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Understanding the Impact of Oil Shocks

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Abstract

This paper provides new empirical evidence on and theoretical support for the close link between oil prices and aggregate macroeconomic performance in the 1970s. Although this link has been well documented in the empirical literature and is further confirmed in this paper, standard economic models are not able to replicate this link when actual oil prices are used to simulate the models. In particular, standard models cannot explain the depth of the recession in 1974-75 and the strong revival in 1976-78 based on the oil price movements in that period. This paper argues that a missing multiplier-accelerator mechanism from standard models may hold the key. This multiplier-accelerator mechanism not only exacerbated the impact of the oil shocks in 1973-74 but also helped create the temporary recovery in 1976-78. This paper derives the missing multiplier-accelerator mechanism from externalities in general equilibrium. Our calibrated model can explain both the recession in 1974-75 and the revival in 1976-78.

Keywords: Oil price shocks; Real business cycle; Indeterminacy; Capacity utilization; Externalities; Monopolistic competition.

JEL classification: E32, E37, E22.

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1 Introduction

A large body of empirical literature has suggested that oil price shocks have an important effect on economic activity. Rasche and Tatom (1981), Hamilton (1983, 1985, 1996, 2003), Burbidge and Harrison (1984), Santini (1985), Gisser and Goodwin (1986), Loungani (1986), Tatom (1988), Mork (1989), Hamilton and Herrera (2004), and many others, for example, have convincingly argued that oil prices were both significant determinants of U.S. economic activity and exogenous to it in the post-war period.¹ However, despite 30 years of research since the first major post-war oil crises in 1973-74, exactly how a sharp rise in oil price causes a severe economic recession still remains an open question. Imported oil as an input for the entire U.S. economy accounted for roughly one percent of the total production cost in the early 1970s. Based on this cost share, and assuming constant returns to scale, even a 100% increase in the price of oil can translate only to approximately a one percent decrease in output, notwithstanding the likely counter effects from factor substitutions. Yet the actual decline in output following the 1973 oil crises, that caused a roughly 80 percent increase in the price of imported oil, was about seven to eight percent from its peak. A strong multiplier is clearly missing in standard models.

Standard economic theory not only substantially under-predicts the contraction of output following the oil shocks in 1973-74, but also fails to explain the revival of the U.S. economy starting in the middle of 1975 despite the continuing rise in oil price level in that period. Standard theory predicts an immediate permanent drop in output after a permanent increase in oil prices, while empirical studies show that output undergoes a U-shaped transitional path after a permanent oil shock.² For example, real GDP dropped by only 2 percent on impact in 1974 and the contraction continued for nearly 5 more quarters until 1975. Also, despite oil prices remaining high and continuing to rise throughout the late 1970s, the U.S. economy started to recover in the middle of 1975, and by the end of 1977 real GDP was already back to its potential trend level.³ Such a dramatic recovery after a nearly permanent oil price increase is not predicted by standard general equilibrium models.

Figure 1 illustrates these multiplier-accelerator effects after the oil shocks in late 1973. In the top panel, the dashed line represents the log price of imported oil, and the solid line represents percentage changes of the oil price. In the middle panel, the dashed line is fluctuations in GDP relative to its trend (defined by the HP filter). In the 4th quarter of 1973 and the first quarter of 1974, when the oil price increased sharply (nearly doubled), real GDP dropped by only two percent, consistent with the prediction of a standard economic model. However, the contraction continued during the entire year of 1974. A trough was not reached until 5 quarters later in early 1975, by then

¹This is especially true before the mid-1980s. Also see the references in Rotemberg and Woodford (1996).

²Empirical tests show that post-war oil prices follow a random walk. This is especially true prior to the early 1980s. This suggests that oil price changes are permanent for the period we study.

³During this period, no major counter-oil shocks were observed. If anything, a second major wave of oil price increases, almost as severe as the first one, was forthcoming in the late 1970s. Hence, the revival in 1976-78 cannot be attributed to anticipation of forthcoming good shocks either.

real GDP had declined more than seven percent from its pre-shock level. Also notice the revival in 1975. Within 3 years, the U.S. economy was back to its pre-shock level again by the 4th quarter of 1978, despite the oil prices remaining high and continuing to rise throughout that period.

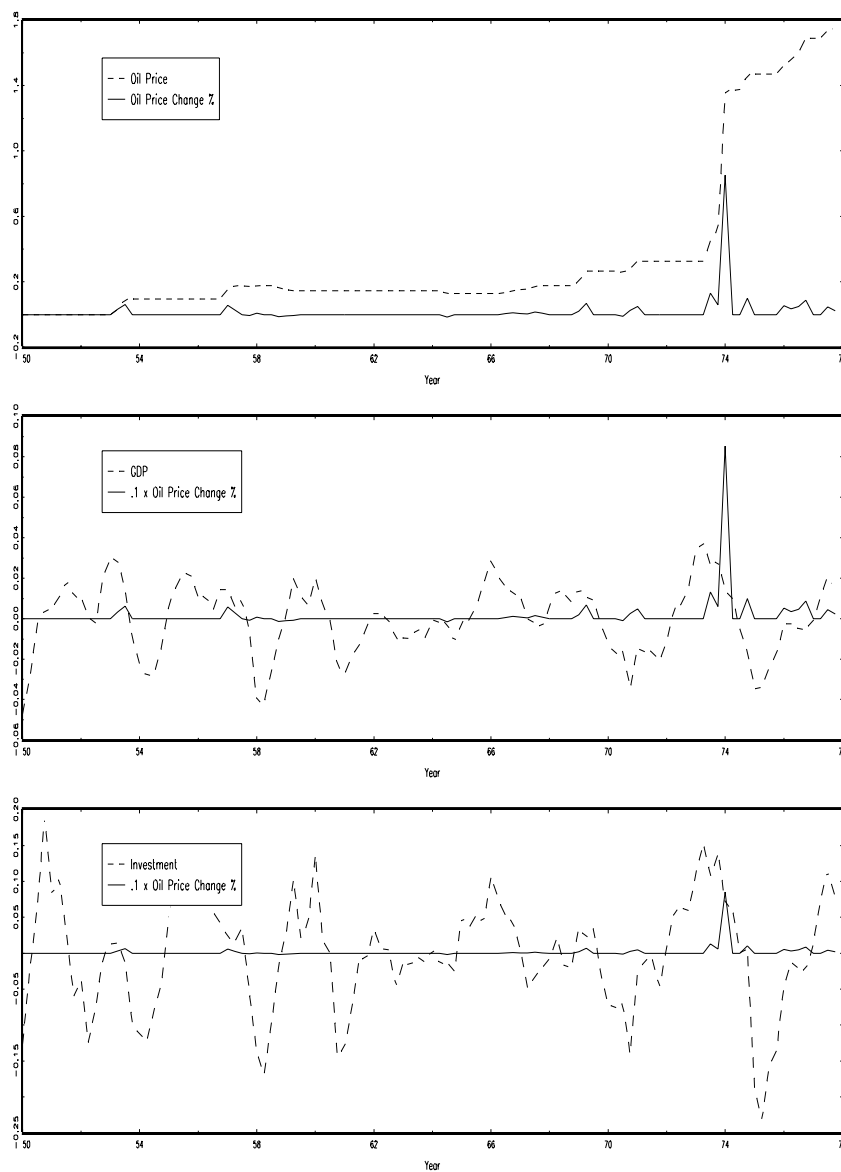


Figure 1. Oil Price and Economic Activity.

Another striking aspect of the 1974-75 recession is that fixed investment suffered the severest hit both absolutely and relative to output. Based on HP-filtered data (the bottom panel in Figure 1), the fall in investment during an average recession prior to the 1973 oil shock was about 20% from a peak to a trough. During 1974-75, however,

investment fell by more than 35% from its peak. Furthermore, the standard deviation of investment is about 4.4 times that of output prior to the 1973 oil shock. This volatility ratio increased to 7.1 during the 1973 oil shock period. In contrast, the ratio of standard deviation of non-durable goods consumption to GDP was about 0.54 prior to the 1973 oil shock, and became 0.31 during the oil shock period.

Thus, there are several major puzzles associated with the 1975 recession following the oil shock in 1973-74:

1. Why was the recession so deep, much deeper than predicted by standard models?
2. Why was the trough of the recession delayed for 4-6 quarters?
3. Why was there a strong recovery in economic activity in 1976-78 despite oil prices remaining high and continuing to rise during that entire period?
4. Why did investment suffer the severest hit during that period compared to other components of GDP?

The first puzzle has already drawn a substantial amount of attention. But the last three puzzles have rarely been emphasized in the theoretical literature. Hamilton and Herrera (2004) also stress that explaining the delay of the effects of oil price shocks is an important challenge for theory, “(...) the greatest effects of an oil shock do not appear until three or four quarters after the shock. Investigating the cause of this delay would seem to be an important topic for research” (Hamilton and Herrera, 2004, p. 281).

