On The Dynamic Effects Of Oil Price Shocks: A Study Using Industry Level Data

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Abstract

This paper analyzes the effects of oil price shocks on demand and supply in various industries. The impulse responses of identified VAR models indicate that for industries that have a large cost share of oil, such as petroleum refinery and industrial chemicals, oil price shocks mainly reduce supply. In contrast, for many other industries, with the automobile industry being a particularly important example, oil price shocks mainly reduce demand. The paper suggests that oil price shocks influence economic activities beyond that explained by direct input cost effects, possibly by delaying purchasing decisions of durable goods.

Keywords: *oil price shocks, identified VAR, industry supply and demand.*
JEL classification: *E30*

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1. Introduction

In this paper we use identified VAR (Vector Autoregression) models to investigate how oil price shocks affect different industries. We find that for industries that are oil-intensive in production, such as petroleum refinery and industrial chemicals, the predominate effects of oil shocks are on the supply side, while for many other industries, the automobile industry in particular, the chief effects of oil price shocks are on the demand side. A reading of trade magazines on the impacts of energy crises reveals diverse pattern across industries and the pattern is consistent with our results obtained from the VARs.

Macroeconomic effect of oil shocks has been debated since the first OPEC oil embargo in the early 1970s. The most extensively explored theories on the direct effects of oil price shocks include an *input-cost effect*, that higher energy cost lowers usage of oil which in turn lowers productivity of capital and labor; and an *income effect*, that higher cost of imported oil reduces disposable income of U.S. households. Researchers find that long-term statistics of the U.S. economy do not lend support for the macroeconomic importance of these effects of oil shocks. For example, Okun (1975), Perry (1977), and Nordhaus (1980) argue that since the economy-wide cost share of energy and the short-term elasticities of substitution between energy and other inputs are both quite small, the input-cost effect of oil price shocks must be very limited. Cross-sectoral observations reveal further evidence against the input-cost theory. Bohi (1989, 1991) argues that if oil shocks are the main cause of recessions then energy intensive sectors should be affected more severely. He finds no correlation between the declines in industry-level outputs and the energy intensities of the industries during energy crises. Several empirical observations suggest that the income effect of oil price shock is also small. First, assuming leisure is a normal good (and ignoring the input-cost effect), the negative income shock should increase labor supply and Industrial Production.[1] But employment and Industrial Production declined

[1] Industrial Production index measures output in physical units, weighted by market values. It differs from GDP, which measures the value-added of domestically produced goods and services. Since the value of imported oil must be deducted in calculation of domestic value-added, the income effect of higher price of imported oil on GDP is negative. It is obvious that the input-cost effects of higher oil price on both IP and GDP are negative. Barsky and Killian (2000) carefully distinguish effects of oil price shocks

substantially during the postwar oil crises. Second, countries that are more dependent on imported oil did not necessarily suffer more during the crises. For example, the United Kingdom experienced a much more severe recession during the 1978-81 oil crisis than Japan did, despite the fact that the U.K. was a net oil exporter and Japan was an oil importer (see Bohi 1991).

Hamilton (1988, 1999) proposes an alternative theory. He suggests that oil price shocks induce recessions mainly because a sharp rise in oil price increases *uncertainty* and raises *operating costs* of certain durable goods, which reduces demand for durables and investment. Pindyck and Rotemberg (1984) also suggest that increased uncertainty during oil crises may have been an important cause of recessions. Quantitative evaluation of the uncertainty and operating-cost theory has been scant since it involves modeling of optimal consumption of durable goods under operating-cost uncertainty and measuring time-varying uncertainty, which goes beyond what can be achieved from utilizing stylized facts and long-term statistics.

The relationship between oil price and macroeconomy is examined via different models in the existing literature. Dynamic equilibrium models (e.g., Pindyck and Rotemberg 1983, Ratti and Raymon 1992, Kim and Loungani 1992, Finn 1995, and Atkeson and Kehoe 1999) mainly focus on the input-cost and income effects of oil price shocks.[2] VAR models, which are without explicit microeconomic foundations, are also employed to examine the aggregate time series data. Several researchers (e.g. Hamilton 1983 and Burbidge and Harrison 1984) conclude that oil price increases predict recessions in the post war period before the mid-1980s. Hooker (1996) shows that oil prices no longer predict output when the sample period is extended to the 1990s. Lee, Ni, and Ratti (1995), Ferderer (1996), and Hamilton (1996) demonstrate that nonlinear transformations of oil prices are powerful predictors of recessions for sample periods that include recent years.

Besides examining direct effects of oil price shocks, researchers also debate whether oil price shocks indirectly cause recessions by triggering monetary contractions. Even in the absence of monetary tightening, oil-price-shock-induced inflation reduces real balances (see Mork 1994).

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in measures of gross and value-added concepts of output and price. The empirical analysis of the present study is based on Industrial Production.

[2] Ni (1996) shows that a standard one-sector stochastic growth model cannot explain the widely documented nonlinearity in the output-oil price relationship.

Dotsey and Reid (1992) show in a VAR model that both the federal funds rate and Mork's (1989) measure of oil price shocks are good predictors of output. Hoover and Perez (1994) show that the timing of several large post-war oil price shocks was close to Romer and Romer (1994) date of monetary tightening. Bernanke, Gerlter and Watson (BGW hereafter) (1997) conclude that oil price shocks do not cause economy-wide output decline once the impacts of the responses of monetary policy to oil shocks are accounted for. Sims (1997) questions BGW's design of the monetary policy response function. Hamilton and Herrera (2000) use BGW's VAR model with a longer lag length and conclude that oil price shocks lead to recessions.[3]

In this paper we show in a time series analysis that the use of industry-level data in addition to aggregate data is crucial in revealing the effects of oil price shocks and in reconciling the conflicting conclusions of the previous studies. We employ an identified VAR model that includes both macrovariables and industry-level variables. Our estimates indicate that oil price shocks reduce the supply of petroleum refinery and industrial chemicals, and that oil price shocks reduce demand of most of the fourteen industries studied in this paper. Among all industries, the automobile industry is most severely affected by oil price shocks.

In addition to the econometric analysis, we also examine how industry trade journals describe the impact of some large oil price shocks. According to trade journals, during the 1973-74 and 1978-81 oil price hikes the petroleum refinery and industrial chemical industries were hampered by shortage of energy inputs, while the automobile industry was devastated by the collapse of consumer demand for low fuel efficiency full-size cars, suggesting that the consumer-operating-cost channel is particularly important for the automobile industry. The results of our econometric study are consistent with the reports in the business press.

The main contribution of our paper is demonstrating that oil price shocks have a variety of negative effects upon U.S. industries. Although any one of the effects (e.g. the input-cost effect or the consumer-operating-cost effect) alone may not be large enough to cause an

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[3] Several studies note that the direct and indirect effects of oil price shocks can be amplified in economies where the wage is rigid (e.g., Mork and Hall 1980), markets are non-competitive (e.g., Rotemberg and Woodford 1996), and relocation of resources is costly (e.g., Hamilton 1988).

economy-wide recession, the combined forces of them may be able to do so, despite the small cost share of oil relative to GDP.

The rest of the paper is organized as follows. Section 2 describes oil consumption across industries. Section 3 provides evidence from trade magazines on how the energy crises in 1973-74 and 1978-81 affected various industries. Section 4 of the paper lays out the framework of the empirical model. Section 5 reports estimation results. Finally, section 6 offers concluding remarks.

2. Some Statistics of Oil Consumption by Industries

Petroleum is the most important source of energy for the U.S., according to the estimates by the U.S. Department of Energy's Energy Information Administration. Table 1 provides an overview on the end-use of petroleum in the U.S. economy from 1959 to 1997. The table shows that during the past four decades, petroleum accounted for approximately forty percent of all energy sources in the nation. The most important end-uses of petroleum products are as gasoline and aviation fuel. According to Table 1, in 1997 about two-thirds of oil was used for transportation, and about one-third was used for industrial production. (Insert Table 1 here)

Not all industries are equal consumers of energy. The industrial use of petroleum is concentrated in two industries, petroleum refinery and industrial chemicals. The energy consumption of these two industries accounted for about fifty-five percent of energy used by all manufacturing industries in 1994. Petroleum refinery is the largest energy user among manufacturing industries. In 1994, the industry's energy consumption was 6.2 quadrillion Btu, most of which was petroleum and natural gas. About half of energy used by refiners is for heat and power; the other half is for feedstocks of non-fuel products. The industrial chemical industry is another major user of energy. In 1994 the total energy input of the industry amounted to 5.3 quadrillion Btu (excluding electricity losses of about one quadrillion Btu), including oil and natural gas input of about 4 quadrillion Btu. About fifty-five percent of the energy input of the industrial chemical industry is for heat and power; the rest is for feedstocks of products such as petrochemicals, plastics, and synthetic fibers. The energy use of petroleum refiners, which is almost seven percent of nation's total end-use of energy, does not adequately reflect the importance of oil to the industry, because most of the oil input of the industry is transformed into energy products. (Insert Table 2 here).

