.0237(-0.2570)	-0.3702(-2.0568)**	-0.3942(-3.5279)***	
Std. error	0.0102	0.0200	0.0125	
R-square	0.3847	0.2986	0.3036	
Durbin-Watson test	1.7482	1.9946	1.9438	
Box-Ljung test	0.0300	0.0013	0.0348	
Heteroskedasticity	0.7296	0.8008	0.7670	
	East Central			
	IN	IL	MI	OH
Oilvol	-0.2134(-2.5969)***	-0.1584(-1.1453)	-0.4238(-2.8200)***	-0.1790(-1.5584)
Std. error	0.0092	0.0163	0.0167	0.0129
R-square	0.4041	0.4330	0.4193	0.4163
Durbin-Watson test	1.7932	1.9390	1.9003	1.9198
Box-Ljung test	0.0355	0.0008	0.0321	0.0280
Heteroskedasticity	0.5749	1.8251	1.0381	0.9480
	West			
	CA	OR	WA	
Oilvol	-0.7395(-2.0723)**	-0.1125(-2.5589)**	-0.1518(-2.3300)**	
Std. error	0.0391	0.0047	0.0076	
R-Square	0.3282	0.3203	0.3354	
Durbin-Watson test	1.9422	1.8642	0.9240	
Box-Ljung test	0.0000	0.0000	0.0004	
Heteroskedasticity	2.0096	1.1132	1.1484	
	Oil Producers			
	LA	ND	OK	TX
Oilvol	-0.1278(-1.2317)	-0.0290(-3.1038)***	-0.0372(-0.8884)	-0.4843(-2.9522)***
Std. error	0.0099	0.0011	0.0047	0.0200
R-square	0.0788	0.5472	0.3760	0.5062
Durbin-Watson test	1.5261	1.8217	1.9100	1.8641
Box-Ljung test	0.0196	0.2163	0.0000	0.0000
Heteroskedasticity	10.3800	1.9617	0.6590	1.0308

Note: *, **, and *** indicate 10%, 5% and 1% significance levels, respectively Numbers in brackets are t-values. P-values are presented for Box-Ljung test. F-statistics are shown for heterskedasticity tests: a high (low) indicates increases (decreases) in variance over time.

Table 4: Comparison between Multivariate and Univariate UCM for South and East Central

		Multivariate UCM			Univariate UCM		
		Coefficient of oilvol	P-value	R-square	Coefficient of oilvol	P-value	R-square
South	AL	-0.0866	0.0572	0.3812	-0.1171	0.0146	0.3254
	KY	-0.1184	0.0087	0.3630	-0.1408	0.0037	0.2806
	NC	-0.1740	0.0669	0.4911	-0.2115	0.0311	0.4557
	TN	-0.1529	0.0182	0.4005	-0.1634	0.0114	0.3513
East Central	IN	-0.2134	0.0099	0.4041	-0.2181	0.0123	0.3710
	IL	-0.1584	0.2530	0.4330	-0.2380	0.1051	0.3994
	MI	-0.4238	0.0051	0.4193	-0.4444	0.0055	0.3712
	OH	-0.1790	0.1202	0.4163	-0.2489	0.0432	0.3694

Table 5: Simulated Effects of 100% Increase in Oil Price Volatility on Employment

South			
AL	KY	NC	TN
-0.2022%	-0.2949%	-0.1957%	-0.2571%

Northeast		
NJ	NY	PA
-0.0268%	-0.1905%	-0.3095%

East Central			
IN	IL	MI	OH
-0.3371%	-0.1233%	-0.4814%	-0.1553%

West		
CA	OR	WA
-0.2313%	-0.3073%	-0.2365%

Oil Producers			
LA	ND	OK	TX
-0.2959%	-0.3482%	-0.1062%	-0.2069%

Note: Assuming a 100% increase in oil price volatility, simulation is conducted using the estimated coefficients of oil price volatility from UCM. Average oil price volatility in 2009 and average state employment in 2009 are used as the base.

Table 6: Estimation of Factors Affecting the Impact of Oil Price Volatility

Variable	Estimate	Std. Error	t-value	p-value
Constant	-0.0394	0.2262	-0.17	0.8649
Petroleum Expenditure per Capita	-0.0292	0.0424	-0.69	0.5052
Petroleum Production	0.0175	0.0145	1.20	0.2542
Manufacturing, All but Motor Vehicle Production	-0.0018	0.0053	-0.35	0.7361
Transportation	-0.0234	0.0599	-0.39	0.7041
Construction	0.0147	0.0327	0.45	0.6616
Motor Vehicle Production	-0.0266	0.0098	-2.73	0.0195
R-square	0.4503			

Note: There are 18 observations in the regression. Dependent variable is the simulated percentage change in employment given 100% growth in oil price volatility in 2009. Petroleum Expenditure data is the per capita petroleum expenditure calculated using the 2008 petroleum expenditure data from the Energy Information Administration (EIA). Petroleum Production, Manufacturing, Transportation, Construction, and Motor Production are the prevalence of these industries as share of GDP; data are from the Bureau of Economic Analysis (BEA).

