ECON 4101 Econometrics
Reproducibility Term Paper

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Background Overview

There are two main competing views of the global market for crude oil:

1. The price of oil is determined by desired stocks. Shifts in the expectations of forward-looking traders (hedgers and speculators) are reflected in changes in the real price of oil and in changes in oil inventories.
2. The real price of oil is determined by shocks to the amount of oil coming out of the ground ("flow supply of oil") and the amount of oil being consumed ("flow demand for oil").

Recently, there has been increasing recognition that both elements of price determination matter. In *The Role of Inventories and Speculative Trading in the Global Market for Crude Oil (2013)*, Kilian and Murphy develop a structural vector autoregressive (VAR) model of the global market for crude oil that nests these two theories together and quantifies the effects of shocks to the speculative demand for oil as well as shocks to flow demand and flow supply of oil. The study stresses the importance of oil inventories data for building a model for price of crude oil. The paper attempts to indirectly identify the effects of shifts in expectations (i.e. without explicit measures of expectations) by including changes in oil inventories in their econometric model. They do this because reliable and substantial data on expectation shifts is not readily available, and because how subjective expectations are formed is too complicated of a nonlinear function to be practical in modeling. The model is built off of four main features (measured monthly from 1973:2 to 2009:8):

1. Percent change in global crude oil production
2. Index of global real activity in deviations from trend
3. Real price of oil
4. Change in above-ground global crude oil inventories

The authors assert that the variables are mutually endogenous. They include two years worth of lags in the model. The paper models four shocks as its responses:

1. Flow supply shock - shock to the flow of crude oil production
2. Flow demand shock - shock to the demand for crude oil driven by the global business
3. Speculative demand shock - shock to the demand for above-ground oil inventories arising from forward-looking behavior
4. Residual shock - captures all structural shocks not otherwise accounted for

Replication of Structural Impulse Responses of Shocks

```
bayesPosterior <- readMat('../BayesPosterior.mat'); IRMposs <- bayesPosterior$IRMposs
IRFelas <- readMat('../IRFelas.mat'); IRFelas <- IRFelas$IRFelas;
findex <- readMat('../findex.mat'); findex <- findex$findex;

xmax = 17
mindist <- 0.0061

IRF <- IRFelas[,,findex]
time <- c(0:xmax);
CI <- apply(IRMposs, c(1,2), quantile, probs = c(.16,.84))
CI1458912=apply(apply(IRMposs, c(1,3), cumsum), c(1,2), quantile, probs = c(.16,.84))
for (i in c(1, 4, 5, 8, 9, 12)) {
  CI[, i, ] <- CI1458912[, , i]
}

CI5 = apply(IRMposs, c(1,2), quantile, probs=c(.025, .975))
CI5_1458912=apply(apply(IRMposs, c(1,3), cumsum), c(1,2), quantile, probs = c(.025, .975));
for (i in c(1, 4, 5, 8, 9, 12)) {
  CI5[, i, ] <- CI5_1458912[, , i]
}
```

```
fn <- function(title, Months, ylabel, y, yl, yu, ylim) {
  df <- data.frame(Months=Months, ylabel = y, yl = yl, yu = yu)
  ggplot(df, aes(x=Months)) +
    geom_line(aes(y=ylabel), color='red') +
    geom_line(aes(y=yl), color='blue', linetype='dashed') +
    geom_line(aes(y=yu), color='blue', linetype='dashed') +
    geom_hline(aes(yintercept=0)) +
    scale_y_continuous(limits = ylim) +
    ggtitle(title) +
    labs(y = ylabel) +
    theme(axis.text=element_text(size=6),
          axis.title=element_text(size=8),
          plot.title=element_text(size=8))
}
```

```
g1 <- fn('Flow Supply Shock', time, 'Oil Production', -cumsum(IRF[1,]), -CI[1,1,], -CI[2,1,], c(-2,2))
g5 <- fn('Flow Demand Shock', time, 'Oil Production', cumsum(IRF[5,]), CI[1,5,], CI[2,5,], c(-2,2))
g9 <- fn('Speculative Demand Shock', time, 'Oil Production', cumsum(IRF[9,]), CI[1,9,], CI[2,9,], c(-2,

g2 <- fn('Flow Supply Shock', time, 'Real Activity', -IRF[2,], -CI[1,2,], -CI[2,2,], c(-10,10))
g6 <- fn('Flow Demand Shock', time, 'Real Activity', IRF[6,], CI[1,6,], CI[2,6,], c(-10,10))
g10 <- fn('Speculative Demand Shock', time, 'Real Activity', IRF[10,], CI[1,10,], CI[2,10,], c(-10,10))

g3 <- fn('Flow Supply Shock', time, 'Real Price of Oil', -IRF[3,], -CI[1,3,], -CI[2,3,], c(-10,10))
g7 <- fn('Flow Demand Shock', time, 'Real Price of Oil', IRF[7,], CI[1,7,], CI[2,7,], c(-10,10))
g11 <- fn('Speculative Demand Shock', time, 'Real Price of Oil', IRF[11,], CI[1,11,], CI[2,11,], c(-10,

g4 <- fn('Flow Supply Shock', time, 'Inventories', -cumsum(IRF[4,]), -CI[1,4,], -CI[2,4,], c(-20,20))
g8 <- fn('Flow Demand Shock', time, 'Inventories', cumsum(IRF[8,]), CI[1,8,], CI[2,8,], c(-20,20))
g12 <- fn('Speculative Demand Shock', time, 'Inventories', cumsum(IRF[12,]), CI[1,12,], CI[2,12,], c(-2
```

```
globs <- list(g1,g2,g3,g4,g5,g6,g7,g8,g9,g10,g11,g12)
```