A more relevant indicator of oil-intensity is the cost share of oil. Table 2 reports the oil-intensities (measured by cost of oil and natural gas for each dollar of sale) of the fourteen industries selected for the present study. Many of these industries are also examined by Bohi (1991) because their energy intensities are either quite high or quite low. Table 2 indicates that petroleum refinery and industrial chemicals are most oil-intensive. The petroleum refinery industry spends 68.3 cents on oil and gas for each dollar of revenue, and 60.7 out of the 68.3 cents are direct cost. In comparison, only 2.5 out of the 18.1 cents of cost of oil are direct cost for each dollar of revenue for the industrial chemical industry. A few other industries such as metals are usually considered energy-intensive. But the main energy source for these industries is coal. For example, the total cost of coal for each dollar of revenue of iron and steel is eight cents, about twice as much as the cost of oil for the industry. However the price of coal is only weakly correlated with oil price in the short run (see Yucel and Guo 1994). Therefore the cost impact of oil price shock on the iron and steel industry is different from that on petroleum refinery or industrial chemicals.

3. Identifying the Impacts of Oil Crises on Industries: A Reading of Trade Magazines

The diverse cross-industry pattern of oil-intensity raises the question of whether industries are affected differently by oil price shocks. In this section we document evidence from trade magazines on the industry-specific effects of two oil crises during 1973-74 and 1978-81. Alderman (1995) offers great detail on the cause of oil price hikes for both episodes. He shows that international incidents such as the October 1973 Arab-Israel war, the October 1978 Iranian revolution, and the 1980-81 Iran-Iraq war caused temporary disruptions in oil supply. The refiners' acquisition cost more than doubled in 1973-74 as well as in 1978-81. The U.S. economy experienced recessions after both oil price shocks. Industrial Production declined by about seventeen percent from March 1973 to March 1975, and by more than five percent from October 1978 to July 1980. With the exceptions of electronic machineries and office & computing machines, most industries suffered output declines during these periods. The outputs of the oil-intensive industries declined moderately in both periods, e.g., by ten percent on average for petroleum refining and by nineteen percent for industrial chemicals. Among all industries, the automobile industry suffered the largest decline-its output plunged more than thirty percent during both oil crises. Discussions in the business press provide ample evidence on how oil price shocks influenced industries.

3.1. Petroleum Refinery and Industrial Chemicals

We have shown earlier that petroleum refinery and chemical industries are the largest industrial users of petroleum products as fuel and feedstocks. In trade magazines such as *Petroleum Engineer International*, *Chemical and Engineering News*, *Chemical Week*, and *Industry Week*, we find overwhelming evidence that these industries were mainly affected by rising input cost during energy crises.

For example, after the oil price shock in late 1973, U.S. petroleum refinery operations slowed. Industry observers attribute the slowdown to "spot feedstock shortages, refineries shutdowns for repairs and possibly the effects of the new federal program for allocating crude oil." (*Petroleum Engineer International* March 1974 page 2). The writings in trade journals also reflect the view that the effect of oil price shocks on demand of petroleum products is not significant in the short run.

As for industrial chemicals, the impact of the 1973-74 oil crisis is well summarized in the following editorial of *Chemical and Engineering News*:

> "In the past, whenever chemical production tapered off, the reason could usually be found in the general health of the economy. Lower production growth usually accompanied a recession, or at least a business slowdown when demand for chemical products just wasn't there. Not so in 1973. The valve that limited production growth was on the supply end of the flow chart, not the demand end. This was particularly true of organic chemicals where shortage of crude oil and natural gas, and the Arab oil embargo put a squeeze on petroleum feedstocks." (*Chemical and Engineering News* May 6, 1974, page 10).

The industrial chemical industry faced a similar challenge during the 1978-81 oil crisis. The November 11, 1979 business column of *Chemical and Engineering News* reports that

> "The tight supply development was due to feedstock problems, which put a ceiling in production. The villain of the piece, at least to petrochemical producers, was gasoline. Gasoline

> shortages, especially of high-octane grades, led oil companies to divert mixed aromatic streams and propylene at oil refineries and some pyrolysis gasoline streams at ethylene-producing steam crackers to gasoline needs. Prices for these materials skyrocketed. Petrochemical producers substituted some natural gas liquids for these materials, but such substitution can go only so far."

Although we also find reports that oil price shocks reduce demand for certain chemical products, the majority of the stories are on the supply-side effect of oil price shocks.

3.2. The Automobile Industry

In contrast to the situation in the petroleum refinery and industrial chemical industries which were troubled by the rising cost of oil, writings in trade journal offer substantial evidence that the automobile industry was devastated by the two oil price hikes mainly because the demand for large cars plummeted. An editorial in *Ward's Auto World* observes during the 1973-74 oil crisis that

> "Automobile sales, especially for standard and intermediate-sized cars, began falling almost with the first realization that the energy crisis is reality… The trade-in value of big gas-guzzlers toppled unmercifully and some dealers were threatening not to take them in trade at all. Gasoline mileage, not size and comfort, suddenly became the paramount concern for the consumer." (*Ward's Auto World,* January 1974, page 46).

John S. Hinckly, president of the National Automobile Dealers Association offers an overview on the state of the automobile market in early 1974:

> "The energy crisis will have an adverse effect on all segments of the US economy… Consumer uncertainty about the fuel situation is having an impact in the marketplace. The crisis is real in thousands of dealerships, particularly those having large and family sized cars. New car stockpiles reached the highest levels ever recorded on Dec. 1 when there are more than 1.6 million unsold new models. There was a 72-day supply of family-sized cars on that date." (*Ward's Auto World,* February 1974, page 15).

The 1978-81 oil crisis had a similar impact on the automobile industry. An editorial in *Industry Week* describes the automobile market of 1979:

> "Detroit was rolling along in '79 until the Iranian crisis turned the market upside down in a matter of weeks. Subcompact and imported cars, which had been gathering dust, were suddenly hot items. As for big cars, virtually nobody wanted them. The plight is exemplified in General

> Motors' offering of rebate on 1979 models this year—when the 1980 model year was more than 25% completed." (*Industry Week* March 31 1980, page 48).

The impacts of oil price shocks for most other industries are complicated and less severe. The trade journals of metals, rubber, and machinery industries frequently cite the depressed automobile market as a major factor in damped activity, but they point out that certain sections of these industries also benefited from increased economic activity in energy exploration and conservation.

3.3. Metals, Machinery, and Other Industries

The steel industry was adversely affected by the slumps in automobile sales, according to *Ward's Auto World* and *Industry Week.* An industry report on the impact of 1973-74 oil price shock observes that

> "The shipment drop last year was almost entirely the result of the automobile industry's reduced demand for steel. This market declined by 4.3 million net tons or 18.4% in 1974 from 1973… Only products for railroads and energy industries will continue in strong demand." (*Industry Week* February 3 1975 page12).

In 1979 the second oil price shock had a similar impact on the steel industry through its impact on automobile demand. Thomas C. Graham, president and CEO of Jones&Laughlin Steel Co. writes that

> "The gasoline shortage that hit the nation last May and June resulted in a dramatic drop in sales of American made full size cars…Consequently we forecast steel shipment to the industry will drop by 2.5 million tons. This 13% decline accounts for nearly one-third of the total decline we expect this year." (*Ward's Auto World* January 1980, page 13)

For nonferrous metals, news stories and commentaries in *Ward's Auto World*, *Industry Week*, and *Chemical Week* suggest that oil prices shocks depressed demand for the metals through their effects on automobiles, consumer durables, and housing. The oil price hikes did not cause immediate surge in the production costs of nonferrous metals. For aluminum,

> "The market changed in late 1974 and with it, the metal's demand plummeted… Aluminum demand is expected to be off 10%. That metal's major markets--housing, autos, and

consumer durables--are suffering the worst of the recession." *(Industry Week*, March 24 1975 page s-4*).*

An industry executive points out that

> "For copper, lead and zinc, the primary effect of the energy shortage will be on the consumption, not production. Production of copper, for example, may exceed consumption by about 100,000 short tons this year because of the bleaker economic outlook caused by energy shortages." (*Chemical Week,* January 16, 1974, page14)

The impact of oil crises on machinery industry were mixed. Demand for some automobile related machinery was down but all machine builders were not equally affected. Demand for certain machinery was up; in particular those related to automakers' retooling for small cars, mining, drilling for oil and gas exploration, and building of railroads and pipelines.

The following table summarizes the explanations by industry observers on the mechanisms through which oil shocks affected the industries. (Insert Table 3 here)

4. The Empirical Framework

4.1 The Structural VAR with Recursive Blocks: Separate Identification of Macroeconomic Shocks and Industry Variable Shocks.

Evaluating the effects of oil price shocks on industry-level output and price requires isolating them from the effects of other macroeconomic and industry-specific shocks. The business press, informative as it is, is not adequate for this task. In this paper we use an econometric model to estimate the effect of oil price shocks. The empirical study involves data of macroeconomy as well as data of a large number of industries. The industries are examined one at a time since it is not feasible to incorporate all industries in one model. In this subsection we set up a VAR model that estimates macroeconomic parameters without using industry-level variables. The block-recursive setting implies that identified macroeconomic shocks (such as money supply shocks) are the same for all industries and makes the cross-industry comparison of responses to the macro shocks meaningful.

Consider the following reduced-form VAR model of N variables.

$$Y_t = c + B(L)Y_t + \varepsilon_t \qquad (1)$$

where $Y_t=\begin{bmatrix} Y_{1t} \\ Y_{2t} \end{bmatrix}$, $c=\begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$, $B(L)=\begin{bmatrix} B_{11}(L) & 0 \\ B_{21}(L) & B_{22}(L) \end{bmatrix}$, $\varepsilon_t=\begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$.