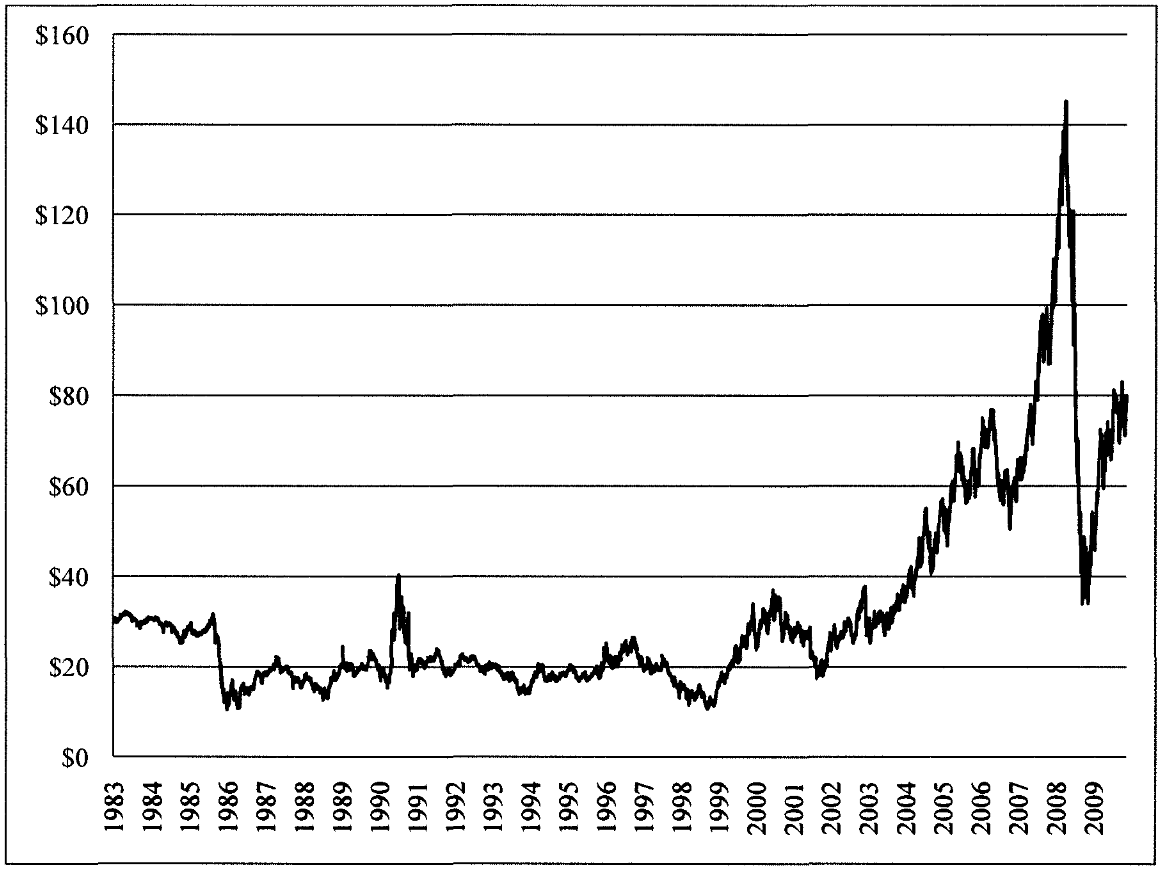

Figure 1: Daily Prices of Crude Oil (Dollars per Barrel)

