APPENDIX: A Simple Model of Oil-Supply Shocks

By assumption:

A.1 Oil demand: $\Delta p = \delta_0 - \delta_1 \Delta q$
A.2 Oil supply: $\Delta p = \sigma_0 + \sigma_1 \Delta q$,

where

$\Delta p \equiv$ deviation from preshock or sample mean, four-quarter percentage change in West Texas Intermediate (WTI) oil price less four-quarter percentage change in core personal consumption expenditures (PCE) price index

$\Delta q \equiv$ deviation from preshock or sample mean, four-quarter percentage change in U.S. total demand for all oil products.

We seek an estimate for σ_1, so that we can solve the supply equation for σ_0.

The supply and demand equations can be solved for Δp and Δq as functions of the slopes of the demand and supply schedules and supply and demand disturbances:

A.3 $\Delta p = [\sigma_1/(\sigma_1 + \delta_1)]\delta_0 + [\delta_1/(\sigma_1 + \delta_1)]\sigma_0$

A.4 $\Delta q = (\delta_0 - \sigma_0)/(\sigma_1 + \delta_1)$.

If δ_0 and σ_0 are contemporaneously uncorrelated, it follows that

A.5 $\sigma_p^2 = [\sigma_1/(\sigma_1 + \delta_1)]^2 \sigma_\delta^2 + [\delta_1/(\sigma_1 + \delta_1)]^2 \sigma_\sigma^2$,

A.6 $\sigma_q^2 = [1/(\sigma_1 + \delta_1)]^2 \sigma_\delta^2 + [1/(\sigma_1 + \delta_1)]^2 \sigma_\sigma^2$, and

A.7 $\mathrm{Cov}(\Delta p/\Delta q) = [\sigma_1/(\sigma_1 + \delta_1)^2]\, \sigma_\delta^2 - [\delta_1/(\sigma_1 + \delta_1)^2]\, \sigma_\sigma^2$,

where σ_δ^2 and σ_σ^2 are the variances of δ_0 and σ_0, respectively. These are three equations in four unknowns: σ_δ^2, σ_σ^2, δ_1 and σ_1. Rearranging and combining:

A.8 $\sigma_1 = [\sigma_p^2 + \delta_1\, \mathrm{Cov}(\Delta p,\Delta q)]/[\delta_1 \sigma_q^2 + \mathrm{Cov}(\Delta p,\Delta q)]$.

Hence, we can pin down σ_1 if we can accurately estimate δ_1.

To estimate δ_1, note that A.3 and A.4 together imply that

A.9 $\Delta p/\Delta q = \sigma_1[\delta_0/(\delta_0 - \sigma_0)] + \delta_1[\sigma_0/(\delta_0 - \sigma_0)]$,

which reduces to $-\delta_1$ in the case of a pure oil-supply shock ($\delta_0 = 0$). For example, in the four quarters ending 1974:Q1, the real price of oil rose 169.24 percent and total U.S. oil demand fell 7.71 percent. In the four years from 1969:Q1 (when oil-demand data are first available) to 1973:Q1, real oil prices fell at a 0.68 percent annual rate and oil demand rose at a 4.99 percent annual rate. Thus, oil-price growth was 169.24 + 0.68 = 169.92 percentage points above its preshock average and quantity growth was 7.71 + 4.99 = 12.70 percentage points below its preshock average. In the four quarters ending 1980:Q1, similarly, oil-price growth exceeded its 1974:Q1–1979:Q1 preshock average by 112.51 – 1.79 = 110.72 percentage points, while quantity growth dropped below its preshock average by 8.97 + 3.80 = 12.77 percentage points. Finally, in the four quarters ending 1990:Q4, oil-price growth exceeded its 1986:Q4–1989:Q4 preshock average by 50.07 – 5.50 = 44.57 percentage points, while quantity growth dropped below its preshock average by 6.29 + 2.30 = 8.59 percentage points. Averaging across all three episodes under the assumption that they were pure supply shocks:[1]

A.10 $\delta_1 = -\Delta p/\Delta q = (169.92 + 110.72 + 44.57)/(12.70 + 12.77 + 8.59) = 9.55$.

Equivalently, the short-run price elasticity of U.S. oil demand is 100/955 = 0.105—a 10 percent exogenous increase in the price of oil causes U.S. oil consumption to fall by about 1 percent.

Before substituting from A.10 into A.8 to obtain an estimate of σ_1, it's important to note that the behaviors of price and quantity are substantially different prior to the 1986 oil-price collapse than after the collapse. In the early sample, oil-price changes are infrequent but large. Demand growth is subject to big swings and is strongly negatively correlated (–0.35) with price growth. Post-1986, price changes are more frequent but smaller. Demand-growth fluctuations are smaller, too, and are essentially uncorrelated with price growth. During the early sample:

A.8' $\sigma_1 = [2034.16 + 9.55 \times (-81.99)]/[9.55 \times 26.98 - 81.99] = 7.12$.

The implied short-run price elasticity of supply is 100/712 = 0.14. During the late sample, the supply price of oil is over twice as sensitive to fluctuations in quantity demanded:

A.8" $\sigma_1 = [872.95 + 9.55 \times 0]/[9.55 \times 5.22 + 0] = 17.51$.

Equivalently, the short-run price elasticity of the supply of oil is about 100/1751 = 0.057—a 10 percent increase in the price of oil raises the supply of oil by a little over 0.5 percent.

Of course, it is the post-1986 sample that is relevant for the GDP growth forecasting model. In view of the above results, we set $\sigma_1 = 17.5$ for purposes of identifying supply-driven changes in the price of oil. From the oil-supply schedule:

$$\sigma_0 = \Delta p - \sigma_1 \Delta q = \Delta p - 17.5\, \Delta q.$$

Here, Δp and Δq are deviations of price growth and quantity growth from their post-1986 sample means of 6.81 percent and 1.34 percent, respectively. (The corresponding pre-1987 mean growth rates are 9.82 percent and 0.97 percent.) It is only adverse oil-supply shocks ($\sigma_0 > 0$) that impact real GDP growth. Formally, we set our oil-shock variable equal to the maximum of 0 and σ_0.

Note

[1] A significant deceleration in nominal GDP growth coincident with the 1990:Q4 oil-price shock suggests there may have been a demand element to the 1990:Q4 slowdown in oil-consumption growth. Excluding the 1990:Q4 episode from the calculations that follow increases the estimate of δ_1 to 11.0 and reduces the post-1986 estimate of σ_1 to 15.2.