Y_{1t} is an N_1 dimensional column vector of macrovariables, Y_{2t} is an N_2 dimensional column vector of industry specific variables (with $N_1+N_2=N$). c_1 and c_2 are vectors of constants. The vector of error term ε_t has zero mean and covariance matrix $E(\varepsilon_t \varepsilon_t')=\Omega=\begin{bmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{bmatrix}$. B(L) is a block recursive matrix of polynomials of the lag operator L. There are no restrictions on B_{11}, B_{21}, and B_{22}. In studies of sectoral and regional labor markets, Davis and Haltiwanger (1999) and Davis et al. (1996) impose the same block-recursive restriction on the lag coefficients as we do here. Our likelihood ratio tests indicate that the block-recursive restrictions are rejected for most industries. However, single-equation F-tests show that industry-level variables are not significant in the macro-variable equations. And most important, the estimate of the covariance of macro-variables, Ω_{11}, is not significantly altered by the presence of the industry-level variables.

An identified VAR model has the following form:

$$A_0 Y_t = A_0 c + A_0 B(L) Y_t + u_t , \qquad (2)$$

or $A_0\begin{bmatrix} Y_{1t} \\ Y_{2t} \end{bmatrix}=A_0\begin{bmatrix} c_1 \\ c_2 \end{bmatrix}+A_0\begin{bmatrix} B_{11}(L) & 0 \\ B_{21}(L) & B_{22}(L) \end{bmatrix}\begin{bmatrix} Y_{1t} \\ Y_{2t} \end{bmatrix}+\begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix}$,

with $\begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix}=A_0\begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$. (3)

The covariance matrix of the structural shocks is given by $E(u_t u_t')=\begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix}$. I_1 and I_2 are identity matrices of dimension N_1 and N_2, respectively. Similar to the assumption on the lag parameters of the reduced-form VAR, A_0 is also assumed to be block recursive. In particular, we let $A_0=\begin{bmatrix} A_{11} & 0 \\ A_{21} & A_{22} \end{bmatrix}$, where A_{11} and A_{22} are N_1 by N_1 and N_2 by N_2 invertible matrices, respectively.

In equation (3), the matrix A_0 maps residuals of the reduced-form VAR into structural shocks, such as demand and supply shocks in money market. The structural shocks are identified from reduced-form innovations through restrictions that are based on economic theories or the timing of information flows. The identified VAR is then used to obtain impulse responses to structural shocks as well as variance decompositions of forecast errors. As is discussed earlier, it is desirable to make the macro block A_{11} independent of industry specific variables Y_{2t}. In the following, we will show that the block recursive structure of A_0 and B(L) allows for independent identification of the macro block and the industry-specific block.

The Gaussian density function of Y_t conditional on Y_{t-j} (j=1,2,..,M) and all unknown parameters, denoted by Φ, is given by

$$f(Y_t \mid Y_{t-1},..,Y_{t-M},\Phi) = (2\pi)^{-N/2} \mid \Omega \mid^{-1/2} \exp(-\varepsilon_t{}'\Omega^{-1}\varepsilon_t / 2) . \tag{4}$$

From (3) we have $\Omega = A_0^{-1}(A_0^{-1})'$. We can then rewrite the sample log likelihood function in terms of structural parameters by plugging in the estimated covariance matrix $\hat{\Omega}$:

$$L(A_0) = \sum_{t=1}^{T} \log[f(Y_t \mid Y_{t-1},..,Y_{t-M},\Phi^*)]$$

$$= -(TN/2)\log(2\pi) + T\log|A_0| - (T/2)\mathrm{Trace}[A_0'A_0\,\hat{\Omega}]$$

$$= -(TN/2)\log(2\pi) + T\log|A_{11}| + T\log|A_{22}| - (T/2)\mathrm{Trace}[A_0'A_0\,\hat{\Omega}]. \tag{5}$$

where Φ^* denotes the set of all parameters except for A_0. Note that

$$\mathrm{Trace}[A_0'A_0\,\hat{\Omega}] = \mathrm{Trace}\begin{bmatrix} E_1 & E_2 \\ E_3 & E_4 \end{bmatrix},$$

where E_1 and E_4 are N_1 by N_1 and N_2 by N_2 matrices with

$E_1 = A_{11}{}'A_{11}\hat{\Omega}_{11} + A_{21}{}'A_{21}\hat{\Omega}_{11} + A_{21}{}'A_{22}\hat{\Omega}_{21}$, and $E_4 = A_{22}{}'A_{21}\hat{\Omega}_{12} + A_{22}{}'A_{22}\hat{\Omega}_{22}$.

To calculate the trace, the off-diagonal matrices E_2 and E_3 are irrelevant, therefore

$$\mathrm{Trace}\begin{bmatrix} E_1 & E_2 \\ E_3 & E_4 \end{bmatrix} = \mathrm{Trace}(A_{11}{}'A_{11}\hat{\Omega}_{11}) + \mathrm{Trace}(A_{21}{}'A_{21}\hat{\Omega}_{11}) + \mathrm{Trace}(A_{21}{}'A_{22}\hat{\Omega}_{21}) + \mathrm{Trace}(A_{22}{}'A_{21}\hat{\Omega}_{12})$$

$$+ \mathrm{Trace}(A_{22}{}'A_{22}\hat{\Omega}_{22}). \tag{6}$$

Substituting (6) into (5) and rearranging the terms we can decompose the log likelihood into two parts:

$$L(A_0) = L_1(A_{11}) + L_2(A_{21},A_{22}), \qquad (7)$$

where

$$L_1(A_{11})= -(T/2)[N_1\log(2\pi) -2\log|A_{11}| +\mathrm{Trace}(A_{11}'A_{11}\hat{\Omega}_{11})], \qquad (8)$$

$$L_2(A_{21},A_{22})=-(T/2)[N_2\log(2\pi) -2\log|A_{22}|+\mathrm{Trace}(A_{21}'A_{21}\hat{\Omega}_{11})+\mathrm{Trace}(A_{21}'A_{22}\hat{\Omega}_{21})+$$

$$\mathrm{Trace}(A_{22}'A_{21}\hat{\Omega}_{12}) +\mathrm{Trace}(A_{22}'A_{22}\hat{\Omega}_{22})].$$

Two important features of the sample likelihood function are worth mentioning. First, the density function of the macro-variable vector Y_1, $L_1(A_{11})$, does not depend on the observations on the industry-specific variable vector, Y_2. As a result, the macro-variable block is the same for different industries. Hence for each industry the last N_2 equations are estimated while the first N_1 equations are kept unchanged. Second, identifying restrictions on A_0 do not create problems for using OLS estimates because there is no restriction within the block $B_{11}(L)$ in (1).

4.2 Identifying Restrictions of the Macro-variable Block

The block of macro-variables includes equations of money market, goods market (aggregate output and price), an equation for long bond, and an equation for oil price. The six macro-variables in the VAR are the logarithm of M2 money stock, the three-month treasury bill rate in annual percentages, the logarithm of Consumer Price Index, the interest rate on ten-year treasury notes in annual percentages, the logarithm of Industrial Production, and an oil price variable. The oil price variable is Hamilton’s (1996) "net oil price increase", defined as the percentage change of oil price over the maximum value of the preceding year if the price of the current month exceeds the previous year's maximum, and zero otherwise. To measure oil price, we follow Mork (1989) by using refiners' acquisition cost for crude oil when possible instead of PPI, and making adjustments to reflect the price controls in the 1970s. The contemporaneous innovations (i.e., residuals of corresponding equations in the reduce-form VAR) in log M2, short-term interest rates, log CPI, long-term interest rates, log IP, and the oil price are denoted by m, r, cpi, lb, ip, oil. The structural shocks u_{md}, u_{ms}, u_{cpi}, u_{lb}, u_{ay}, u_{oil}, correspond to shocks in money demand, money supply, price setting, bond yield, aggregate demand, and the net oil price increase. The elements of matrix A_{11}, which determines the relationship between reduced-form VAR residuals and the structural shocks of the macro block, are estimated through maximizing the likelihood function $L_1(A_{11})$ for a given matrix $\hat{\Omega}_{11}$, the latter is obtained from OLS residuals of the macro-block. The maximum number of parameters in A_{11} is N_1^2. The number of independent moments in $\hat{\Omega}_{11}$ is $N_1(N_1+1)/2$. Thus, the number of identifying restrictions should be at least $N_1(N_1-1)/2$. The number of independent moments in the covariance matrix $\hat{\Omega}_{11}$ is 21 and the number of free parameters is 20. Thus, the degree of over-identification is one. The restrictions on A_{11} are as follows. (Expected signs are in parentheses and question marks denote the uncertain signs.)