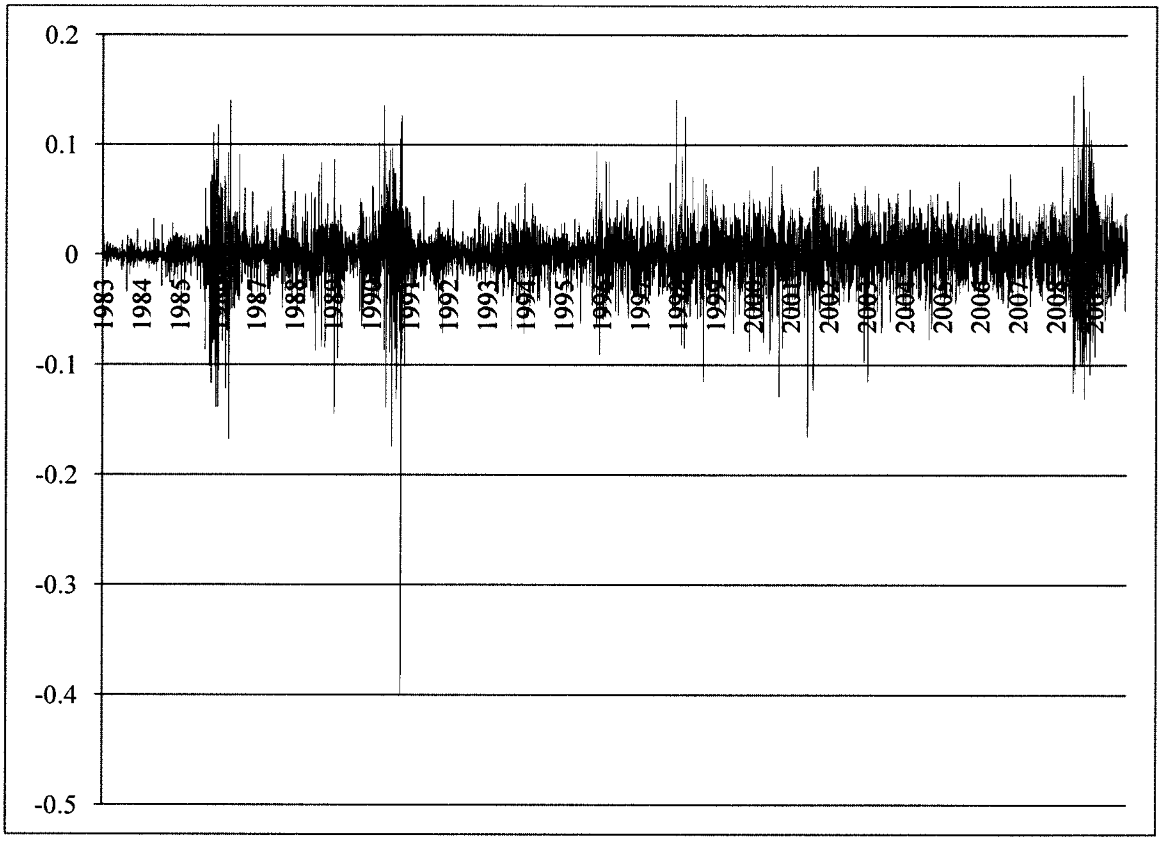

Figure 2: Daily Oil Price Returns

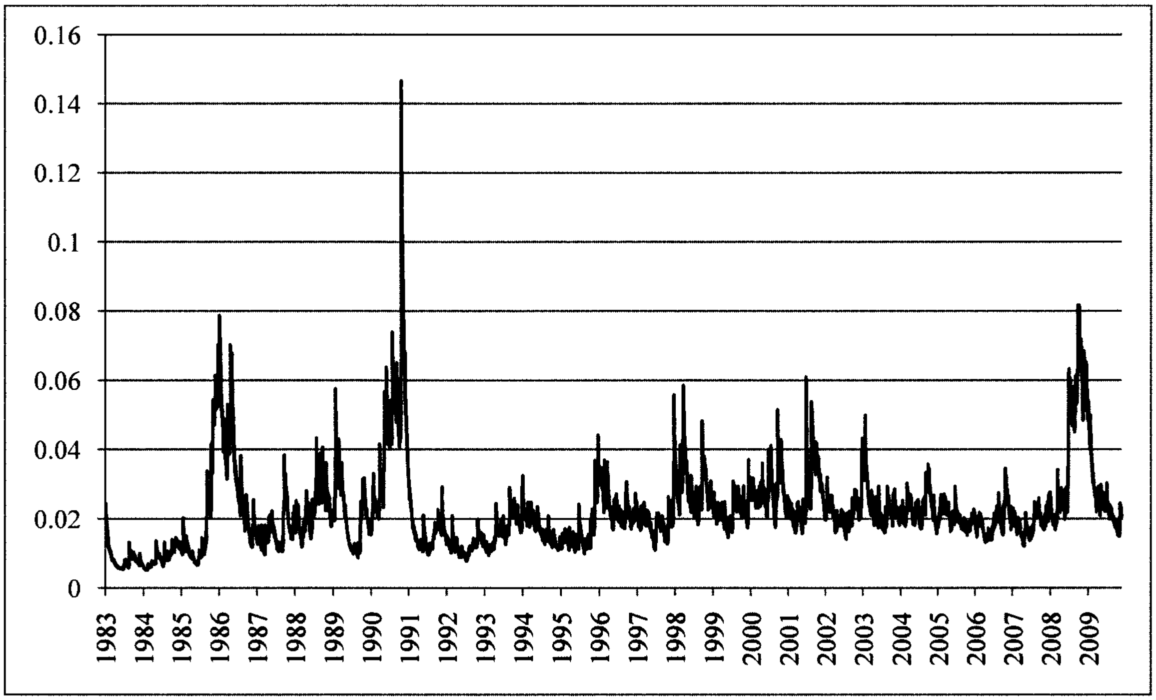

Figure 3: Daily Oil Price Volatility

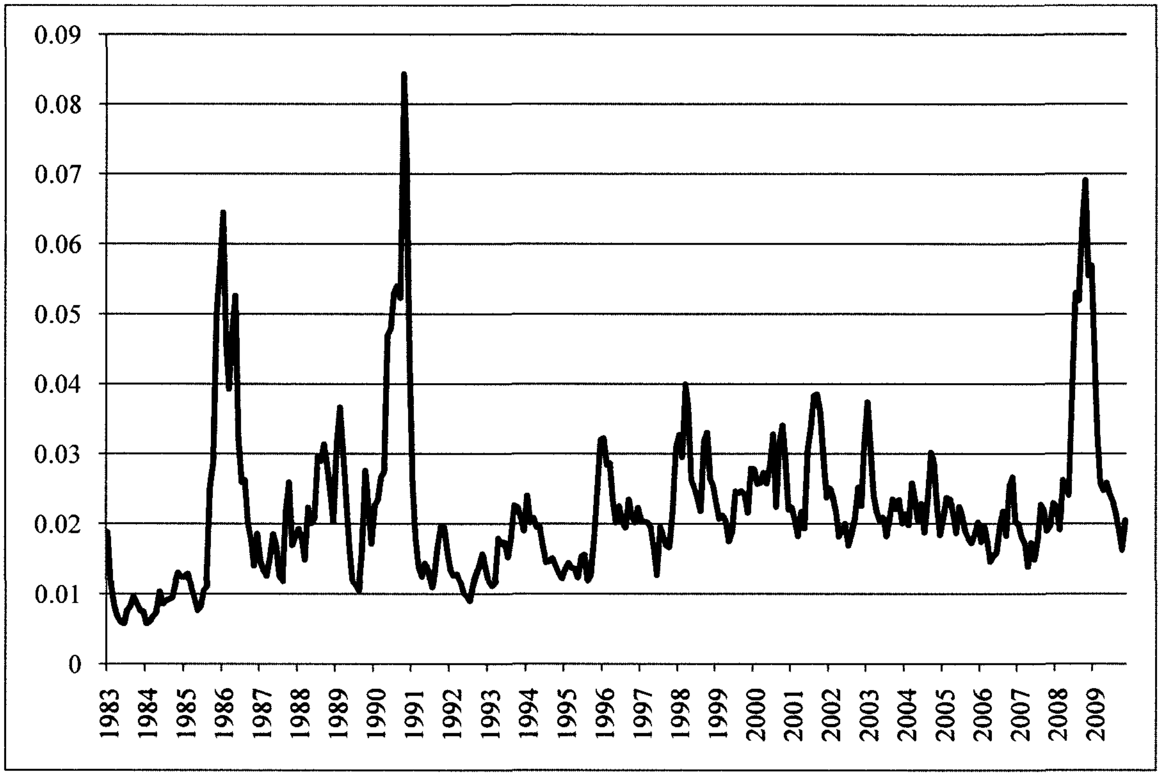

Figure 4: Monthly Oil Price Volatility

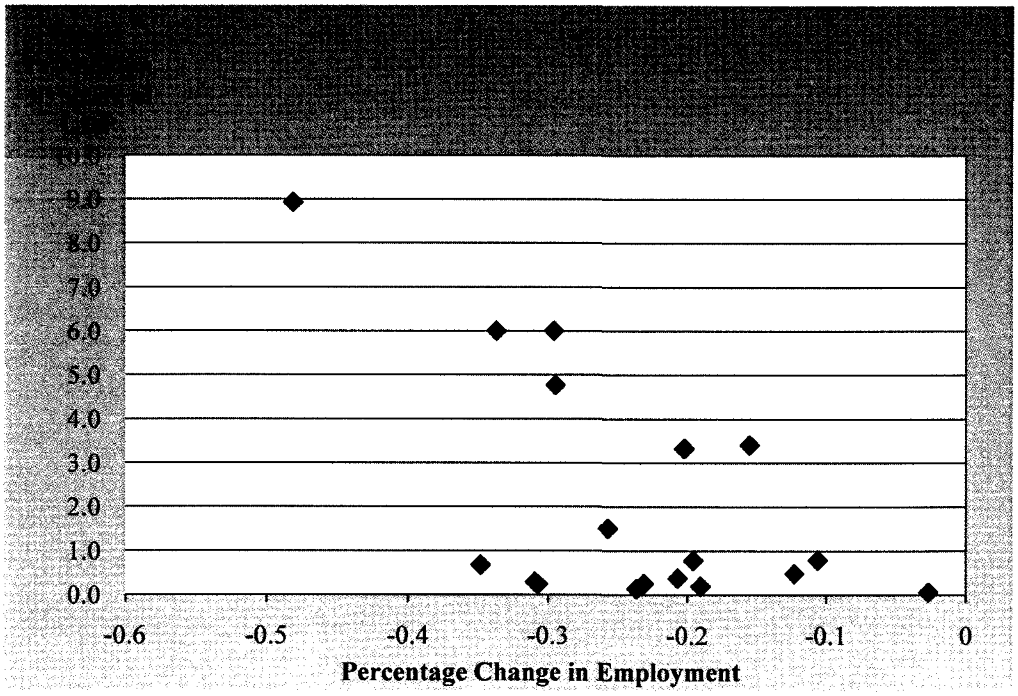

Figure 5: Oil Price Volatility Impact and State Economic Characteristics

Table A1: Estimation Result of GARCH (2,1)

Parameter	Value	Standard Error	t-Statistic
C	0.0002	0.0002	1.1220
K	0.0000	0.0000	8.1836
GARCH (1)	0.3369	0.0457	7.3771
GARCH (2)	0.5431	0.0440	12.3294
ARCH (1)	0.1201	0.0052	23.1283