Original Figure 1: Structural Impulse Responses

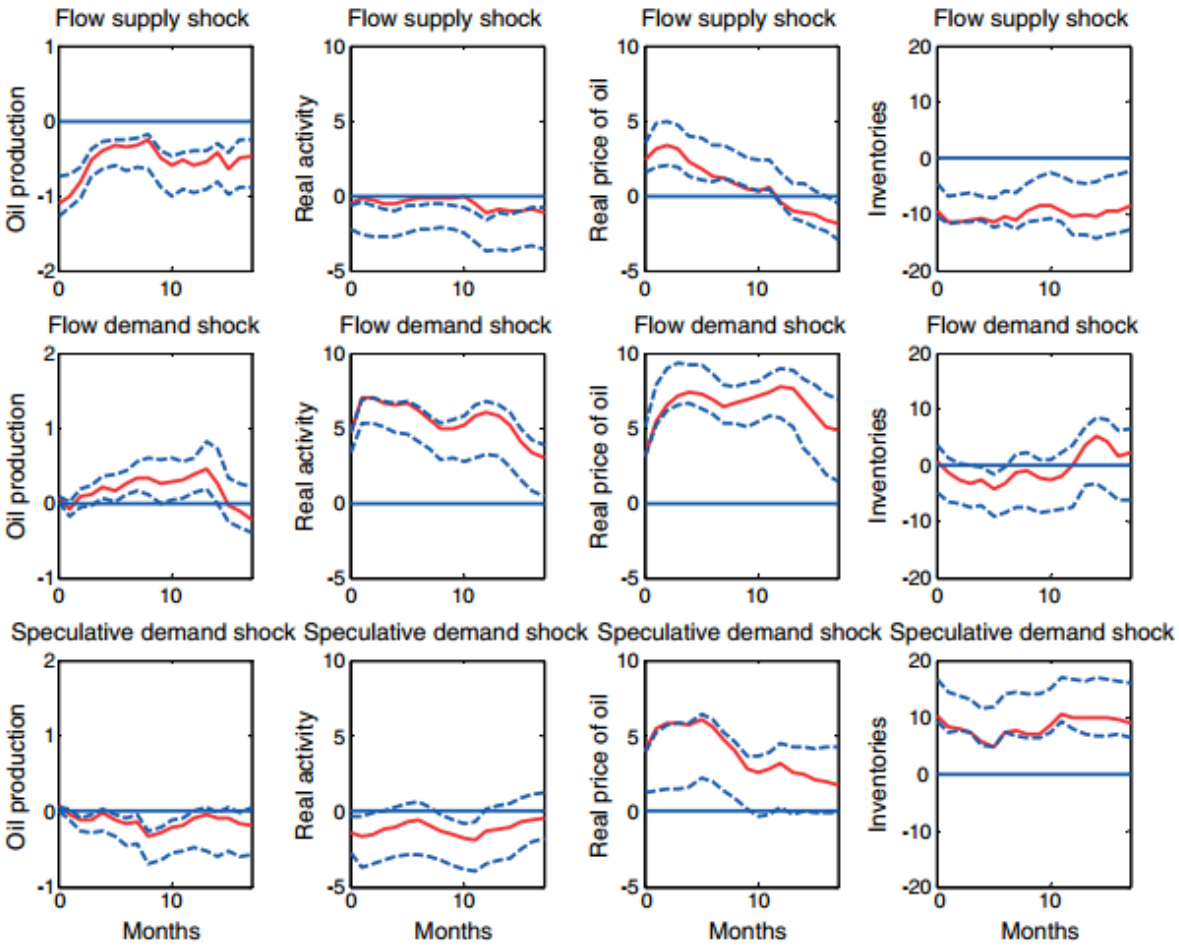
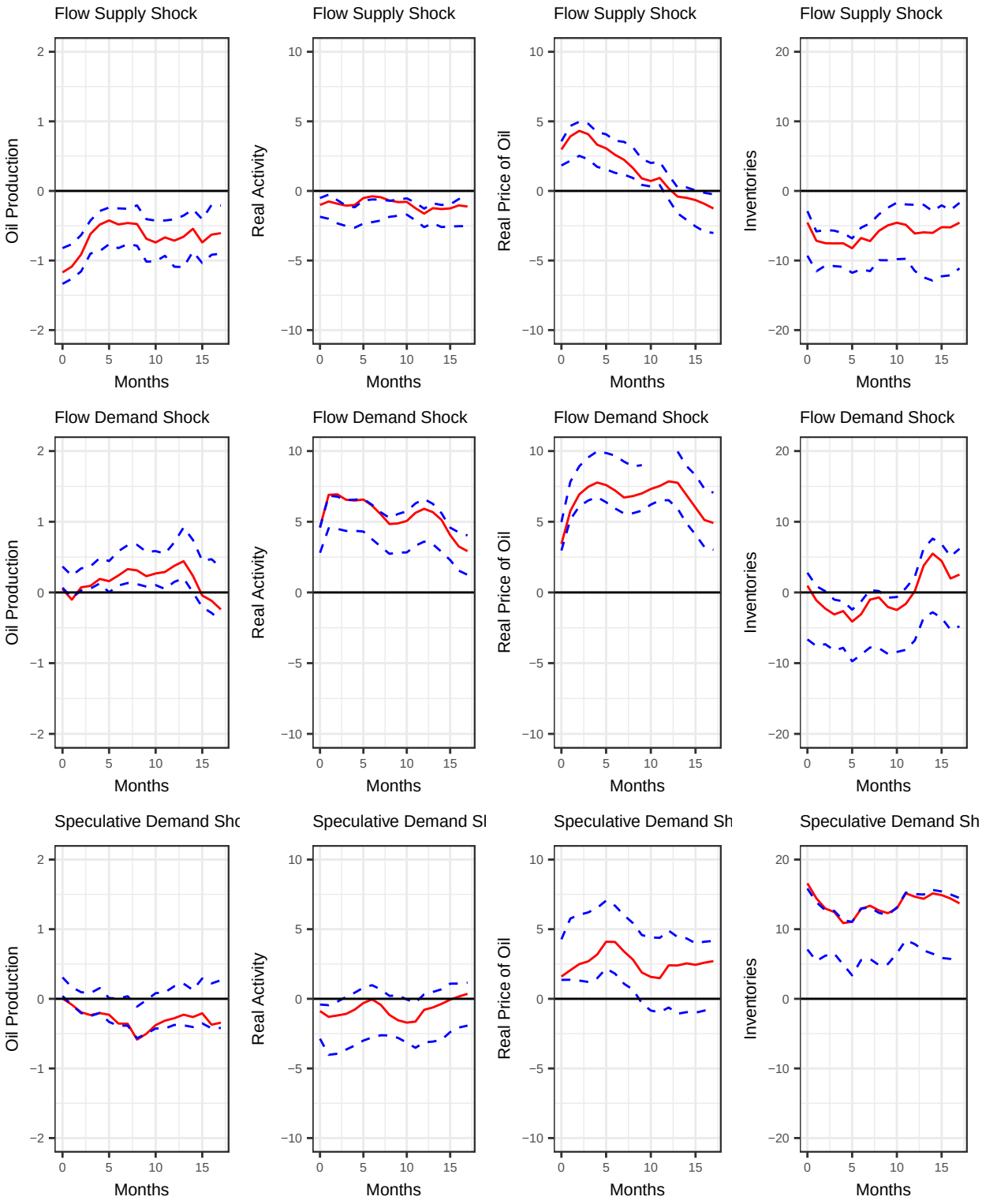