$c_1 m = c_2 r + c_3 cpi + c_4 ip + u_{md}$,	demand for M2
(+) (-) (+) (+)	
$c_5 r = c_6 m + c_7 lb + c_8 oil + u_{ms}$,	supply of M2
(+) (+) (+) (?)	
$c_9 cpi = c_{10} ip + c_{11} oil + u_p$.	aggregate price setting
(+) (+) (+)	
$c_{12} lb = c_{13} m + c_{14} r + c_{15} cpi + c_{16} ip + c_{17} oil + u_{lb}$,	long bond yield
(+) (+) (+) (+) (?) (?)	
$c_{18} ip = c_{19} oil + u_{ay}$,	aggregate output
(+) (-)	
$c_{20} oil = u_{oil}$.	oil price equation
(+)	

These restrictions should be viewed as useful working hypotheses rather than a "structural" economic theory. In constructing identification restrictions of the macroeconomic block, we borrow heavily from Sims (1986), Sims and Zha (1998), and Gordon and Leeper (1994). Following the "information-based" approach of these authors, we assume that the money supply equation does not include current output and CPI, which are not observable within a month, but it does include long-term interest rate and oil price variable, which are observable daily. The long bond equation reflects the term structure of interest rates and the fact that the bond market reacts to current shocks in all markets. Implicitly we assume that financial market quickly absorbs information both reported and yet unreported in official publications.[4] We also assume that goods market does not respond to current money market disturbances. The money demand and money supply equations are similar to those in Gordon and Leeper (1994). The aggregate price setting equation and the output equation follow those in Sims and Zha (1998). The main difference between our model and theirs is that the Sims-Zha equations contain producer's price index of crude and intermediate materials instead of oil price.

The structure of the macro-block presented above is not recursive (i.e. triangular). Christiano, Eichenbaum, and Evans (1999) (CEE) examine the performance of several block-recursive VAR models that identify monetary policy indicators by different variables. The CEE model is block-recursive in the sense that the identification of monetary policy shock is dependent on the position of the monetary policy variable relative to blocks of other variables but is independent of the ordering of variables within blocks placed before and after the monetary policy variable. We also experimented with a couple of block-recursive identified VAR models similar to those suggested by CEE and found that the aggregate and industry-level output responses in the block-recursive VAR models are quite similar to the responses in the non-block-recursive VAR model presented above.

We treat oil price shock as exogenous. This may be controversial. Barsky and Kilian (2000) question the notion that oil price changes mainly reflect supply shocks in the oil market. They argue that increases in demand, aided by expansionary U.S. monetary policy, pushed up the equilibrium price of oil and sudden adjustment from dis-equilibrium of the oil market resulted in surge of oil price in the1970s. Hamilton (1983,1985) argues that large disruptions in oil market were caused by international crises that did not correspond to macroeconomic conditions in the U.S. Alderman (1995) provides evidence that these oil price increases were not driven by

[4] Gordon and Leeper (1994) impose structural restrictions only on the money market, as a result shocks in the money markets do not affect the long-term interest rate contemporaneously.

scarcity of oil reserves, increases in extraction cost, or increases in consumer demand. He shows that the world oil reserve more than doubled from 1960 to 1970 during a period of low and declining oil price. Alderman argues that oil price increased in the 1970s when OPEC seized the opportunities created by international crises to raise taxes on oil exports, cut back production, and threaten for future tightening of oil supply. We assume that the timing of these events that lead to large disruptions in the oil market is not predictable in monthly frequency. For these reasons the oil price equation does not include other contemporaneous macro-variables, despite our view that in the long-run demand for oil is an important determinant of oil price. Our identification allows oil price to be influenced by shocks in demand factors with a delay of a month, it is therefore not excessively restrictive.

4.3. *Identifying Restrictions of the Industry-Variable Block*

The industry-level variables include industrial output and price. By definition the last two rows of the matrix A_0 (i.e., A_{21} and A_{22}) identify the industry-level equations. A_{21} represents the contemporaneous relationship between macro-variables and the industry-level output and price. A_{22} represents the contemporaneous relationship between industry output and price. A_{21} and Ω_{21} contain the same number of elements. We decide not to impose any restriction on A_{21} because we do not have a strong prior on the role of macro-variables in demand and supply functions of particular industries. Because three out of the four moments in Ω_{22} are independent we need to impose at least one restriction on the elements of A_{22}. To illustrate the identifying restriction we specify the industry-level equations in (9) and (10).

$$c_{21}m + c_{22}r + c_{23}cpi + c_{24}lb + c_{25}ip + c_{26}oil + c_{27}y_i + c_{28} p_i = u_{yi} \quad (9)$$
$$c_{29}m + c_{30}r + c_{31}cpi + c_{32}lb + c_{33}ip + c_{34}oil + c_{35}y_i + c_{36}p_i = u_{pi}. \quad (10)$$

In equations (9) and (10) price elasticities of output are given by $-c_{28}/c_{27}$ and $-c_{36}/c_{35}$, respectively. Estimation results of the reduced-form VAR (1) indicate that the contemporaneous output-price correlation is very weak for almost all industries. In the covariance matrix of the reduced-form VAR that includes both macrovariables and industry-level output and price, the correlation between residuals in industrial output and price is less than five percent in absolute value for most industries. This corresponds to two scenarios: a flat demand curve and steep supply curve or a steep demand curve and flat supply curve, depending on the sign of the parameters c_{27}, c_{28}, c_{35}, and c_{36}. A reasonable restriction is to assign a negative constant value to the product of the slopes, $c_{28}c_{36}/(c_{27}c_{35})$. But this constraint involves a nonlinear restriction that makes it harder to precisely estimate the parameters. We estimate (9) and (10) using an alternative approach. First, we scale the logarithms of industry-level output and price data by their standard deviations of reduced-form VAR residuals. The scaling makes the estimated parameters c_{27} and c_{36} close to unity. We then use the scaled data to estimate (9) and (10) under the restriction $c_{35} = -\theta c_{28}$. As a result, the product of the price elasticities of output in (9) and (10) is approximately $-1/\theta$. The estimate of A_{21} and A_{22} in structural VAR with unscaled data can be recovered from its counterpart in structural VAR with scaled data. The impulse responses of unscaled data to structural shocks can also be calculated from the estimates using scaled data. The details of the calculation are in a technical appendix available from the authors upon request.

Following the approach of Blanchard (1989), we fix the positive hyper-parameter θ when we estimate c_{28}, along with other parameters in (9) and (10). The same parameter θ is used for all industries. One may question whether the conclusion of the paper is sensitive to the identification of (9) and (10). It turns out not to be the case. We select a set of values of θ {0.5, 1, 2, 10} for every industry and find that choosing different values of θ neither materially affect the maximum likelihood nor change the impulse responses of industrial output and price. The point estimate of c_{28} is small for most industries for each fixed value of parameter θ, largely because of the weak contemporaneous output-price correlation.

In an earlier version of the paper we experimented with another identifying scheme. Instead of restricting the two off-diagonal elements of A_{22}, c_{28} and c_{35}, to be proportional, we set one of them to zero. We found that in all cases c_{27} and c_{36} are positive. If c_{28} is set at zero and c_{35} turns out to be negative, we identify (10) as the supply function and (9) as the demand function of the industry. Alternatively, if c_{35} is set at zero, the equations are labeled according to the sign of c_{28}. The difference between the alternative restrictions is that if c_{28} is zero then output in (9) is perfectly price inelastic, while if c_{35} is zero then output in (10) is perfectly price elastic. We discovered that the rest of the parameters in (9) and (10) as well as impulse responses to structural shocks are very similar when c_{28} or c_{35} is set at zero, and they are not materially different from those obtained under the scheme we employ in the present paper. Our exercises suggest that the impulse responses to structural shocks are quite robust to identification of industry-level equations.

The structural VAR used in this paper relies on historical macroeconomic data for estimation of responses of variables to oil price and monetary policy shocks. In a world where firms and consumers solve dynamic optimization problems under rational expectations, changes in economic environment and government policy may cause correlations among industry-level output and macroeconomic variables to deviate from historical values. Sargent (1982) argues that it is more useful to estimate structural parameters characterizing taste and technology that are invariant to changes in economic environment. In defense of identified VAR models, Sims (1986), Leeper, Sims, and Zha (1996) suggest that it is plausible to treat policy changes, including those involving changes in policy rule, as a sequence of shocks. Furthermore, they note that linearized Dynamic Stochastic General Equilibrium (DSGE) models and VAR models are not fundamentally different for the purpose of analyzing the short-run effect of macroeconomic shocks. This, they argue, is because restrictions used to identify VAR models are often a subset of the restrictions used in linearized DSGE models, so that former can be viewed as weakly restricted version of the latter. Sims and Zha (1998) explicitly construct a DSGE model to illustrate this point. The argument is applicable to our industry-level demand and supply equations, given the weak identifying restrictions placed on the equations. There are tradeoffs of using these alternative models: Since VAR models are more loosely restricted, they tend to fit data better. On the other hand, DSGE models are likely to produce sharper estimates of parameters pertaining to behavioral theories in economics and are therefore more effective in analyzing the long-term effect of unprecedented policy changes. For the present study we use identified VAR models because we are mainly interested in the business cycle implications of oil price shocks.

5. The Empirical Results

The empirical results are obtained from the following procedure.

5.1. Estimation of a Six-Macrovariable Reduced-Form VAR.

The purpose of this step is to estimate the 6x6 variance-covariance matrix of the residuals of reduced-form VAR, $\hat{\Omega}_{11}$. The sample is monthly data from 1959:1 to 1997:9. The lag length of the VAR is twelve. The estimated covariance matrix is reported in Table 4. The impulse responses of the reduced-form VAR with monthly data are quite similar to those with quarterly data that are more commonly studied in the literature and are therefore not included here. In what follows, we examine the estimation results of the structural VAR model. (Insert Table 4 here.)

5.2. Estimation of Structural Parameters of the Macrovariable Block.

The covariance matrix of the reduced-form macrovariable VAR is used for estimation of A_{11}. The estimates of the structural parameters are reported in Table 5. The structural equations contain one over-identifying restriction that can be used to test the restrictions. The likelihood ratio test statistic of the structural model against the reduced-form model is 1.087 while the five percent critical value of the Chi-square distribution with a single degree of freedom is 3.841. Thus the test does not reject the structural restrictions. The signs of the estimates are consistent with a priori assumptions.