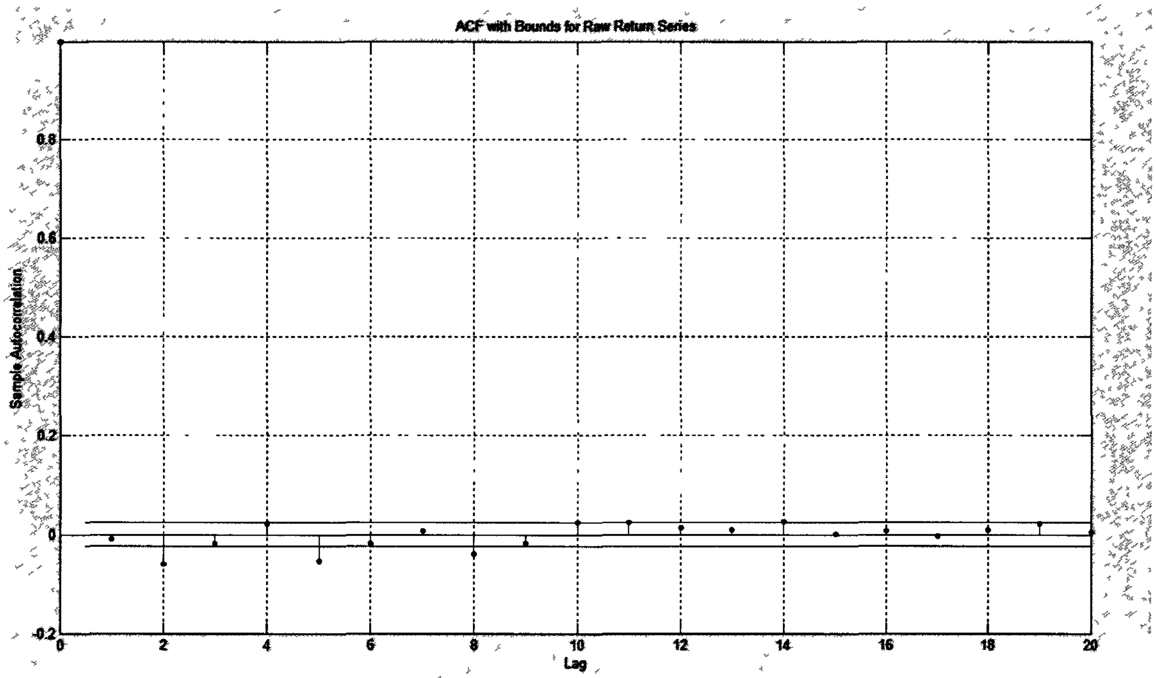

Figure A1: ACF for Oil Price Return Series

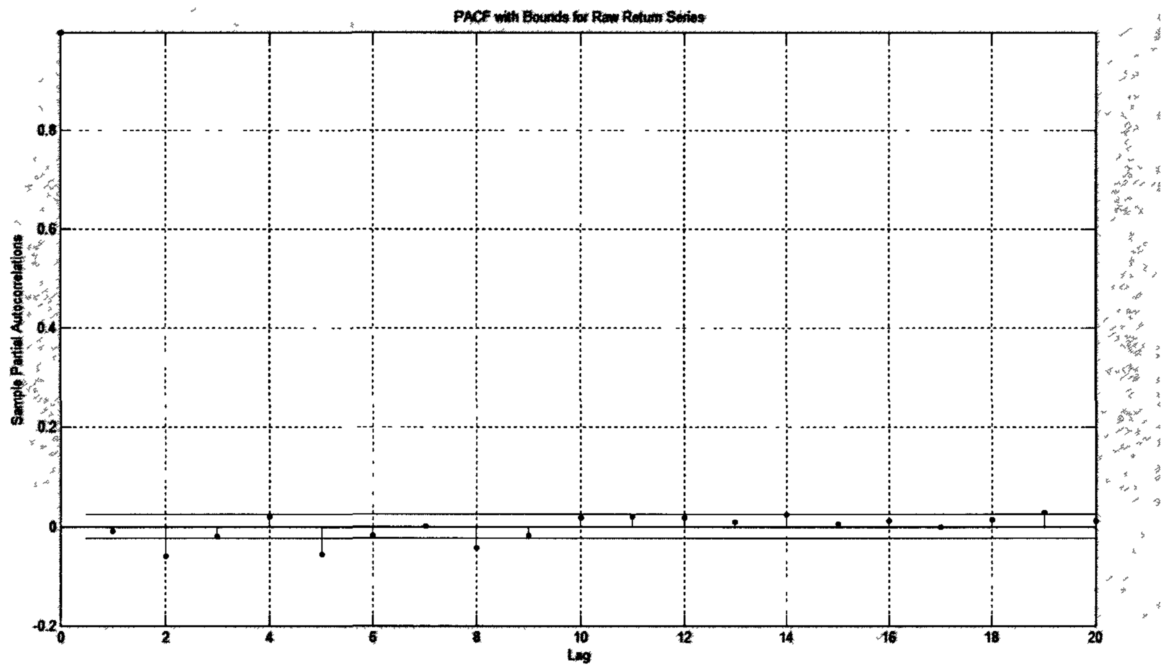

Figure A2: PACF for Oil Price Return Series

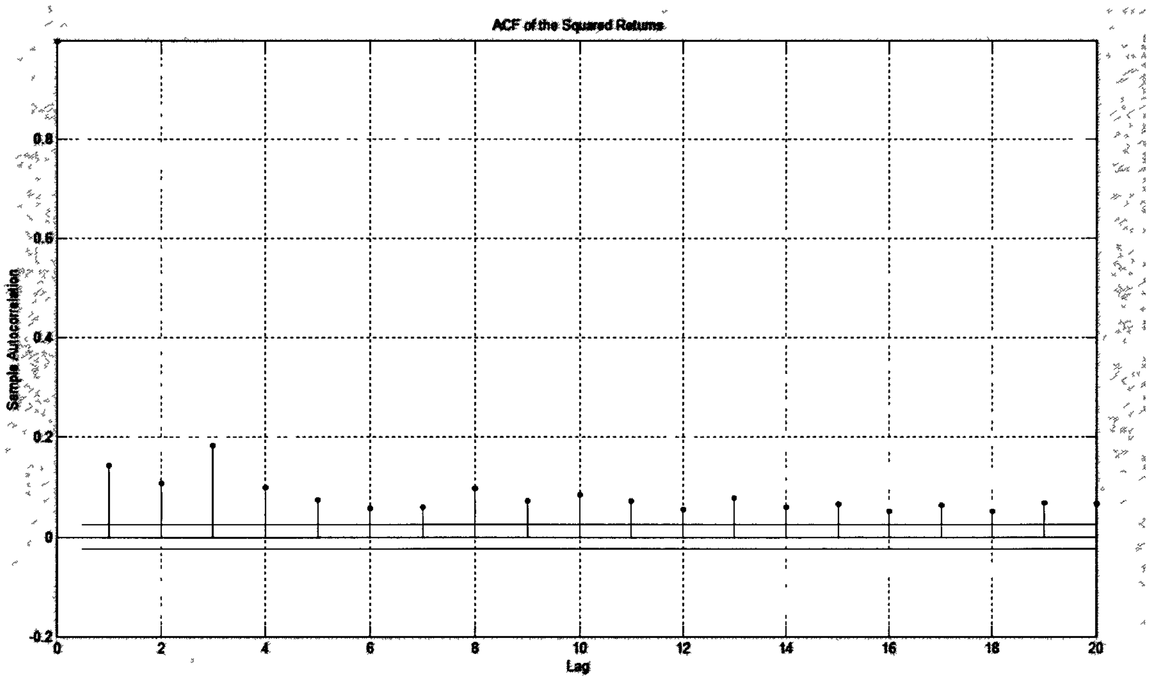

Figure A3: ACF for the Squared Oil Price Returns

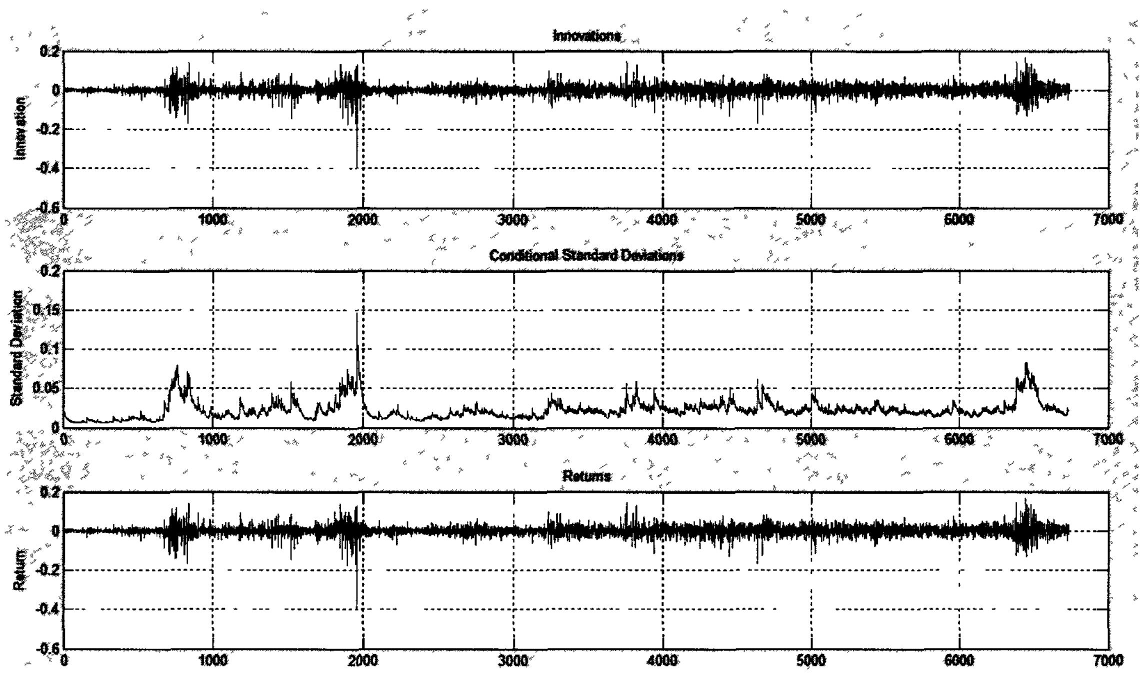

Figure A4: Innovations, Conditional Standard Deviations, and Returns

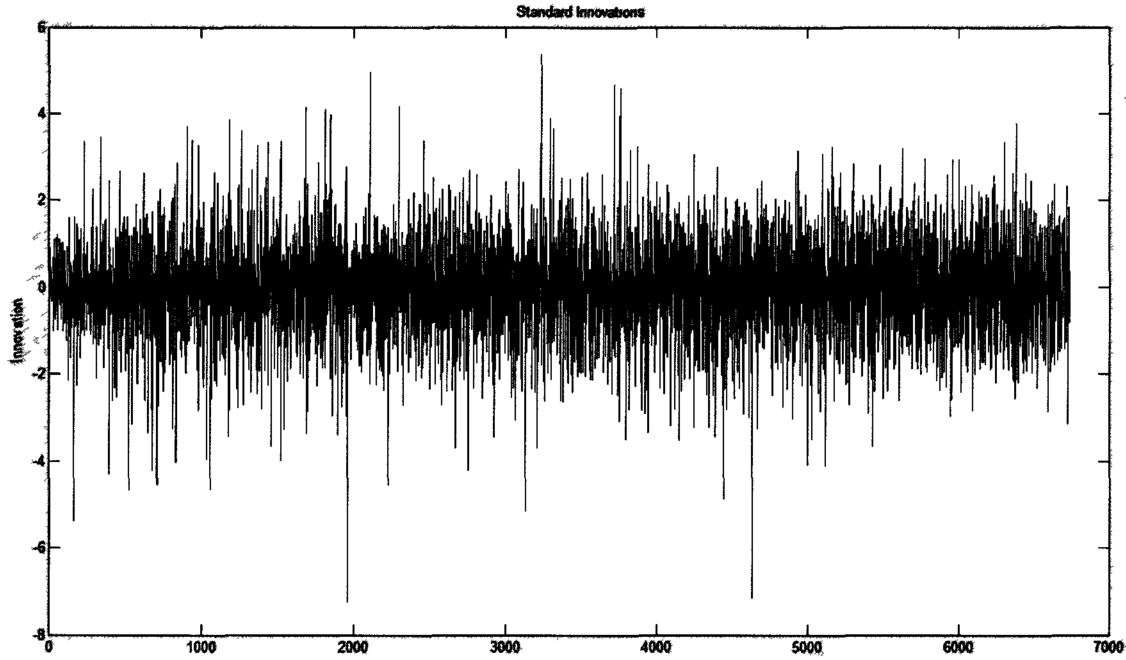

Figure A5: Standard Innovations

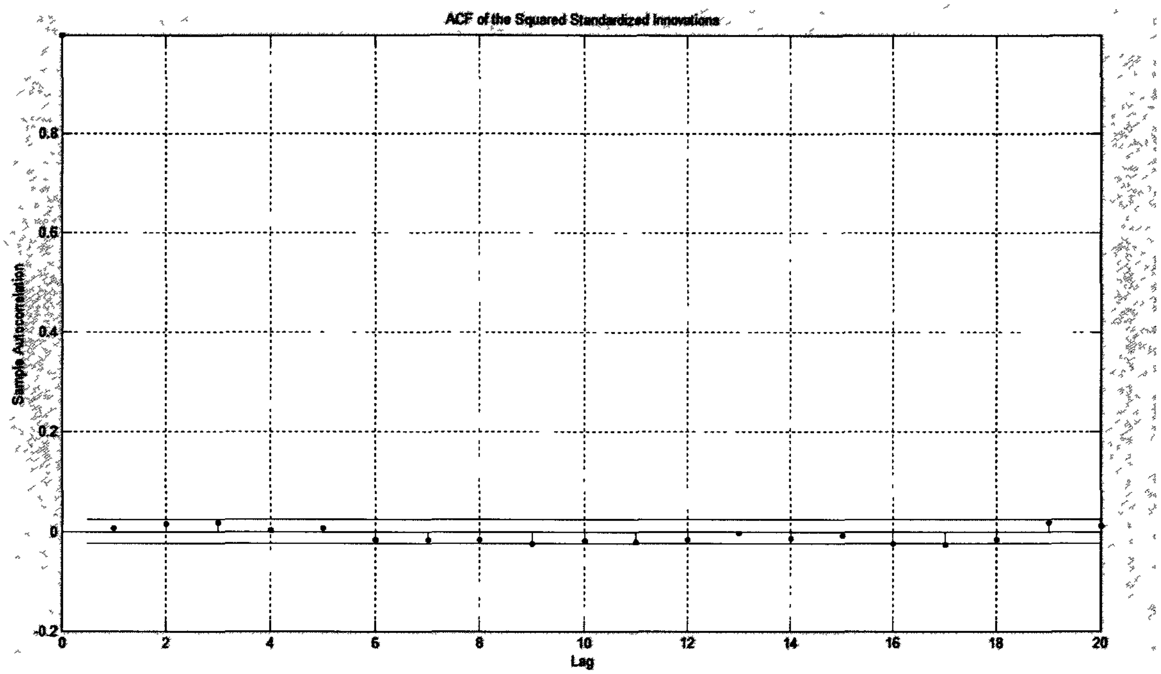

Figure A6: ACF of the Squared Standardized Innovations

Conclusion

This dissertation consists of three essays that examine the effects of oil prices on state economies. The relationship between oil prices and aggregate economic activity has been investigated at the national level in many