Kim and Loungani (1992) show that a standard model is not able to account for more than 16–35 percent of the reduction in output during the oil crises. Rotemberg and Woodford (1996) argue that monopolist competition is responsible for amplifying the impact of the oil shock. Finn (2000) argues that perfect competition can also account for the depth of the recession if firms’ capacity utilization rate is allowed to vary in response to the oil shock. Neither of these factors, however, are able to explain the accelerator effect of the oil shock: the greatest effects of the oil shock do not appear until several quarters after the shock, and a strong recovery is observed within a couple of years despite oil prices remaining high. If actual oil prices are used in simulating a theoretical model, then following the sharp increase in oil prices in 1973-74, both Finn and Rotemberg and Woodford’s models predict an immediate recession that will last throughout the entire 1970s without recovery. Such a prediction contradicts what we see in figure 1.⁴

Adjustment costs could be responsible for the delay of the recession. However, since adjustment costs work against the multiplier effect of monopolistic competition and capacity utilization, explanations of the gradual contraction based on the adjustment-cost story requires a much stronger multiplier than that offered by Finn and Rotemberg and Woodford.⁵

There are several possible explanations for the economic recovery during 1976-78. First, factor substitutions and obsolescence of energy intensive technologies after the oil shocks may explain the full recovery of the U.S. economy after 1975. While plausible, no rigorous models have been developed to address this possibility. To our knowledge, the only exception is Wei (2003). But Wei’s analysis still implies that a permanent rise in

⁴The recovery in 1976-78 is not an artifact of the HP filter. In what follows we will document the recovery more carefully using non-detrended data.

⁵Rotemberg and Woodford argue forcefully that sticky prices are unlikely the key. Herrera argues that inventory accumulation may be responsible for the delay.

oil prices should cause a permanent decrease in GDP on impact despite the possibility of new investment in energy saving machines in her model. In addition, if the U.S. economy had already switched to energy saving technologies by the end of 1975, which made the recovery possible, then it is puzzling to see another similar deep recession in 1982 following the second major oil price shock in 1979-1980. Second, there may have been other positive, counter-oil shocks in 1975-77 to pull the U.S. economy out of the recession. No strong empirical evidence exists, however, to show large enough positive macroeconomic shocks hitting the economy during 1975-78.⁶ Thirdly, some economists have blamed contractional monetary policy conducted in 1974 for the deep recession in 1974-75 (see, for example, Bernanke et al. 1997, and Barsky and Kilian 2001). This theory, however, cannot explain the full rebound of the economy in 1978 (starting in late 1975). No realistic monetary policy could have generated enough output growth to lead the U.S. economy into a full recovery (see Hamilton and Herrera, 2004). This notwithstanding, a credible monetary view requires a workable monetary model and a quantitative simulation of the model using the actual money growth series to show that monetary policies conducted during that period were indeed responsible for the recession in the mid-1970s and the recovery in the last half of the 1970s. To the best of our knowledge, no such quantitative exercises have been carried out in the literature.⁷

In this paper, we provide further empirical evidence regarding the importance of oil shocks. We document that the oil shocks in 1973 were indeed the chief cause of the recession in 1974-75. In particular, we document that after a permanent increase in oil prices in 1973, the U.S. economy underwent a U-shaped transitional dynamic phase (particularly in aggregate investment), revealing a strong multiplier-accelerator mechanism. Based on this, we propose a model to explain the multiplier-accelerator effect of oil shocks on the U.S. economy in the 1970s. To account for the gradual contraction in 1974-75, we do not rely on contractionary or miss-managed monetary policy, which we think is still open for debate and requires empirical support. To explain the recovery in 1976-78, we do not rely on the quick obsolescence of energy intensive technologies, which we think may take place in a period lasting much longer than 3-5 years due to the high costs involved in developing alternative forms of energy, nor on some unobservable good shocks hitting the U.S. economy in 1975. Our explanation builds on the insights of Rotemberg and Woodford (1996) and Finn (2000) and is closely related to the suggestion of Hamilton (1988a, 1988b and 2003). According to Hamilton, the oil crises in 1973-1974 affected the aggregate economy mainly by depressing aggregate demand, such as consumption and investment. In this paper we focus on investment demand. One possible way to model such a demand-side effect on investment is to allow for externalities among firms. Due to externalities among firms, the strength of aggregate demand facing an intermediate goods producer is a function of the production level of other

⁶We support this statement in Section 2 by decomposing output into movements caused by non-oil shocks (such as technology shocks, aggregate demand shocks, and monetary shocks) and by oil shocks. We show that non-oil shocks played little role in reviving the economy in that period.

⁷Leduc and Sill (2004) can be considered a first step in this direction. However, their analysis falls short in addressing our questions because they did not seek to answer whether historical monetary shocks or oil shocks are responsible for generating the historical time series properties of the recession in the mid-1970s. Instead, they calibrate the parameters of their model, such as the cost share of oil in output (or the steady state relative price of oil), so that the depth of the average recession between 1970:2 and 2000:4 is automatically matched.

firms. Thus, when the oil crises hit the U.S. economy, contractions in economic activity at each firm reinforce each other via the externalities, giving rise to a strong multiplier effect. The same force of interdependence and reinforcement among firms' production decisions also cause the economy to over-shoot when converging to the steady state, resulting in cyclical fluctuations. Such a cyclical propagation mechanism is responsible for the temporary revival of the U.S. economy in 1976-78.

Like Finn, we allow for variable capacity utilization in our model. This helps to bring the degree of increasing returns to scale required for generating the accelerator effect in our model to a minimal and empirically plausible level. Since our model can be represented in two equivalent forms, one featuring perfect competition with aggregate production externalities and another featuring monopolistic competition with private increasing returns to scale, our model is also related to Rotemberg and Woodford. We show that the recession in 1974-75 and the recovery in 1976-78 can be fully rationalized by the oil price increase in 1973-74 alone, without the need to resort to other unobserved shocks in that period. This prediction is consistent with our VAR analysis of the impact of oil shocks on the U.S. economy in that period.

The rest of the paper is organized as follows. We first document in Section 2 the multiplier-accelerator effect of oil shocks in the U.S. economy. Our empirical results show, consistent with the existing empirical literature (e.g., Hamilton 1983), that the oil shocks in 1973-74 were largely responsible for the recession in 1974-1975 and the revival in 1976-78. We then show in Section 3 that a general equilibrium model with demand externalities is consistent with historical fact. Section 4 concludes the paper with remarks on further research.

2 Empirical Evidence

This section documents that the sharp increase in oil prices during the 1973 OPEC embargo is primarily responsible for the deep recession in the U.S. economy in 1974-1975. Most importantly, we show that the contraction of GDP driven by exogenous oil price shocks undergoes a U-shaped transition period of gradual contraction and recovery, revealing a typical multiplier-accelerator dynamic phenomenon. We focus our attention to the effect of the OPEC oil embargo in 1973.

Although the empirical literature has convincingly argued that post-war movements in oil prices (at least up to the mid-1980s) were largely exogenous to U.S. economic activity, we nevertheless take a precautionary position by not excluding the possibility that U.S. economic activity might also have had potential impact on oil prices through demand-side effects. Hence, to study the effects of exogenous oil shocks on the U.S. economy, we first decompose movements in the price of imported oil into those driven by non-domestic (or exogenous) factors and those driven by domestic (or endogenous) factors. Our methodology for identifying the exogenous factors is based on a long-run restriction imposed on the effect of an oil shock (e.g., the OPEC decision to raise the oil price) on the nominal oil price, following the econometric methodology of Blanchard and Quah (1989). Econometric tests show that post-war oil prices can be best described as random walks. Hence, we assume that an exogenous oil shock is the innovation that can have permanent effects on the oil price, and that endogenous factors, which we call non-oil shocks, can only have transitory effects on the oil price.

Based on this identification assumption, we can use VAR to decompose movements in the U.S. economy into those driven by oil shocks and those driven by non-oil shocks. In order to best capture the effect of non-oil shocks on the U.S. economy, we have included in our VAR several variables: GDP, consumption, investment, and employment. In a later section, we also show that our results are robust when monetary policy variables, such as the interest rate and money supply, are included in the VAR.

Denote Δp as the percentage change in the oil price and Δz as the growth rates of the other non-oil related variables. Assuming that all these variables are jointly stationary, we can then uncover the Wold representation via vector autoregression:

$$x_t = \sum_{j=0}^{\infty} B(j)v_{t-j}, \quad (1)$$

where $x = [\Delta p \ \Delta z]'$ and $vv' = \Sigma$. The above presentation can be consistently estimated using VARs. The structural representation of x , on the other hand, is defined as

$$x_t = \sum_{j=0}^{\infty} A(j)\varepsilon_{t-j}, \quad (2)$$

where ε is an $n \times 1$ vector of structural shocks with an identity covariance matrix. The first structural shock is defined as an “oil shock” and the rest as “non-oil shocks”. The vector of innovations in the Wold representation, v , and the vector of structural shocks in the structural representation, ε , are related by

$$v = A(0)\varepsilon, \quad (3)$$

where $A(0)$ is an $n \times n$ real matrix satisfying $\Sigma = A(0)A(0)'$, and the VAR coefficient matrices in the two different representations are related by

$$A(j) = B(j)A(0). \quad (4)$$

The “oil shocks” are identified as innovations that have a permanent effect on the oil price level and the “non-oil shocks” are identified as innovations that do not have long-run effects but may have short-run effects on the oil price through demand-side effects. Namely, the sequence of matrices A is such that all its upper right-hand entries in the first row sum to zero:

$$\sum_{j=0}^{\infty} a_{12}(j) = \sum_{j=0}^{\infty} a_{13}(j) = \dots = \sum_{j=0}^{\infty} a_{1n}(j) = 0. \quad (5)$$

These restrictions imply that only oil shocks are responsible for any permanent changes in the oil price. This assumption is consistent with the empirical fact that oil price movements, especially in the 1970s, are largely exogenous to the U.S. economy (see, e.g., Hamilton, 1983). We do not impose prior restrictions on the impact of oil shocks on the other variables in the VAR, such as the output level, consumption level, investment level, and employment level. Instead, we allow the data to tell us how those U.S. variables respond to the oil shocks so identified.