As is mentioned earlier, we also consider alternative identification schemes for the macro-block. In particular, we use two recursive VAR models suggested by Christiano, Eichenbaum, and Evans (1999), with the addition of oil price. The variables in the first model (named the Federal Funds Rate Model because the federal funds rate is chosen as the monetary policy variable) are in the order of log IP, log CPI, the logarithm of commodity price index, the federal funds rate, the logarithm of nonborrowed reserves, the logarithm of total reserves, log M2 and Hamilton's net oil price increase. In the second model (the Nonborrowed Reserves Model), the federal funds rate switches place with the logarithm of nonborrowed reserves. We experiment with alternative block-recursive models by placing the oil price variable in various positions and find that the output responses to oil price shocks are not significantly different. We compare the responses of IP to monetary policy shocks and oil price shocks in these models and plot them against the IP responses in the non-block-recursive model presented in section 4.2. The impulse responses of output to monetary policy shocks are reported in Figure 1.

(Insert Table 5 and Figure 1 here)

Several patterns in Figure 1 are worth mentioning. The output responses to oil price shocks are identical in CEE's Fed Funds Rate model and Nonborrowed Reserve model and both are similar to the output response under our identifying scheme. Output starts a steep decent after a lag of ten months following an oil price shock. The output decline hits the bottom at around the fifteenth month and start to recover. The peak output effect of a one-standard-deviation oil price shock is about 0.4% under all three identifications. Using the structural equation in section 4.2 and the variance-covariance matrix of the macro-variable VAR in Table 4, one can find the standard deviation of oil price residuals to be 1.9%. A typical large oil price shock can be several times of the size of the standard deviation and results in large estimated output effect. In comparison, the size of a typical monetary policy shock is likely to be moderate. One should not compare the magnitudes of output responses to monetary policy shocks under different identifications because monetary policy is represented by different variables. However, the three identifications produce similar output responses to monetary policy shocks, which are distinctly different from the output responses to oil price shocks. Output declines more quickly and recovers much more slowly after a contractionary monetary policy shock than it does after an oil price shock. In sum, the output responses are quite robust under alternative identifying schemes of the macro-block.

Before moving on to the industry-level study, we conduct split-sample checks on the macroeconomic part of our identified model in section 4.2 because the data sample includes unusual episodes such as oil crises and changes of Federal Reserve's official target variable. We examine two different sample splits, 1959:1-79:12 and 1980:1-97:9 to account for the oil crisis and the change in the monetary policy variable in the late 1970s and early 1980s, and 1959:1-85:12 and 1986:1-97:9 to reflect the changes in the world oil market. As in Sims (1998), we use the Schwarz criterion that compares twice the difference of log likelihoods (a statistic we call S) to degrees of freedom times the logarithm of sample size. Degrees of freedom are 458 since a sample split creates 438 additional parameters in the 6-variable 12-lag VAR and 20 additional parameters in A_{11} matrix. The statistic S is 1209.5 and 698.9 for the first and second sample split, respectively, much smaller than the Schwarz criterion threshold value of 2801.1 and therefore strongly favors using the same set of parameters for the whole sample. The threshold value of the Hannan-Quinn criterion is 1658.8, which provides the same conclusion.

5.3. Estimation of Reduced-Form Eight-Variable VARs That Include Industry Data

For each industry, industry output and relative price are added to the set of six macro-variables. The relative price is defined as the producer price of the industry divided by the aggregate producer price of finished goods. We use the relative producer price because the contemporaneous industry-level demand and supply equations are specified in a static partial equilibrium setting, therefore the aggregate price is a natural numeraire. By adding the industry output and price to the six macro-variable system, an eight-variable VAR can be estimated. The last two rows of the estimated covariance matrix of the eight-variable VAR provide $\hat{\Omega}_{21}$ and $\hat{\Omega}_{22}$.

5.4. Estimation of Structural Parameters in the Industry-Specific Equations

We now turn to the contemporaneous effects of oil price shocks on the industry demand and supply. Following the discussion in Section 4.3, we estimate (9) and (10) using scaled data under constraint $c_{35}= -\theta c_{28}$, then rescale the estimates of (9) and (10) to obtain estimates that correspond to the original data and report them in Table 6. Note that the rescaled estimates are no longer constrained by $c_{35}= -\theta c_{28}$. The third column of Table 6 reports the oil price coefficients $\{c_{26}, c_{34}\}$, the fourth column reports the output coefficients $\{c_{27}, c_{35}\}$, and the fifth column reports price coefficients $\{c_{28}, c_{36}\}$ in equations (9) and (10). The parameter θ is set at 2. As we indicated earlier, choosing alternative values for θ does not qualitatively changes the results. (Insert Table 6 here)

By construction, parameters c_{27} and c_{36} are positive. The signs of c_{28} and c_{35}, which are opposite, determine the identification of (9) and (10). The estimated coefficients c_{28} and c_{35} are quite small, suggesting that the industry demand curve is nearly vertical with supply curve nearly horizontal, or demand curve is nearly horizontal with supply curve nearly vertical. The signs of parameters c_{26} and c_{34} indicate the contemporaneous impact of oil price shocks on industry demand and supply. For example, Table 6 shows that an increase in oil price significantly reduces the supply of petroleum refinery while slightly reduces the demand of the industry. The contemporaneous industry-level output and price responses to oil price shocks can be calculated from estimates of macrovariable-block and estimates of industry-level equations (9) and (10). The output elasticity of oil price is given by $(c_{28}c_{34}-c_{26}c_{36})/(c_{27}c_{36}-c_{28}c_{35})$. As is shown by Table 6, c_{27} and c_{36} are much larger than other parameters; hence the output elasticity is approximately $-c_{26}/c_{27}$. Similarly, the price elasticity of oil price is approximately $-c_{34}/c_{36}$. Table 6 shows that the contemporaneous output elasticities do not correlate with the oil-intensities of industries and are quite small, except for the automobile industry. The price elasticities to oil price shocks are negligible in all industries with petroleum refinery being the exception. In response to a shock in oil price, the contemporaneous elasticity of automobile output is about -0.4, the contemporaneous elasticity of petroleum refinery price is about 0.4. The estimates of equations (9) and (10) show that an oil price hike induces reduction in supply of petroleum refinery and reduction in demand of automobiles.

5.5. Impulse Responses of Industry-Level Output and Price

The estimates of (9) and (10) determine the elements of matrices A_{21} and A_{22} that are used to produce the impulse responses of industry-specific variables to oil price shocks. Figure 2 reports the impulse responses of output and producer price of all industries up to 36 months after a one standard deviation shock in Hamilton's net oil price increase. Also shown are equal-tailed 68% posterior probability bands calculated using the Bayesian algorithm of Sims and Zha (1999). It is important to note that the scales of the impulse response graphs in Figure 2 are different for different industries. Hence one should not use the figure to make quantitative cross-industry comparisons.

Table 7 describes the pattern of impulse responses of industry-level output and price to oil price shocks. The table reports the nature of peak impulse responses. If output and price move in the same (opposite) direction after an oil price shock, the dominant effect is on the demand (supply) side. Based on the pattern of the responses of output and price to oil price shocks, the main effects of oil price shocks are identified in the last column. (Insert Table 7 here)

The pattern of impulse responses of outputs and prices suggest that oil price shocks affect oil-intensive industries, such as petroleum refinery and industrial chemical, mainly as supply shocks.[5] The output of petroleum refinery is not significantly affected by oil price shocks while its price is significantly increased. This result is consistent with the notion that in the short run the demand for this industry is price inelastic and the supply curve shifts leftward by an oil price increase. The output of industrial chemical decreases but its price increases substantially, also indicating reduction of the industry supply. In contrast to the oil-intensive industries, declines in automobile output are accompanied by decreases in prices. The automobile industry responses are explained by a shift in the demand following an oil price shock. For most industries, the automobile industry in particular, the estimated magnitudes of peak output-responses to oil price shocks are quite large. According to the variance-covariance matrix of the macro-variable VAR in Table 4, the standard deviation of oil price shocks is 1.9%. The impulse responses of automobile output after an oil price shock of one standard deviation peak after 13 months. The peak automobile output response is about 1.7%. The peak responses of most other industries are of the order of one-half this amount. The large effect of oil shocks on demand for automobiles is not surprising. An oil price shock in the short-run may affect demand for automobiles more than it does to consumption of gasoline because the latter is largely determined by factors that are costly to adjust, such as the types of cars households own and the locations of homes and workplaces. After an oil price shock, demand for automobiles is weakened since a potential new-car owner may opt for other means of transportation to save the operating cost of automobile, or postpone purchasing a new car because uncertainty about future fuel prices makes it harder to decide which type of car to buy. Oil price increases also change the composition of the demand for cars. The demand for full-size cars is weakened much more compared to small cars. The U.S. carmakers suffer more severely from surging oil price because they produce disproportionably more full-size cars than their foreign competitors. These effects are vividly documented in trade

[5] An alternative way to characterize the cross-industry pattern of the impulse responses is that oil price increases reduce the supply of intermediate goods industries and the demand of final goods industries.

journals during the 1973-74 and 1978-81 oil crises. Our empirical results indicate that these short-run demand effects of oil price shocks are significant.