studies; the main contribution of this dissertation is that it explores the impact of oil price shocks on state economies. In this dissertation, three different methodologies have been proposed.

This dissertation begins with an investigation of the sensitivity of state economic activity to oil price changes. More specifically, the relationship between oil price changes and the growth of private state incomes is explored using ARDL models. The estimation results demonstrate strong evidence of asymmetry in the impact of oil price changes on state incomes, with states exhibiting different levels of sensitivity to oil price changes. Further analysis reveals that these differences can be explained by the proportion of manufacturing and petroleum production in the state economies. States more dependent on manufacturing will be more negatively affected by oil price increases, while oil-producing states are likely to benefit from rising oil prices.

The second essay in this dissertation continues to examine the relationship between oil price changes and state incomes using a regime-switching approach. The essay uses STAR models to estimate the tolerance and delay of response of a state economy to an oil price shock. Results show that states that are more dependent on oil respond more quickly to oil price changes. States also present differences in the tolerance to oil price shocks, which can be partially explained by state-specific economic characteristics.

The third essay estimates the effects of oil price volatility on state employment. In this essay, states in five regions are examined, and a multivariate unobserved component model is fitted into each region. Significant negative impacts of oil price volatility on employment are found in most states. Further analysis on the determinants of the impacts of oil price volatility indicates that states with a higher proportion of motor vehicle production in GDP are likely to experience more job losses during periods of high oil price volatility.

This dissertation provides strong evidence of differences in state economies' responses to oil price shocks. Due to the lack of state-level data and theoretical guidance, investigation on the determinants of these differences yields limited findings. Future research is needed to explore the nature of these determinants.