The data used in our analysis are seasonally adjusted quarterly data starting in 1950:1 and ending in 1978:4, right before the second major oil shock hit the economy in

1979 (which is also a time when the economy was completely recovered to its pre-1973 shock level relative to the trend). The oil price data we use is the spot oil price of the West Texas Intermediate (available from the St. Louis Fed’s website). The data for output, consumption, investment, and employment are real GDP, real consumption for non-durables plus services, real fixed investment, and total non-farm employees, respectively.⁸ To obtain the Wold representation (1), we first estimate a VAR for x_t and then invert it to obtain a moving average representation. A constant and 4 lags are included in the VAR. After the matrix $A(0)$ is identified, we can then decompose each time series in the vector x into two components: one pertaining to the influence of the oil shocks and another pertaining to the influence of the other non-oil shocks. Since we are only interested in the joint effects of all of the non-oil shocks, and we are not interested in further distinguishing the non-oil shocks from each other, how these non-oil shocks are individually identified does not matter. What matters are the identifications imposed on the non-oil shocks as a group. We therefore apply the Choleski triangularization to the long-run matrix $\sum_{j=0}^{\infty} B(j)A(0)$ to obtain $A(0)$.⁹ To uncover the levels of the time series, we cumulate the decomposed growth rates for each series by adding a constant to the growth rate (based on the mean growth rate of the data) to induce a linear growth trend.¹⁰

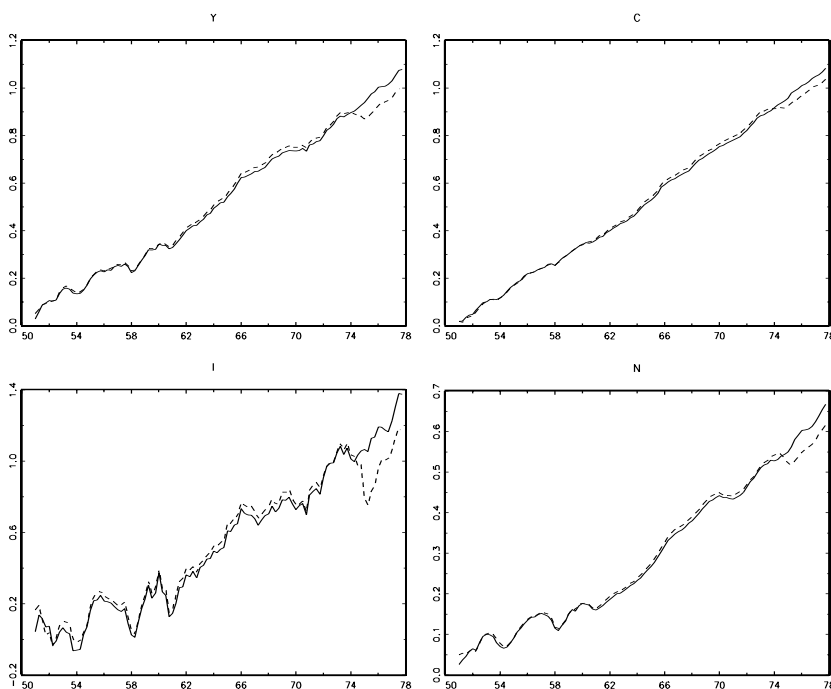


Figure 2. Effects of Non-Oil Shocks on U.S. Economy.

⁸The data for output, consumption, and investment are taken from the NIPA table for domestic production, available at the Bureau of Economic Analysis website, <http://www.bea.gov/beahome.html>. The data for employment is taken from Bureau of Labor Statistics (series ID is CES0000000001) at <http://www.bls.gov/>.

⁹See Blanchard and Quah (1989) for details.

¹⁰Recall that the linear growth trends were removed during the VAR estimation.

The empirical results are reported in several figures. First, the identified effects of the non-oil shocks on output, consumption, investment, and employment are reported in Figure 2. We see that fluctuations driven by non-oil shocks track the actual movements in output, consumption, investment and employment very well between 1950 and the early 1970s, suggesting that the oil shocks are not the main source of the business cycle for the entire period prior to 1973.¹¹ In other words, non-oil shocks have been mainly responsible for all of the business cycles in the U.S. from 1950 until 1973. Starting from 1974, however, the picture changes dramatically. Non-oil shocks are no longer able to explain the fluctuations in output, consumption, investment and employment. This stunning fact can also be seen in Figure 3, which shows the sole effects of the oil shocks on the U.S. economy. There we see that, in complement to Figure 2, oil shocks have contributed very little to output fluctuations in the entire sample period prior to the recession 1974-75. Starting in 1974, however, oil shocks become the dominating force in output, consumption, investment and employment.

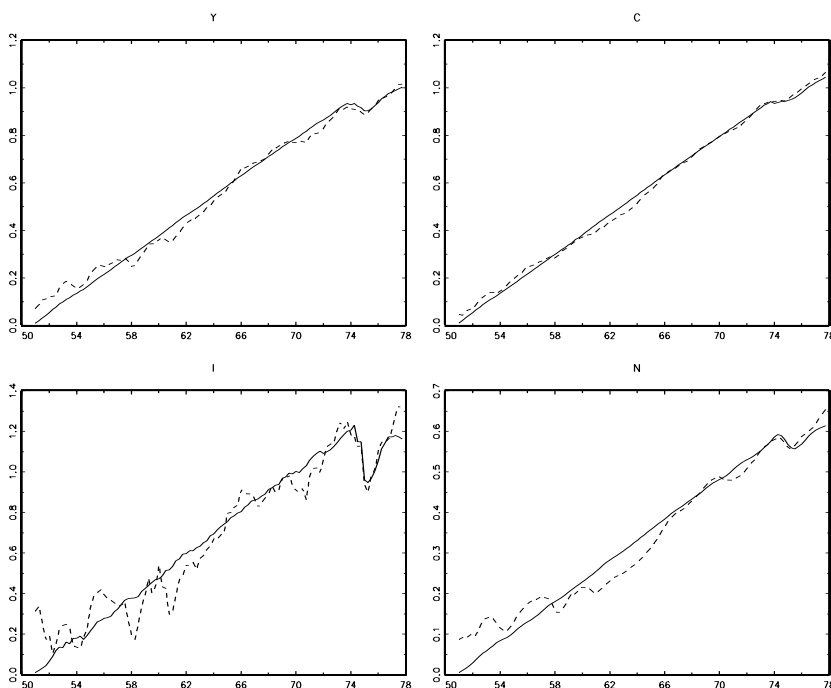


Figure 3. Effects of Oil Shocks on U.S. Economy.

If we follow the existing literature by defining the potential trend of output as the low frequency movement captured by the HP filter instead of by a linear trend, and the business cycle component of output as the high frequency movement around the HP trend, then the part of the business cycle movements caused by oil shocks are graphed by the solid lines in Figure 4. Changes in the oil price are represented

¹¹This does not imply that the oil shocks are not related to or responsible for recessions prior to 1973. Figure 2 simply indicates that at a quantitative level, oil shocks on their own did not play a crucial role in U.S. economic activity prior to 1973.

by the dashed lines in the background (the oil price changes are multiplied by 0.1 in order to highlight the magnitude of the other series), and the actual time series for output, consumption, investment and employment are represented by the dotted lines. There we see that although the two major oil price increases in 1951-52 (the Iranian nationalization) and 1956-57 (the Suez crises) precede the two recessions in 1953-54 and 1958-59 respectively, oil shocks, quantitatively speaking, have played little role in driving output fluctuations prior to 1973. After the OPEC oil embargo in 1973, oil prices reached their highest point between the last quarter in 1973 and the first quarter in 1974. Following that, output and consumption started to fall. Investment and employment lagged consumption and output by one to two quarters, as has been the case for each post-war business cycle. Driven by the sharp increase in the oil price, the economy underwent a U-shaped recession throughout the mid and late 1970s. The trough of the recession was not reached until 1975. After that, the economy started to recover. By the end of 1977, output, consumption, investment and employment were all back to or above their pre-shock levels relative to trend. Notice how closely the series driven by oil shocks track the actual movements in output, consumption, investment and employment in the 1970s. Based on this empirical evidence, it is fair to conclude that the deep recession in 1974-1975, as well as the recovery in 1976-78, are almost entirely due to the oil shocks in 1973-74.

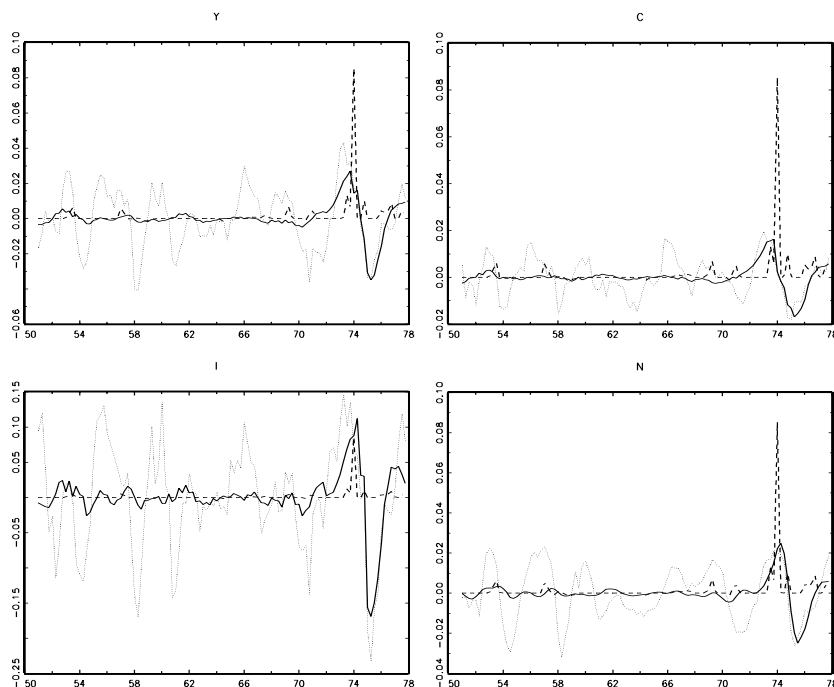


Figure 4. Business Cycle Effects of Oil Shocks.