The cross-industry pattern on the effects of oil price shocks exhibited in Table 7 is consistent with that in Table 3, indicating that observations in the business press agree quite well with the explanations offered by our VAR model, especially for the automobile industry and the oil-intensive petroleum refinery and industrial chemical industries.

As is observed in the introduction of the paper, based on estimated production functions many authors argue that the input cost effect of oil price shocks is not large enough to generate the post-war recessions. This view is consistent with our finding that the supply channel is not the most important channel through which oil price shocks affect most industries. However, it does not follow from the weak supply effect that the effect of oil price shocks is weak. Our estimates from the VARs are consistent with the view that the demand effect of oil price shocks is more important than the supply effect in many industries and the effects of oil price shocks should be investigated taking both demand and supply effects into account.

For most industries the impulse responses of output to oil price shocks show a very similar pattern. A noteworthy feature of the output responses to oil price shocks is that they are delayed and short-lived. The responses of outputs are typically small for the first nine months after an oil price shock, take steep dips between the tenth to eighteenth months, and then quickly recover from the slumps thereafter. This cross-industry similarity is striking given the diverse nature of the industries. The delays in the responses of industrial output to oil price shocks may reflect buildups of inventory followed by temporary shutdowns in production. Whether the output responses are consistent with intertemporal optimizations of producers is an interesting future research question.

The pattern of the output responses at the industry level is useful in understanding how oil price shocks are transmitted through the macroeconomy. Figure 1 shows that in the identified six-variable VAR (the macro-block) the impulse responses of aggregate output to an oil price shock exhibit the same pattern as the responses of output in most industries in Figure 2. The similarity of the macro and industry-level output responses suggests that oil price shocks can induce economy-wide recessions by reducing output in many industries at the same time. A widely accepted theory on the transmission mechanism of oil shocks is that labor migrates from sectors that are directly affected by oil price shocks to sectors that are not, and aggregate output declines during the period of sectoral shift of resources. Hamilton (1988) illustrates the mechanism in a general equilibrium model. Loungani (1986) finds a positive correlation between dispersion of sectoral output growth and oil price shocks.[6] Recently, using micro-panel data Keane and Prasad (1996) find that oil price shocks are correlated with the decline in employment and real wage in all sectors, and there is no clear pattern of labor flowing to sectors with higher productivities. Their finding disputes the importance of the sectoral shift mechanism. Our findings support the conclusion of Keane and Prasad. We do not find evidence that oil price shocks cause imbalances across industries that are large enough for any industry in our sample to experience increases in demand or supply (with the exception of office machines) after an oil price shock. Furthermore, if sectoral relocation is the main cause of output decline then industries that experience resource outflows after an oil price shock should have output-responses different from those of industries that experience resource inflows. But we find that the output responses to oil price shocks exhibit similar patterns across nearly all industries. Our finding is consistent with the view that oil price shocks simultaneously drive down demand in many industries, causing economy-wide recessions. However, it is important to note that the similarity in the cross-industry pattern of output responses to oil price shocks does not necessarily imply that oil price shocks do not induce resource relocations, since within-industry relocations cannot be revealed by the industry-level data we use in the present study. Furthermore, our results concern only fourteen manufacturing industries. It is possible that oil price shocks cause resource shifting across service industries and manufacturing industries that are not examined in this study.

We will now investigate the output responses of various industries to other macroeconomic shocks and compare them with the responses to oil price shocks. The graphs of the impulse responses are available upon request. First, we study the responses of industry-level output to monetary policy shocks. In all industries the output-responses to a contractionary

[6] A large literature documented the sectoral relocations of labor during business cycles, see for example, Davis (1987) and Loungani and Rogerson (1989). Bohi (1991) finds no cross-industry correlation between changes in employment and energy intensities.

monetary policy shock show a distinctly different pattern from those to an oil price shock. Output starts to decline after a contractionary monetary shock in all industries, and the decline deepens and reaches its peak at around tenth to eighteenth month. Compared with the responses to an oil price shock, the responses to a monetary policy shock are much more persistent. The pattern of industry-level output responses to a monetary policy shock duplicates the response of aggregate output shown in Figure 1. The magnitudes of peak responses of outputs to a one-unit contractionary monetary policy shock are comparable to those to a one-unit oil price shock. Sims and Zha (1998) show that estimated effect of monetary policy on aggregate output depends on the measurement of monetary variables. When money stock is measured by M2, Sims and Zha's output-responses to money supply shocks are similar to those in this paper. But they find that when M2 is replaced by total reserves, the output-responses to money supply shocks are considerably smaller. Outputs in all industries except petroleum refinery show similar responses to a shock in aggregate output. Industry-level output surges sharply upward following a positive shock in aggregate output but the effect diminishes over time. Output-responses to positive money demand shocks are short-lived and insignificant in many industries. Output-responses to inflation are uniformly negative across industries. Following a positive shock in CPI, outputs (after moderate and short-lived increases for some industries) decline continuously and persistently.

By observing the pattern of impulse responses of outputs and prices, we find that money supply shocks induce shifts of industry demand as well as shifts of industry supply. The predominate effects of contractionary money shocks are reduction of supply in six industries and reduction of demand in eight other industries. The diverse pattern across industries underscores the importance of looking beyond economy-wide aggregate data in searching for the transmission mechanisms of macroeconomic shocks. We also calculate variance decompositions of forecast errors of industry outputs and find that oil price shocks are estimated to account for on average five percent of forecast errors of outputs in the fourteen industries. The relative small shares of oil price shocks in the variance decompositions of industrial outputs reflect more of the temporary nature of the oil price shock effects than the severity of the effects.

6. Concluding Remarks

This paper analyzes the dynamic effects of oil price shocks using industry-level data. There is considerable similarity of output responses to oil price shocks in most industries. In response to a shock in oil price, output decline occurs after a ten-month delay and the decline is short-lived. There is little correlation between severity of oil-price-triggered output decreases and industries' oil intensity. While both demand and supply of industries are affected by oil price shocks, we find that oil price shocks mostly reduce the supply of oil-intensive industries while they mostly reduce the demand of many other industries, especially the automobile industry. For most industries, the conclusion drawn from our identified VAR models on the industry-level effect of oil price shocks confirms the views expressed in the business press during the oil crises of 1973-74 and 1978-81. The findings of this study lend support to the theory that increased operating cost of durable goods and heightened uncertainty are major reasons for oil price shocks to induce recessions. Our study provides rationale for incorporating these demand effects of oil price shocks into dynamic general equilibrium business cycle models.