Thus, the challenge to economic theory is clear: can standard economic models driven by actual movements in oil prices explain the deep recession in 1974-75 and the recovery in 1976-78? Ironically, they cannot. Oil shocks have been assigned prominent

roles in contemporaneous macroeconomic models as examples of supply-side disturbances. This includes the modern version of the IS-LM model (see, e.g., Abel and Bernanke 2001) and the neoclassical business-cycle models (see, e.g., Hamilton 1988a). Yet, when actual oil prices are used for simulations, standard economic models cannot explain the deep recession in 1974-75 or the recovery in 1976-78 by the oil increase in 1973-74. Kim and Loungani (1992), for example, show that standard models can account for at most 16–35 percent of the reduction in output during the oil crises in 1973-74.

A strong multiplier-accelerator effect is clearly missing in standard models. For this reason, Barsky and Kilian (2001) argue that the recession in 1974-75 and the subsequent recovery in 1976-78 may have nothing to do with the oil shocks in 1973-74. Instead, they argue that the expansionary monetary policies conducted in the early 1971-72 were responsible for the recession in 1974-75 and the inflation in 1975-76. Their argument is based on a multiplier-accelerator monetary transmission mechanism. This mechanism generates an economic boom after the expansionary monetary policy in the early 1970s, and it was this boom that planted the seed for its own destruction in the mid-1970s. While intriguing, this argument remains a hypothesis unless quantitative simulations using actual money supply data can be conducted based on their theoretical model, so as to show that the simulated time series replicate the U.S. data.¹²

3 Theory

3.1 The Model

The model we study is a slightly modified version of the model of Wen (1998), which is based on Benhabib and Farmer (1994). There are two types of goods in the economy, final goods and intermediate goods. The final good sector is competitive and it uses intermediate goods to produce output according to the technology,

$$Y = \left(\int_{i=0}^1 y_i^\lambda di \right)^{\frac{1}{\lambda}}, \quad (6)$$

where $\lambda \in (0, 1)$ measures the degree of factor substitutability among the intermediate goods (the exact elasticity of substitution is $\frac{1}{1-\lambda}$). Let p_i be the relative price of intermediate good i in terms of the final good. Profits of a final good producer are given by

$$\Pi = Y - \int_{i=0}^1 p_i y_i di. \quad (7)$$

The price of the final good is normalized to one. First order conditions for profit maximization lead to the following inverse demand functions for intermediate goods,

$$p_i = Y^{1-\lambda} y_i^{\lambda-1}. \quad (8)$$

Assume that each intermediate-good producing firm i is a monopolist specializing in producing good i . The strength of the monopoly power, however, depends on the elasticity of substitution among the intermediate goods. Notice that the aggregate production

¹²Also see the skepticism on the monetary view raised by Blanchard (2001) and Blinder (2001).

level, Y , serves as a demand externality for individual firms due to complementarity among the goods they supply to the final good sector.

The technology for producing intermediate goods is given by

$$y_i = (e_i k_i)^{a_k} n_i^{a_n} o_i^{a_o}, \quad (9)$$

where $e \in [0, 1]$ denotes the capacity utilization rate, k denotes capital stock, n denotes labor, and o denotes oil. We assume that oil cannot be domestically produced and the elasticities satisfy $\{a_o, a_k, a_n\} \in [0, 1]$ and $(a_k + a_n + a_o) \geq 1$, indicating possible increasing returns to scale at the firm level. Assuming that firms are price takers in the factor markets, the profits of firm i are then given by

$$\pi_i = p_i y_i - (r + \delta_i) k_i - w n_i - p^o o_i, \quad (10)$$

where $(r + \delta_i)$ denotes the user's cost of capital, w denotes real wage, and p^o denotes the real price of imported oil. Notice that factor prices are common to all firms. Following Greenwood et al. (1988) and Wen (1998), we assume that firm i 's capital depreciation rate depends on its capacity utilization rate:

$$\delta_i = \frac{1}{\theta} e_i^\theta, \quad \theta > 1. \quad (12)$$

Since intermediate good producers are monopolists facing downward sloping demand curves, their profit functions can be rewritten as

$$\pi_i = Y^{1-\lambda} y_i^\lambda - (r + \delta_i) k_i - w n_i - p^o o_i, \quad (13)$$

which is concave as long as $\lambda(a_k + a_n + a_o) \leq 1$. Profit maximization by each intermediate-good producing firm leads to the following first order conditions:

$$e_i^{\theta-1} k_i = \lambda a_k \frac{p_i y_i}{e_i}, \quad (14)$$

$$r + \delta_i = \lambda a_k \frac{p_i y_i}{k_i}, \quad (15)$$

$$w = \lambda a_n \frac{p_i y_i}{n_i}, \quad (16)$$

$$p^o = \lambda a_o \frac{p_i y_i}{o_i}. \quad (17)$$

In a symmetric equilibrium, we have $n_i = n$, $k_i = k$, $e_i = e$, $\delta_i = \delta$, $o_i = o$, $y_i = y = Y$, $\pi_i = \pi$, and $p_i = 1$. Also, we have in equilibrium that

$$\Pi = Y - \left(\int_{i=0}^1 y_i^\lambda di \right)^{\frac{1}{\lambda}} = 0, \quad (18)$$

$$\pi = (1 - \lambda(a_k + a_n + a_o)) Y. \quad (19)$$

In words, perfect competition in the final good sector leads to zero profits and imperfect competition in the intermediate good sector leads to positive profits if $\lambda(a_k + a_n + a_o) < 1$.

A representative consumer in the economy maximizes the expected life-time utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log c_t - b \frac{n_t^{1+\gamma}}{1+\gamma} \right) \quad (20)$$

subject to

$$c_t + s_{t+1} = (1 + r_t)s_t + w_t n_t + \pi_t, \quad (21)$$

where s denotes aggregate savings. Since the aggregate factor payment for oil, $p^o o$, goes to foreigners, it is not included in the consumer's income. The first order conditions for utility maximization with respect to labor supply and savings are given, respectively, by

$$b n_t^\gamma = \frac{1}{c_t} w_t, \quad (22)$$

$$\frac{1}{c_t} = \beta E_t \left\{ \frac{1}{c_{t+1}} (1 + r_{t+1}) \right\}. \quad (23)$$

In equilibrium, $s_t = k_t$ and factor prices equal marginal products. The first order conditions and the budget constraint then become

$$b n_t^{1+\gamma} = \frac{1}{c_t} \lambda a_n y_t, \quad (24)$$

$$\frac{1}{c_t} = \beta E_t \left\{ \frac{1}{c_{t+1}} \left(1 + \left(1 - \frac{1}{\theta} \right) \lambda a_k \frac{y_{t+1}}{k_{t+1}} \right) \right\}, \quad (25)$$

$$c_t + k_{t+1} = k_t + \left(1 - \lambda a_o - \frac{\lambda a_k}{\theta} \right) y_t, \quad (26)$$

where the variables $\{o, e\}$ have been substituted out using their respective equilibrium demand functions.

By similar substitutions using the equilibrium factor demand functions for oil and the capacity utilization rate, the production function can be reduced to

$$y_t = \phi \left(\frac{1}{p_t^o} \right)^{\frac{a_o \tau_n}{1 - a_o \tau_n}} k_t^{\frac{a_k \tau_k}{1 - a_o \tau_n}} n_t^{\frac{a_n \tau_n}{1 - a_o \tau_n}}, \quad (27)$$

where ϕ is a positive constant and $\tau_n \equiv \frac{\theta}{\theta - a_k} > 1$ and $\tau_k \equiv \frac{\theta - 1}{\theta - a_k} < 1$. Equations (24)-(27) constitute the dynamic system of the model for $\{k_{t+1}, c_t, n_t, y_t\}$.

After rewriting the production function as $y_t \equiv \phi A_t^{\gamma_o} k_t^{\gamma_k} n_t^{\gamma_n}$, we can notice several things. First, oil price serves as an adverse productivity shock in the model ($A_t = \frac{1}{p_t^o}$). In particular, the larger the cost share of oil, a_o , the larger the impact an oil price shock has on total factor productivity (since $\gamma_o = \frac{a_o \tau_n}{1 - a_o \tau_n}$ increases with a_o). In addition, the cost share of oil enhances the output elasticity of labor (since $\gamma_n = \frac{a_n \tau_n}{1 - a_o \tau_n}$ also increases with a_o). Second, capacity utilization amplifies the impact of oil shocks. Capacity utilization introduces a new term, $\tau_n = \frac{\theta}{\theta - a_k} > 1$ (since $\theta > 1$), into the output elasticities with respect to p^o and n . Thus, capacity utilization magnifies the impact of an oil shock via two channels: a direct channel via its positive effect on the output elasticity of total factor productivity (γ_o) and an indirect channel via its positive effect on the output elasticity of labor (γ_n). Third, capacity utilization enhances returns

to scale if $a_k + a_n + a_o > 1$, because $\gamma_k + \gamma_n \geq a_k + a_n + a_o$, with equality only if $a_k + a_n + a_o = 1$. These effects of capacity utilization are discussed in more detail in Wen (1998) and Finn (2000).¹³

The model can be solved by log-linearizing the first order conditions around the steady state as in King et al.(1988). It was shown by Wen (1998) and Aguiar-Conraria and Wen (2004) that with very mild externalities this model possesses multiple dynamic equilibria around a unique steady state. In particular, equilibrium output and capital stock in the model follow the following dynamic process (circumflex variables denote percentage deviations from the steady state values),

$$\begin{pmatrix} \hat{y}_t \\ \hat{k}_t \end{pmatrix} = M \begin{pmatrix} \hat{y}_{t-1} \\ \hat{k}_{t-1} \end{pmatrix} + R_1 E_{t-1} \hat{p}_t + R_2 \hat{p}_{t-1} + \begin{pmatrix} 1 \\ 0 \end{pmatrix} \Theta_t, \quad (28)$$

where M is a full-rank coefficient matrix with both eigenvalues lying inside the unit circle on the complex plane and Θ_{t+1} is a one-step ahead forecasting error of output, defined as

$$\Theta_t = \hat{y}_t - E_{t-1} \hat{y}_t, \quad (29)$$

which satisfies $E_t \Theta_{t+1} = 0$ for all t . The forecast error may serve as a source of sunspots or animal spirits in this model when indeterminacy arises.¹⁴ Assuming that the only major fundamental shocks to the U.S. economy in the 1970s were oil shocks, the forecast error can then be further decomposed into two orthogonal *i.i.d.* processes: $\Theta_t = \zeta \varepsilon_t + v_t$, where $\varepsilon_t \equiv p_t - E_{t-1} p_t$ is innovation in the fundamental shocks (i.e., the oil price) and v_t , a measure of confidence (i.e., shocks to non-fundamentals) which is often named sunspots in the literature. Notice that both the coefficient, ζ , and the variance of the sunspots, σ_v^2 , are free parameters in the model. If the forecast error is assumed to be uncorrelated with the fundamentals, then $\zeta = 0$. Otherwise ζ can take any value on the real line. In this paper, we assume $\zeta = 0$ and there are no sunspots. In other words, we set $\Theta = 0$. This implies that the indeterminacy of the initial output level, given the state $\{\hat{k}_0, p_0\}$, is resolved by setting $\hat{y}_0 = 0$.¹⁵

3.2 Calibration

We calibrate the model using the following parameter values, which are standard in the literature for quarterly models: $\gamma = 0$ (Hansen's 1985 indivisible labor),¹⁶ $\beta = 0.99$ and $\theta = 1.4$ (implying a steady-state rate of capital depreciation equal to ten percent a year). Since the model can be mapped into a perfectly competitive model with aggregate externalities, we calibrate the technology parameters, $\{\lambda, a_k, a_n, a_o\}$, according to an externality version of the model. Denote η as the externality parameter for production,

¹³Finn's (2000) model of capacity utilization is slightly different from this one, but the mechanisms are similar.

¹⁴See Cass and Shell (1983), Shell (1977, 87), and Benhabib and Farmer (1994) for discussions on sunspots-driven fluctuations.

¹⁵See Farmer (1999) and Benhabib and Wen (2004) for discussions on calibrating indeterminate models. Our results are robust to other choices of the initial value of output. For example, we can also assume that investment or employment have inertia so that $\hat{i}_0 = 0$ or $\hat{n}_0 = 0$, and the results do not change significantly.

¹⁶With the indivisible labor assumption, employment in our model, n , denotes the fraction of labor force in the economy instead of the fraction of hours devoted to work.

in a symmetric equilibrium the aggregate version of the production function (9) can then be written as

$$y_t = (e_t k_t)^{\alpha_k(1+\eta)} n_t^{\alpha_n(1+\eta)} o_t^{(1-\alpha_k-\alpha_n)(1+\eta)}, \quad (30)$$

where the aggregate returns to scale are given by $1 + \eta$. This model is equivalent to the monopolistic competition model if $\lambda(1 + \eta) = 1$, $a_k = \alpha_k(1 + \eta)$, $a_n = \alpha_n(1 + \eta)$, and $a_o = (1 - \alpha_k - \alpha_n)(1 + \eta)$.¹⁷ Thus, we can calibrate the output elasticity parameters in the production function according to each production factor's cost share in output. Following the existing literature (e.g., Benhabib and Farmer 1994 and Wen 1998), we set the labor's share $\alpha_n = 0.7$. Nordhaus (2002) estimates imported oil's share in GDP for the post-war period to be about one percent (with a standard error of 0.67 percent). Rotemberg and Woodford (1996, p. 564-565) also suggest that imported oil account for about 1.6 percent of GDP. Hence we set oil's share $\alpha_o = 0.015$ as our benchmark. This implies capital's share $\alpha_k = 0.285$. Laitner and Stolyarov (2004) recently re-estimated the aggregate returns to scale for the U.S. economy. Their robust estimate of returns to scale is in the range of 1.09 – 1.11. We choose $\eta = 0.108$, which is in line with their estimates. This implies a markup of around 11 percent ($\frac{1}{\lambda} = 1 + \eta \approx 1.11$) in the monopolistic version of our model.

We also need to assume a stochastic process for the oil price in order to compute the equilibrium decision rules, which are functions of the forecast of future oil prices, $E_t p_{t+j}$. Hamilton (1983, 1996), Burbidge and Harrison (1984), Gisser and Goodwin (1986), and others have argued that oil prices are exogenous to the U.S. economy, at least up to the mid-1980s. Also, based both on the Dickey Fuller test and on the Augmented Dickey Fuller test, we cannot reject the hypothesis of a unit root in oil prices for either the entire post-war sample (1950:1-2003:4) or the sample period we use (1950:1-1978:4). In particular, when running univariate autoregressions for oil prices with several lags and a constant, all the coefficients except that for the first lag are found to be statistically insignificant, and we cannot reject the null hypothesis that the coefficient of the first lag is unity. We tested for serial correlation in the residuals using the Breusch-Godfrey LM test of order 4. No evidence of serial correlation was found. Hence the logarithm of oil price can be reasonably characterized as following a random walk: $E_t p_{t+1} = p_t$, implying that the best forecast of future oil prices is its current value, and past information is not helpful for predicting future changes in the oil price. The random walk assumption is also consistent with our empirical VARs in Section 2.

3.3 Predictions

Before presenting the predictions of our model, we first present the predictions of standard models so as to highlight the importance of the multiplier-accelerator mechanism missing in standard models. The predictions of a model with constant returns to scale ($\eta = 0$), perfect competition ($\lambda = 1$), and fixed capacity utilization ($e = 1$) are presented in Figure 5, where the dashed lines represents U.S. data. It shows that the standard model cannot generate a recession. The recession in the model is barely observable. Output contracts only by two percent in the model after a near doubling of the oil price in 1974, while the actual contraction is about eight percent in the data.

¹⁷See Benhabib and Farmer (1994) and Benhabib and Wen (2004) for a rigorous proof.

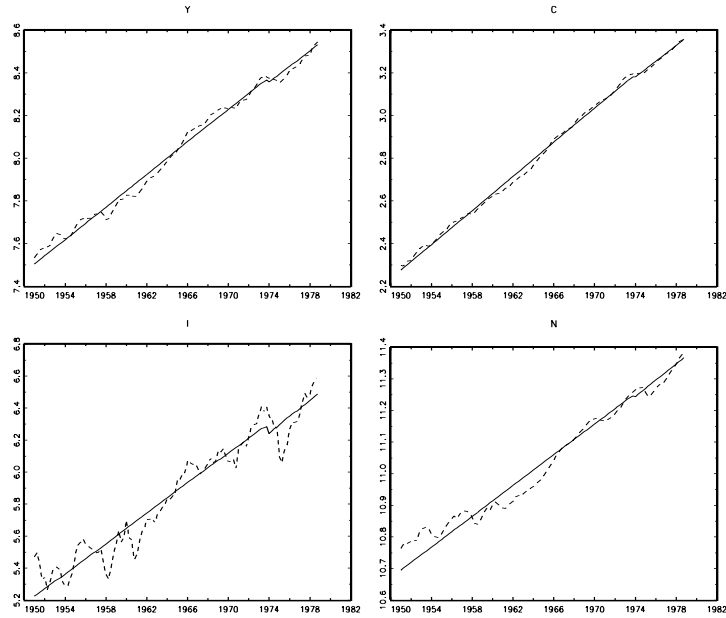


Fig. 5. Predictions of a Standard RBC Model (solid lines).

Allowing for capacity utilization can greatly magnify the impact of oil shocks. This can be seen from the predictions of Finn’s (2000) capacity utilization model presented in Figure 6 (Figure 6.1 zooms in on the period of the 1970s). Figure 6 shows that Finn’s model is able to match the depth of the 1975 recession in output. This is attributable to a variable capacity utilization that amplifies the impact of the oil shocks. However, the model still fails to match the data on several grounds. First, it predicts an immediate permanent recession after the oil shock in 1973, failing to explain the gradualness of the recession in 1974-75 and the recovery in 1975-78. Second, the model cannot match the depth of the recession in investment and employment, and it over-predicts the depth of the recession in consumption. Furthermore, the model fails to predict the delay of the recession in employment by several quarters. Among these failures, the failure to match the U-shaped transitional dynamics of the recession is the most striking.¹⁸

¹⁸Since Finn (2000) shows that her model and the model of Rotemberg and Woodford (1996) give almost identical predictions, we omit replicating Rotemberg and Woodford’s model.