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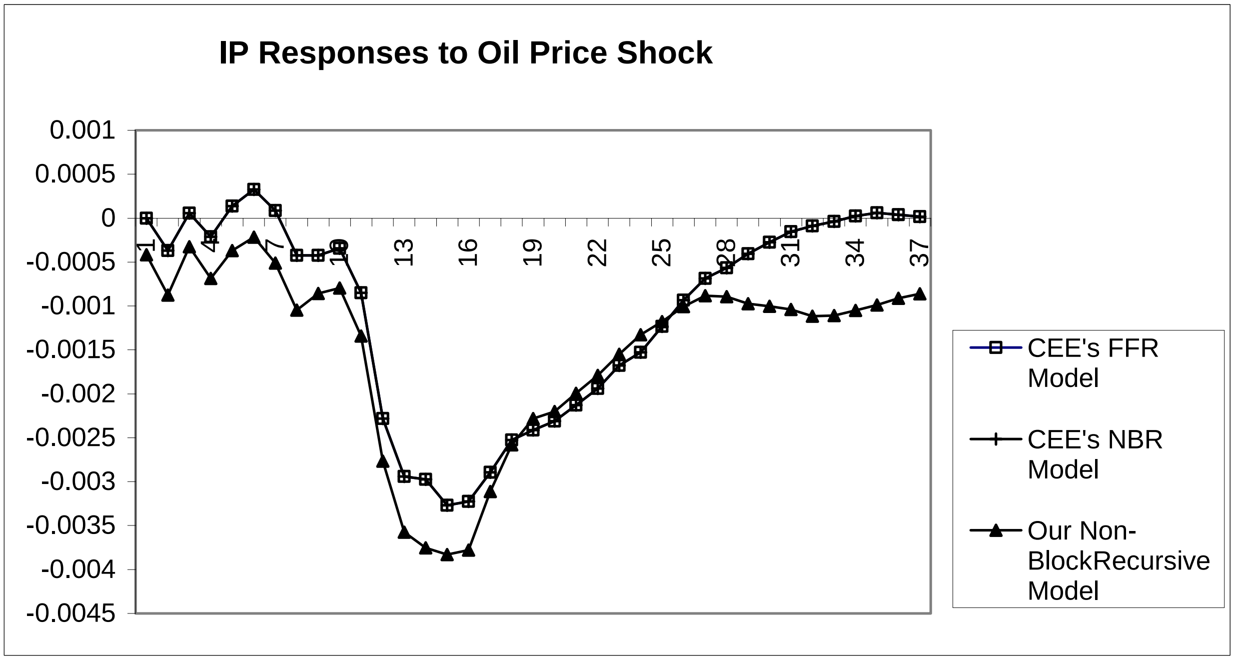
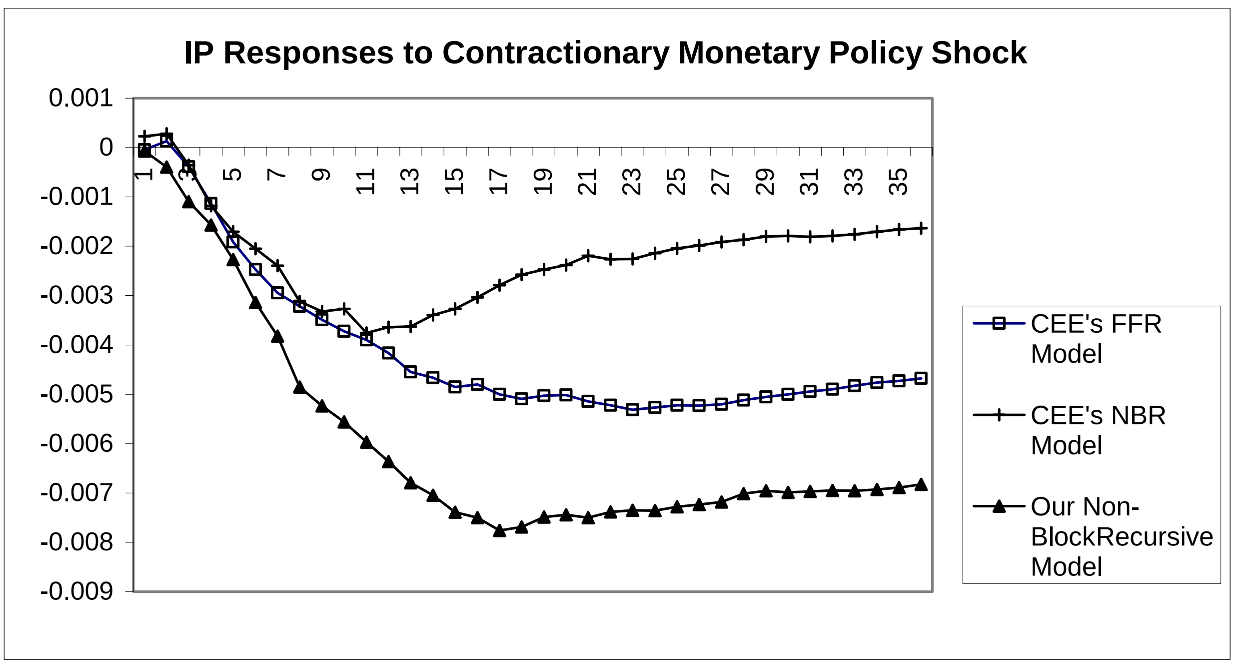
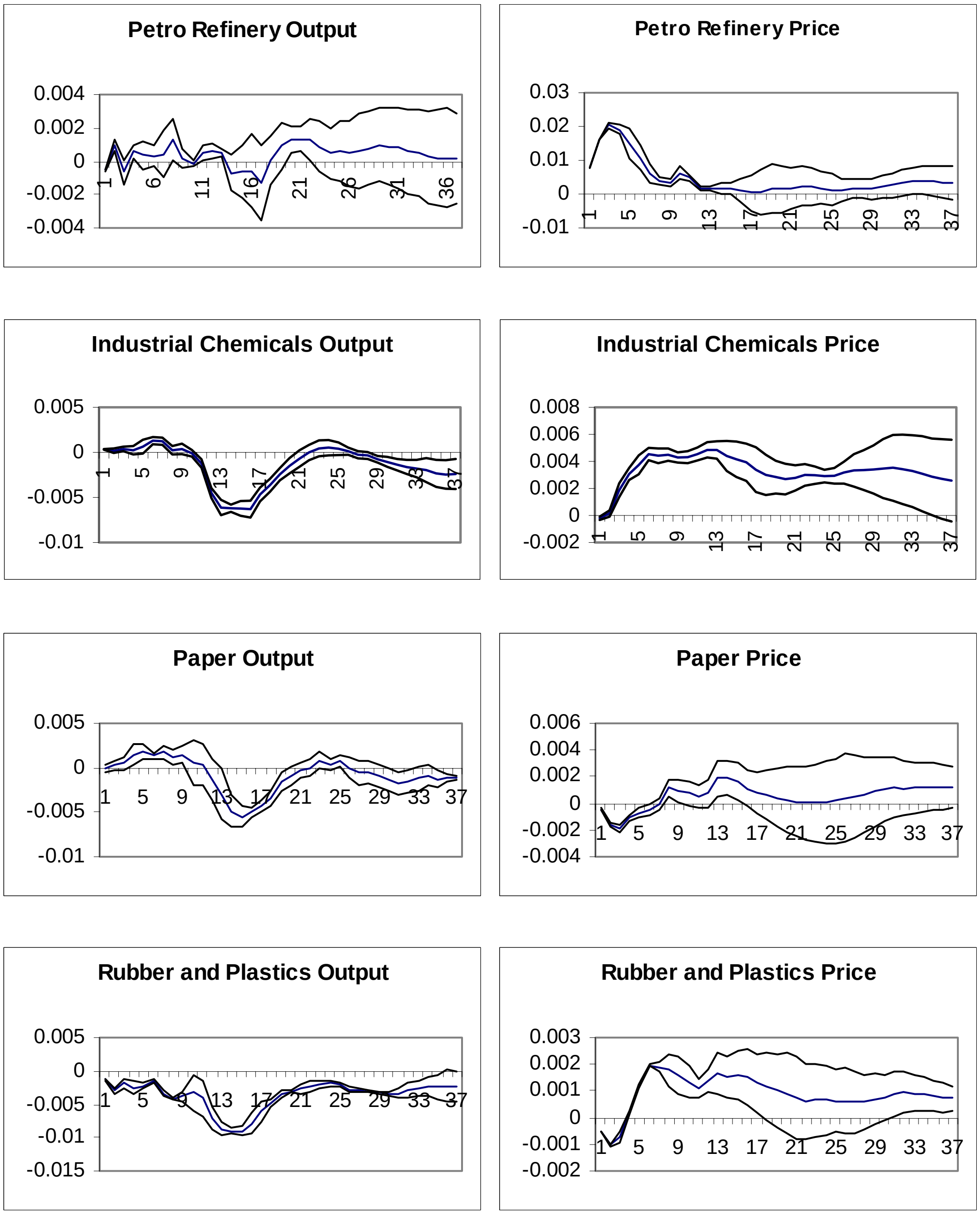
Figure 1. Industrial Production Responses under Alternative Identifying Schemes of the Macro-Block.

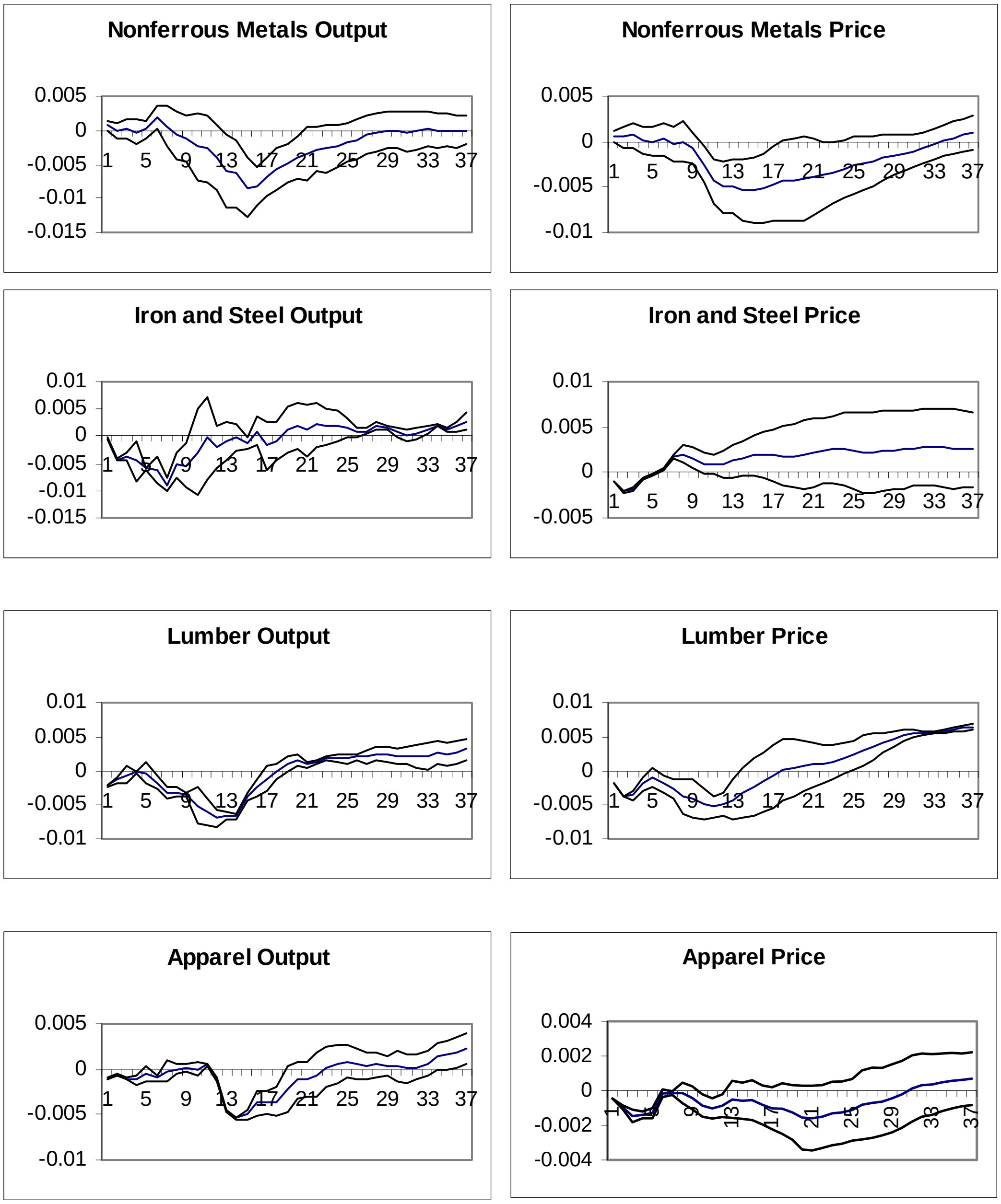


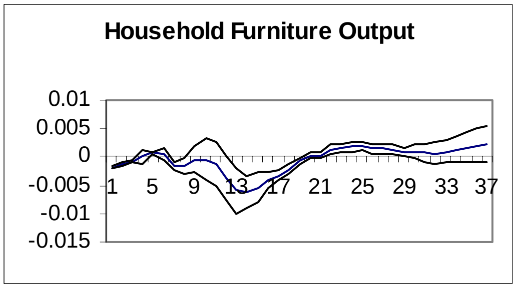


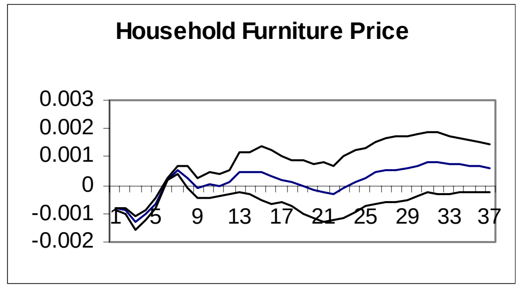
Note: The FFR and NBR models are the Fed Funds Rate and NonBorrowed Reserves models in Christiano, Eichenbaum, and Evans (1999), except for the addition of Hamilton's net oil price increase variable. The Non-BlockRecursive model is described in Section 4.2 in the paper.

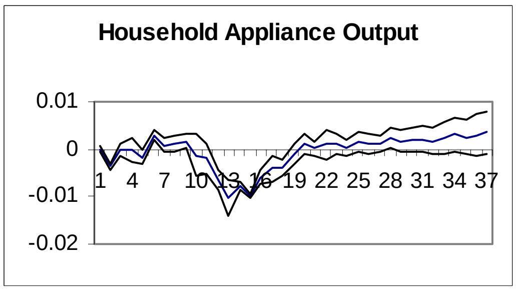
Figure 2: Impulse Responses of Industry-Level Output and Price to Oil Price Shock

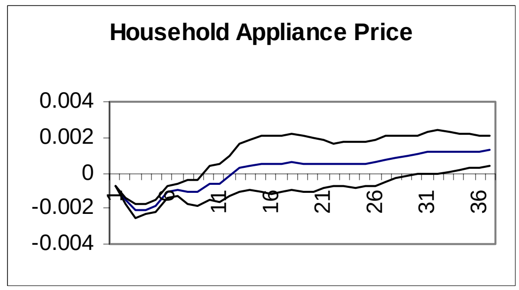


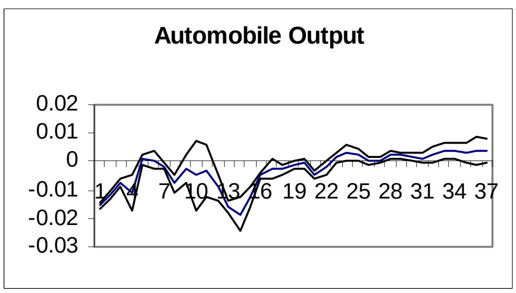

Nonferrous Metals Output
0.005
0
-0.005
-0.01
-0.015
1 5 9 13 17 21 25 29 33 37
Nonferrous Metals Price
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37
Iron and Steel Output
0.01
0.005
0
-0.005
-0.01
-0.015
1 5 9 13 17 21 25 29 33 37
Iron and Steel Price
0.01
0.005
0
-0.005
1 5 9 13 17 21 25 29 33 37
Lumber Output
0.01
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37
Lumber Price
0.01
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37
Apparel Output
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37
Apparel Price
0.004
0.002
0
-0.002
-0.004
1 5 9 13 17 21 25 29 33 37

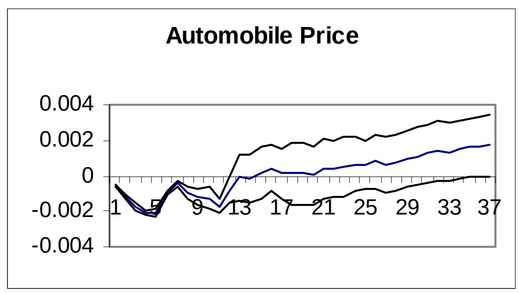

Household Furniture Output
0.01
0.005
0
-0.005
-0.01
-0.015
1 5 9 13 17 21 25 29 33 37

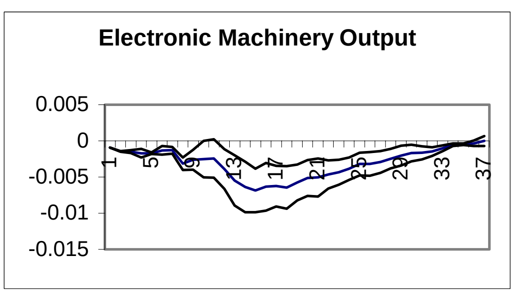

Household Furniture Price
0.003
0.002
0.001
0
-0.001
-0.002
1 5 9 13 17 21 25 29 33 37

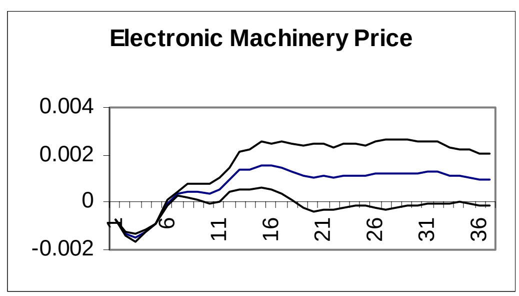

Household Appliance Output
0.01
0
-0.01
-0.02
1 4 7 10 13 16 19 22 25 28 31 34 37

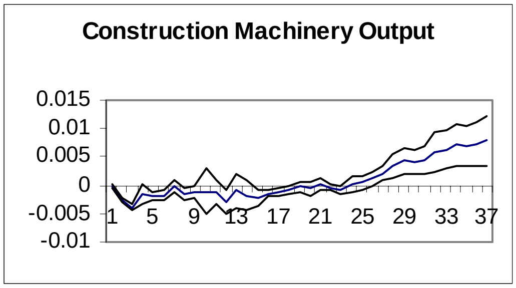

Household Appliance Price
0.004
0.002
0
-0.002
-0.004
1 6 11 16 21 26 31 36

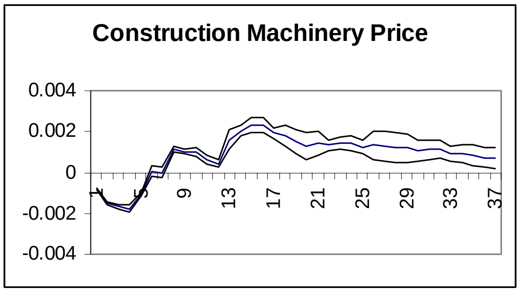

Automobile Output
0.02
0.01
0
-0.01
-0.02
-0.03
1 4 7 10 13 16 19 22 25 28 31 34 37

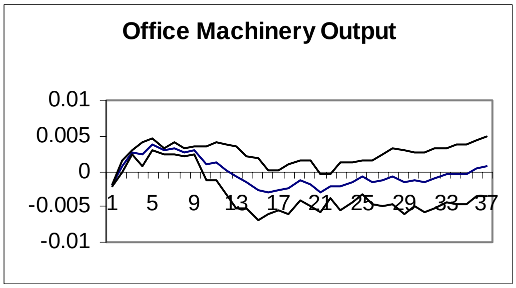

Automobile Price
0.004
0.002
0
-0.002
-0.004
1 5 9 13 17 21 25 29 33 37

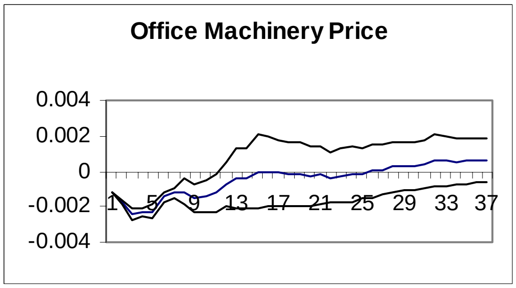

Electronic Machinery Output
0.005
0
-0.005
-0.01
-0.015
1 5 9 13 17 21 25 29 33 37


Electronic Machinery Price
0.004
0.002
0
-0.002
1 6 11 16 21 26 31 36


Construction Machinery Output
0.015
0.01
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37


Construction Machinery Price
0.004
0.002
0
-0.002
-0.004
1 5 9 13 17 21 25 29 33 37


Office Machinery Output
0.01
0.005
0
-0.005
-0.01
1 5 9 13 17 21 25 29 33 37


Office Machinery Price
0.004
0.002
0
-0.002
-0.004
1 5 9 13 17 21 25 29 33 37