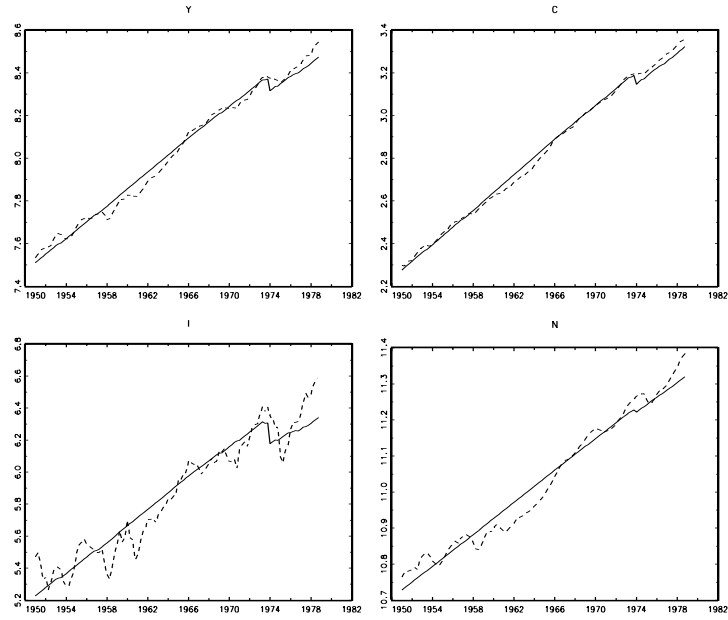


Fig. 6. Predictions of Finn's (2000) Capacity Utilization Model.

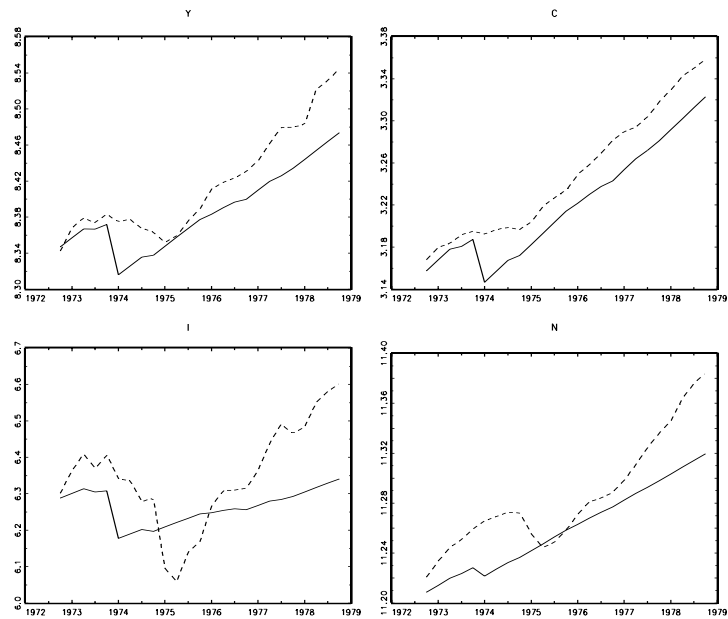


Fig. 6.1. Predictions of Finn's Model (zoom in on Fig. 6).

Figure 7 (Figure 7.1 zooms in on the 1970s period in Figure 7) shows that our model improves the predictions of the standard models substantially on several grounds. First, it can predict not only the depth of the 1975 recession in U.S. output, but also the depth of the recession in investment and employment. Second and most strikingly, the model is able to predict the U-shaped transitional dynamics seen in the data. For example, the model predicts that the trough of the recession is delayed by 4-6 quarters after the oil price increase in late 1973, and that there will be a recovery in 1976-78. However, the model tends to under-predict the recession in consumption and over-predict the recession in employment.¹⁹ Overall, however, the improvement of the model over the standard models are significant.

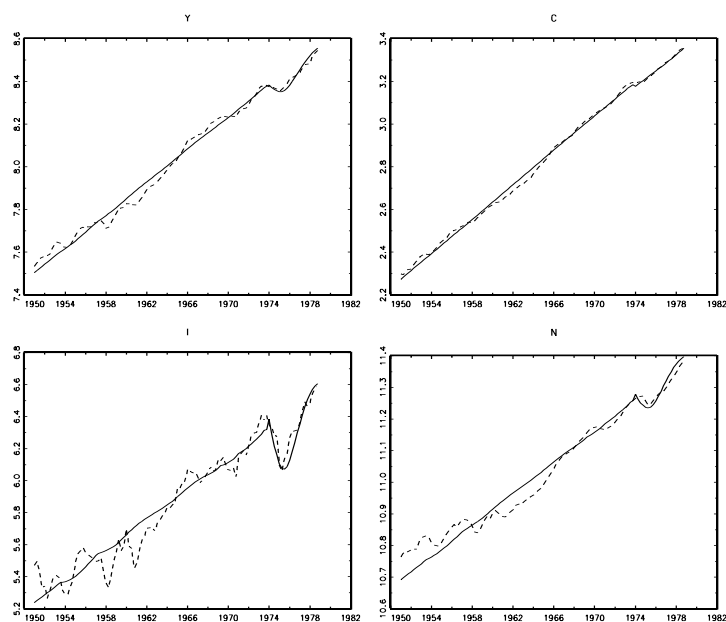


Fig. 7. Predictions of Our Model.

¹⁹This has to do with the smoothness of the real wage in the current model (see Wen, 1998, for explanations). This failure also implies that the current model is not able to match the depth of the recession in labor's productivity, which Finn's (2000) model is able to match.

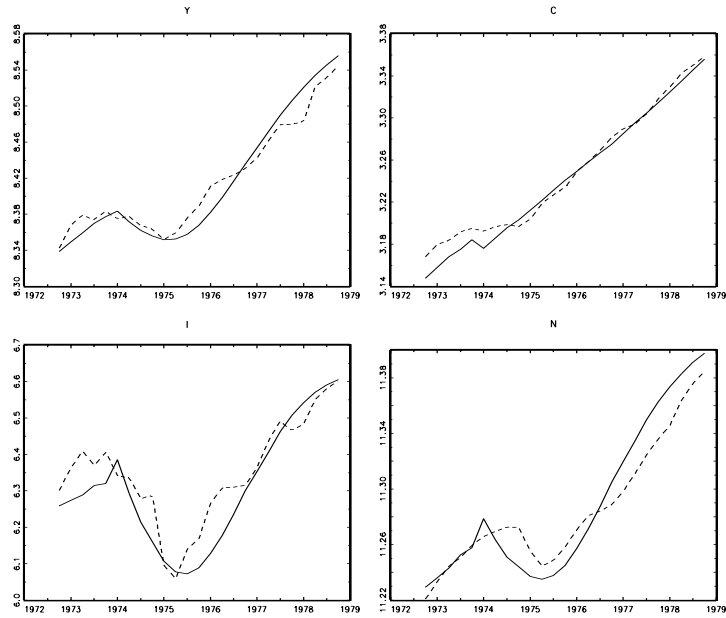


Fig. 7.1. Predictions of Our Model (zoom in fig. 7).

The reason for the model's success lies in a multiplier-accelerator mechanism emerging under externalities (or monopolistic competition with increasing returns to scale). This mechanism gives rise to dampened cycles as can be seen from the impulse response functions of the model in Figure 8. The impulse response of GDP, consumption, investment and employment to a doubling of the oil price in the U.S. data also exhibits similar dampened cycles as can be seen in Figure 9.²⁰

²⁰These estimated impulse responses of the US economy to an oil shock are computed directly from the estimated structural representation in Section 2.

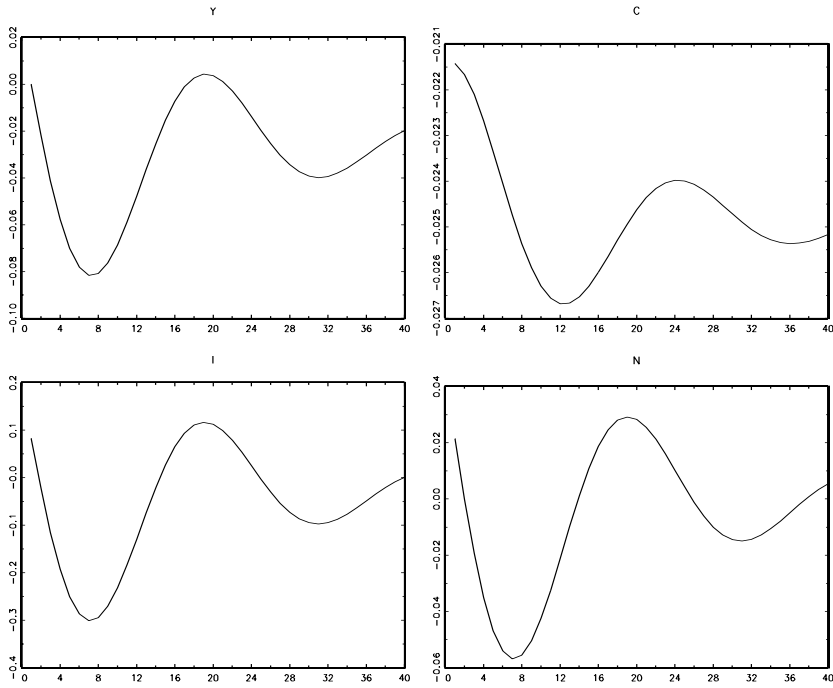


Fig. 8. Impulse Responses to a Doubling of the Oil Price (Model).

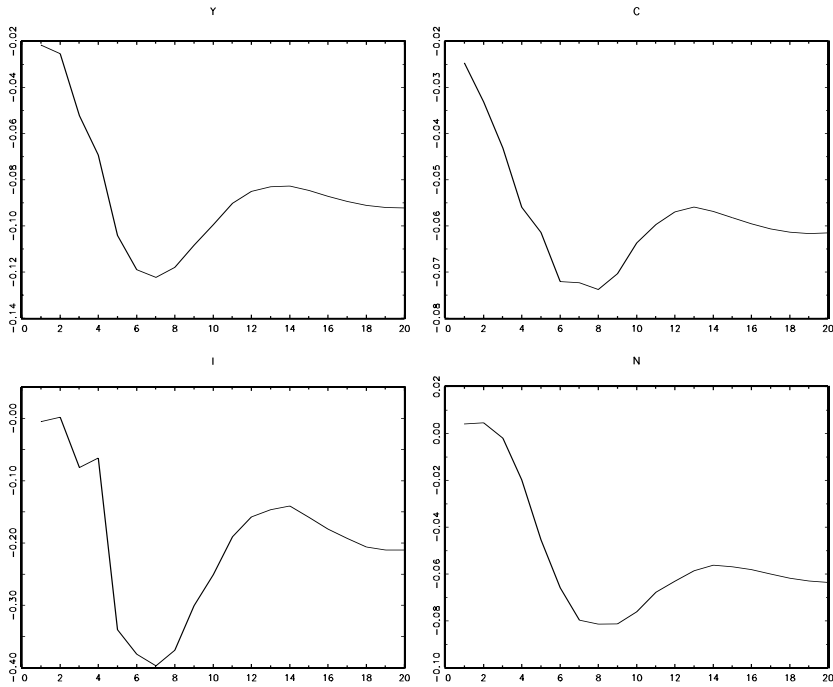


Fig. 9. Impulse Responses to a Doubling of the Oil Price (U.S. data).

3.4 Dissecting the Multiplier Effect and the Accelerator Effect

Recall that the reduced-form production function is given by

$$y_t = \phi \left(\frac{1}{p_t^o} \right)^{\frac{\alpha_o \tau_n}{1 - \alpha_o \tau_n}} k_t^{\frac{\alpha_k \tau_k}{1 - \alpha_o \tau_n}} n_t^{\frac{\alpha_n \tau_n}{1 - \alpha_o \tau_n}}, \quad (31)$$

where ϕ is a positive constant and $\tau_n \equiv \frac{\theta}{\theta - \alpha_k}$, $\tau_k \equiv \frac{\theta - 1}{\theta - \alpha_k}$. If, on the other hand, we use the externality version of the model by setting $a_o = \alpha_o(1 + \eta)$, $a_k = \alpha_k(1 + \eta)$, $a_n = \alpha_n(1 + \eta)$, and $\alpha_o + \alpha_k + \alpha_n = 1$, the reduced-form aggregate production function is given by

$$y_t = \phi \left(\frac{1}{p_t^o} \right)^{\frac{\alpha_o(1+\eta)\tau_n}{1 - \alpha_o(1+\eta)\tau_n}} k_t^{\frac{\alpha_k(1+\eta)\tau_k}{1 - \alpha_o(1+\eta)\tau_n}} n_t^{\frac{\alpha_n(1+\eta)\tau_n}{1 - \alpha_o(1+\eta)\tau_n}}, \quad (32)$$

where $\tau_n \equiv \frac{\theta}{\theta - \alpha_k(1+\eta)}$, $\tau_k \equiv \frac{\theta - 1}{\theta - \alpha_k(1+\eta)}$.

Suppose there are no externalities ($\eta = 0$) and there is no variable capacity utilization ($\theta = \infty$ and $\tau_n = \tau_k = 1$). Then the output elasticity of the oil price is given by $-\frac{\alpha_o}{1 - \alpha_o}$, and the output elasticity of labor is given by $\frac{\alpha_n}{1 - \alpha_o}$. Based on our calibration of oil's share in production ($\alpha_o = 0.015$), the oil elasticity is 0.015 and the labor elasticity is 0.71, suggesting that a doubling of the oil price (a 100% increase in the oil price) translates to less than a 1.5% change in output, holding labor constant. Since a higher oil price decreases labor's productivity, employment will also decrease, amplifying the impact of oil price on output. For simplicity, assume that labor decreases by 1%, then there will be another 0.71% additional change in output. The total output change is thus about 2.2%.

If capacity utilization is variable, then the oil price elasticity is given by $-\frac{\alpha_o \tau_n}{1 - \alpha_o \tau_n} = -0.019$, and the effective labor elasticity is given by $\frac{\alpha_n \tau_n}{1 - \alpha_o \tau_n} = 0.9$. A doubling of the oil price then can lead to about a 3% decrease in output under the maintained assumption that labor decreases by just 1%. Thus the multiplier effect of capacity utilization is approximately 1.3. This multiplier effect, however, is still not sufficient for accounting for the data, which shows that output dropped by almost eight percent in 1975 from its peak.²¹ Notice that these standard models do not have cyclical propagation mechanisms, hence there is no dynamic multiplier but only a contemporaneous multiplier. That is, the maximum impact of the oil shock always takes place in the impact period.

If we allow for externalities or increasing returns to scale in the capacity utilization model, although the size of the contemporaneous (or instantaneous) multiplier does not change dramatically for small externalities, an accelerator will emerge, giving rise to an intertemporal (or dynamic) multiplier. Under the intertemporal multiplier, output not only decreases in the impact period but also continues to decrease over time, leading to a deeper slump. For example, if $\eta = 0.1$, the output elasticity of the oil price becomes 0.02 and the labor's elasticity becomes approximately 1.0. Hence, judged by the instantaneous multiplier, the total change in output is still roughly 3% in the impact period. But, under the influence of the intertemporal multiplier (i.e., the accelerator),

²¹The reason that Finn's (2000) model has a large enough multiplier to match the depth of the recession is that she assumes a much larger oil share in the US aggregate production. Her calibration is equivalent to setting $\alpha_o = 0.043$, implying an output elasticity of the oil price in the order of $\frac{\alpha_o \tau_n}{1 - \alpha_o \tau_n} \approx 6\%$. This elasticity, combining with a fall in labor, can account for the fall in output.

output continues to decrease for several quarters before a trough is reached. Based on our parameter calibration, at the trough, output is about 8% below its initial value (see Figure 8).

Hence, once externalities are allowed, one of the most striking features of the model arises: it now exhibits persistent oscillations around the steady state. The cyclical mechanism arises under externalities because firms' production decisions and investment activities reinforce among each other, causing the aggregate economy to overshoot the steady state as the economy converges. Such over-shooting behavior implies cycles. Consider a permanent increase in the oil price. The rise in oil price increases the marginal cost of production at the firm level, hence reducing oil demand as well as employment and capacity utilization. This causes a contraction in output. Anticipating a lower future productivity of capital, firms also reduce investment spending, depressing aggregate demand and leading to a fall in the capital stock. Due to the force of externalities among firms, this becomes a cumulative process of contractions. As the contraction continues, the rising marginal product of capital dictates that the decrease in output slows down (de-accelerating). The result is that sooner or later the capital stock and output must stop declining, and capacity utilization and investment must start to increase to exploit the excessively high marginal product of capital at a business-cycle trough. But a rise in the investment demand then also triggers output expansion. Thus, the above propagation mechanism reverses itself, leading to a cumulative process of recovery and expansion.

3.5 Robustness

The above predictions are generated by using the nominal oil price. One may argue that what matters for the U.S. economy is the movement in the real oil price. For this reason, we have also simulated our model using the real oil price, defined as the ratio of the nominal oil price to the GDP deflator. The results are almost exactly the same as those obtained under the nominal oil price. We have also tried to follow the idea of Rotemberg and Woodford (1996) by identifying the component in the real oil price that is due to oil shocks in the nominal oil price. For example, we run a VAR with first differences in nominal and real oil prices and identify the oil shocks using the same methodology outlined in Section 2. Then the movements in the real oil price due to the oil shocks are fed into our theoretical model. The predictions of the model remain essentially the same.²²

We have also conducted robustness analysis on the empirical VAR exercises in Section 2. First of all, we have checked that replacing the nominal oil price by the real oil price in our VAR does not alter our results at all. This is true since real oil prices move very closely with nominal oil prices in that period. Secondly, Bernanke et al. (1997) and especially Barsky and Kilian (2001) argue that monetary policy, instead of oil shocks, could have been responsible for the recession in 1975. Hence we have also re-estimated our measure of oil shocks and their impact on the U.S. economy in Section 2 by extending our VAR to include some measures of monetary policy (e.g., the growth rate of the money supply and the interest rate).²³ Our empirical estimates of the impact of the oil

²²The results are available from the authors upon request.

²³We use the currency component of M1 as our measure of the money supply. The interest rate used

shocks on the U.S. economy between 1950 and 1978 remain essentially unchanged when these measures of monetary policy are included in the VAR (see Figure 10).²⁴ Thus, we are able to re-confirm our earlier empirical findings that non-oil shocks, whether they be technology shocks, aggregate demand shocks, or monetary policy shocks, as long as they do not cause permanent changes in the price of imported oil (our identifying assumption), are not responsible for the recession in 1975 and the subsequent recovery. Only shocks that caused permanent changes in oil prices – such as the OPEC embargo in 1973 – are the culprit of the business cycle observed in the 1970s.

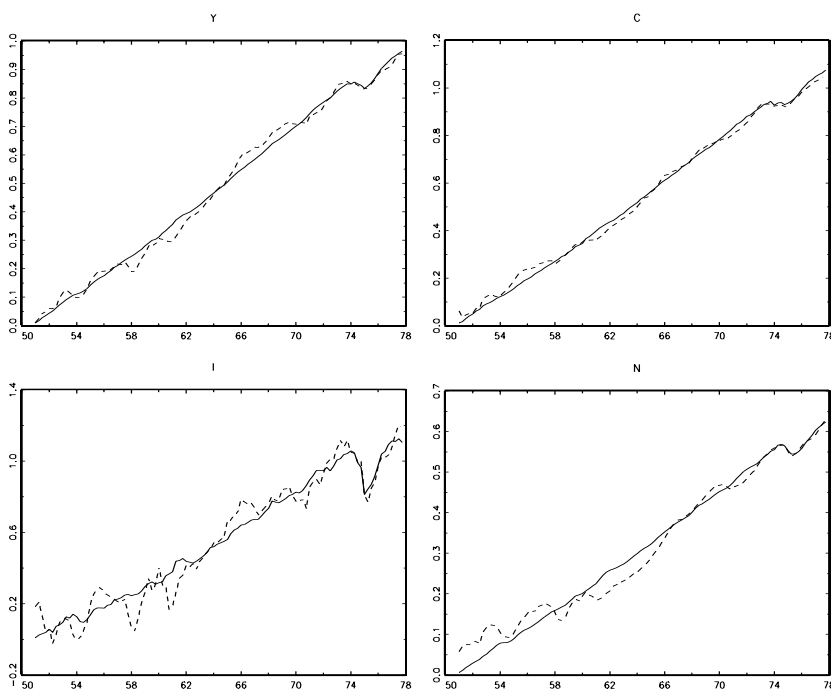


Fig. 10. Estimated Effects of Oil Shocks on U.S. Economy in a 7-Variable VAR.

4 Concluding Remarks

In this paper, we provide further empirical evidence for the importance of oil shocks in driving U.S. economic fluctuations. Our results strengthen the previous findings of the empirical literature, showing that the oil crises in the early 1970s are the culprit of the deep recession in the mid-1970s. However, standard models are not able to quantitatively account for this oil-driven recession despite the common belief that oil shocks in the 1970s are responsible for that recession. In fact, it is common for textbooks and the literature to cite the oil crises in 1973 as a leading example of productivity-shocks that drive post-war business cycles. We argue that the failure of standard models hinges on

is the 3-month treasury bill rate in the secondary market. The data is available at the St. Louis Federal Reserve Bank's homepage. The VAR includes 4 lags, a constant, and a linear time trend.

²⁴Our results thus confirm the skepticism raised by Blanchard (2001) and Blinder (2001) regarding the importance of monetary shocks in explaining the recession after the oil shocks in the 1970s.

a missing multiplier-accelerator mechanism that serves to amplify and propagate the impact of oil shocks on the U.S. economy. We construct such a multiplier-accelerator mechanism using a general equilibrium model featuring capacity utilization and externalities; we show that the mechanism is capable of explaining the important features of the data.

Our model, however, still has shortcomings. In particular, our model is not able to fully predict the depth of the recession in consumption and productivity. Possible remedies include allowing for labor hoarding as in Wen (2004). Due to labor hoarding, firms can adjust the utilization rate of labor in addition to that of capital, giving firms an extra margin for improving the elasticity of output relative to employment. This can lead to a more procyclical real wage and possibly to more volatile consumption. Also, like other models, our model cannot explain the asymmetrical effects of oil shocks. We hope to address these issues in future research. Another interesting challenge is to simultaneously account for the high inflation (stagflation) in the mid-1970s. This requires introducing money, and possibly an endogenous monetary policy, into our model. Since this will inevitably complicate our model substantially, we leave this as a task for future research.

References

- [1] Abel A. and B. Bernanke, 2001, *Macroeconomics*, 4th edition, Addison Wesley Longman, Inc.
- [2] Aguiar-Conraria, L. and Y. Wen, 2004, Foreign trade and equilibrium indeterminacy, CAE Working Paper #04-09, Cornell University.
- [3] Barsky, R. and L. Kilian, 2001, Do we really know that oil caused the great stagflation? A monetary alternative, *Macroeconomics Annual*, 137-183.
- [4] Benhabib, J. and R. Farmer, 1994, Indeterminacy and increasing returns, *Journal of Economic Theory* **63**, 19-41.
- [5] Benhabib, J. and Y. Wen, 2004, Indeterminacy, aggregate demand, and the real business cycle, *Journal of Monetary Economics* 51(3), 451-670.
- [6] Bernanke, B., M. Gertler and M. Watson, 1997, Systematic monetary policy and the effects of oil price shocks, *Brookings Papers on Economic Activity* 1, 91-142.
- [7] Blanchard, O., 2001, Comment, *Macroeconomics Annual*, 183-192.
- [8] Blanchard, O. and D. Quah, 1989, The dynamic effects of aggregate demand and supply disturbances, *American Economic Review* 79, 655-673.
- [9] Blinder, A., 2001, Comment, *Macroeconomics Annual*, 192-197.
- [10] Burbidge, J., Harrison, A., 1984, Testing for the effects of oil-price rises using vector autoregressions, *International Economic Review* 25, 459-484.
- [11] Cass, D. and K. Shell, 1983, Do sunspots matter? *Journal of Political Economy* **91**, 193-227.
- [12] Farmer, R., *Macroeconomics of Self-fulfilling Prophecies*, Second Edition, 1999, The MIT Press.
- [13] Finn, M., 2000, Perfect competition and the effects of energy price increases on economic activity, *Journal of Money Credit, and Banking*, 400-417.
- [14] Gisser, M., Goodwin, T., 1986, Crude oil and the macroeconomy: tests of some popular notions, *Journal of Money, Credit, and Banking*, 18, 95-103.
- [15] Greenwood, J., Z. Hercowitz and G. Huffman, 1988, Investment, capacity utilization, and the real business cycle, *American Economic Review* **78**, 402-417.
- [16] Hamilton, J., 1983, Oil and the macroeconomy since World War II, *Journal of Political Economy* 91, 228-248.
- [17] Hamilton, J., 1985, Historical causes of postwar oil shocks and recessions. *Energy Journal* 6, 97-116.
- [18] Hamilton, J., 1988a, A neoclassical model of unemployment and the business cycle, *Journal of Political Economy* 96, 593-617.

- [19] Hamilton, J., 1988b, Are the macroeconomic effects of oil-price changes symmetric? A comment, *Carnegie-Rochester Series on Public Policy* 28, 369-378.
- [20] Hamilton, J., 1996, This is what happened to the oil price-macroeconomy relationship, *Journal of Monetary Economics* 38, 215–220.
- [21] Hamilton, J., 2003, What is an oil shock?, *Journal of Econometrics* 113, 363–398.
- [22] Hamilton, J. and A. Herrera, 2004, Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy, *Journal of Money, Credit, and Banking*, 36, 265–286.
- [23] Hansen, G., 1985, Indivisible labour and the business cycle, *Journal of Monetary Economics* 16, 309-325.
- [24] Herrera, A., 2000, Inventories, oil shocks, and aggregate economic behavior, Unpublished Ph.D. dissertation, University of California at San Diego.
- [25] Kim, I.-M. and Loungani, P. 1992, The role of energy in real business cycle models, *Journal of Monetary Economics* 29, 173–189.
- [26] King, R., C. Plosser and S. Rebelo, 1988, Production, growth and business cycles: I. The basic neoclassical model, *Journal of Monetary Economics* 21, 195-232.
- [27] Laitner, J. and D. Stolyarov, 2004, Aggregate returns to scale and embodied technical change: Theory and measurement using stock market data, *Journal of Monetary Economics*, 51, 191–234.
- [28] Leduc, S. and K. Sill, 2004, A quantitative analysis of oil-price shocks, systematic monetary policy, and economic downturns, *Journal of Monetary Economics*, 51, 781–808.
- [29] Loungani, P., 1986, Oil price shocks and the dispersion hypothesis, *Review of Economics and Statistics* 58, 536-539.
- [30] Mork, K. A., 1989, Oil and the macroeconomy when prices go up and down: An extension of Hamilton’s results, *Journal of Political Economy* 91, 740–744.
- [31] Nordhaus, W., 2002, The Economic Consequences of a War with Iraq, Yale University mimeo.
- [32] Rasche, R. and J. Tatom, 1981, Energy price shocks, aggregate supply, and monetary policy: The theory and international evidence, *Carnegie-Rochester Conference Series on Public Policy* 14, 9-93.
- [33] Rotemberg, J. and Woodford, M., 1996, Imperfect competition and the effects of energy price increases on economic activity, *Journal of Money, Credit, and Banking* 28, 549–577.
- [34] Santini, D., 1985, The energy-squeeze model: Energy price dynamics in U.S. business cycle, *International Journal of Energy and Resources* 8, 159-194.

- [35] Shell, K., 1977, Monnaie et allocation intertemporelle, Mimeo, *Seminaire d'Econometrie Roy-Malinvaud, Centre National de la Recherche Scientifique*, Paris.
- [36] Shell, K., 1987, Sunspot equilibrium, in *The New Palgrave: A Dictionary of Economics* (J. Eatwell, M. Milgate, and P. Newman, eds.), Vol. 4, New York: Macmillan, 549-551.
- [37] Tatom, J., 1988, Are the macroeconomic effects of oil price changes symmetric? *Carnegie-Rochester Conference on Public Policy* 28, 325-368.
- [38] Wei, C., 2003, Energy, the stock market, and the putty-clay investment model, *American Economic Review* 93, 311-323.
- [39] Wen, Y., 1998, Capacity utilization under increasing returns to scale, *Journal of Economic Theory* 81, 7-36.
- [40] Wen, Y., 2004, What does it take to explain procyclical productivity? *Contributions to Macroeconomics* 4 (No. 1, Article 5).