Figure 1. Structural impulse responses: 1973:2–2009:8. Solid lines indicate the impulse response estimates for the model with an impact price elasticity of oil demand in use closest to the posterior median of that elasticity among the admissible structural models obtained conditional on the least-squares estimate of the reduced-from VAR model. Dashed lines indicate the corresponding pointwise 68% posterior error bands. 'Oil production' refers to the cumulative percent change in oil production and inventories to cumulative changes in inventories

Figure 1:

Replicated Figure 1: Structural Impulse Responses

```
grid.arrange(grobs=globs, layout_matrix = matrix(1:12, byrow = T,nrow=3))
```


Flow Supply Shock
Oil Production
Real Activity
Real Price of Oil
Inventories
Months
Flow Demand Shock
Oil Production
Real Activity
Real Price of Oil
Inventories
Months
Speculative Demand Shc
Speculative Demand Sl
Speculative Demand Sh
Speculative Demand Sh
Oil Production
Real Activity
Real Price of Oil
Inventories
Months

Replication of Historical Decompositions of Cumulative Effects of Shocks

```
bayesPosterior <- readMat('../BayesPosterior.mat'); IRMposs <- bayesPosterior$IRMposs
IRFelas <- readMat('../IRFelas.mat'); IRFelas <- IRFelas$IRFelas;
findex <- readMat('../findex.mat'); findex <- findex$findex;
U <- readMat('../U.mat'); U <- U$U
BETAnc <- readMat('../BETAnc.mat'); BETAnc <- BETAnc$BETAnc

IdentMat <- matrix(IRFelas[,1,findex], nrow=4)
Uhat <- U
p=24;
t=439; # length(kmData)
K <- nrow(IdentMat)
q <- ncol(IdentMat)

# Compute structural multipliers
A = rbind(BETAnc, cbind(diag(K*(p-1)), diag(x=0, K*(p-1), K)))
J = cbind(diag(K), diag(x=0, K, K*(p-1)))
IRF = matrix(J %*% (A %^% 0) %*% t(J) %*% IdentMat, nrow = K^2, ncol = 1)
for (i in 1:(t-p-1)) {
  IRF = cbind(IRF, matrix(J %*% (A %^% i) %*% t(J) %*% IdentMat, nrow = K^2, ncol = 1))
}

# Compute structural shocks Ehat from reduced form shocks Uhat
Ehat = MASS::ginv(IdentMat) %*% Uhat[1:q,];

# Cross-multiply the weights for the effect of a given shock on the real
# oil price (given by the relevant row of IRF) with the structural shock
# in question
yhat1 = diag(x=0,t-p,1);
yhat2 = diag(x=0,t-p,1);
yhat3 = diag(x=0,t-p,1);
yhat4 = diag(x=0,t-p,1);
for (i in 1:(t-p)) {
  yhat1[i,] = IRF[3, 1:i] %*% Ehat[1, i:1]
  yhat2[i,] = IRF[7, 1:i] %*% Ehat[2, i:1]
  yhat3[i,] = IRF[11, 1:i] %*% Ehat[3, i:1]
  yhat4[i,] = IRF[15, 1:i] %*% Ehat[4, i:1]
}

time = seq(from = (1973+2/12+1/12*p), to = 2009+8/12, by = 1/12); # starts at 1975.2
cumshock = yhat1 + yhat2 + yhat3 + yhat4;
```

```
df <- data.frame(Years=time, CumEffect=yhat1)
g <- ggplot(mapping=aes(x=time)) + geom_vline(aes(xintercept=1978+9/12)) +
  geom_vline(aes(xintercept=1980+9/12)) +
  geom_vline(aes(xintercept=1985+12/12)) +
  geom_vline(aes(xintercept=1990+7/12)) +
  geom_vline(aes(xintercept=1997+7/12)) +
  geom_vline(aes(xintercept=2002+11/12)) +
  geom_hline(aes(yintercept=0), linetype = 'dashed') +
  geom_hline(aes(yintercept=-50), linetype = 'dashed') +
```

```
  geom_hline(aes(yintercept=50), linetype = 'dashed') +
  scale_y_continuous(limits = c(-100, 100)) +
  ylab('')
g1 <- g + geom_line(aes(y=yhat1), color='blue') +
  ggtitle('Cumulative Effect of Flow Supply Shock on Real Price of Crude Oil')
g2 <- g + geom_line(aes(y=yhat2), color='blue') +
  ggtitle('Cumulative Effect of Flow Demand Shock on Real Price of Crude Oil')
g3 <- g + geom_line(aes(y=yhat3), color='blue') +
  ggtitle('Cumulative Effect of Speculative Demand Shock on Real Price of Crude Oil')
```

Original Figure 2: Historical Decompositions

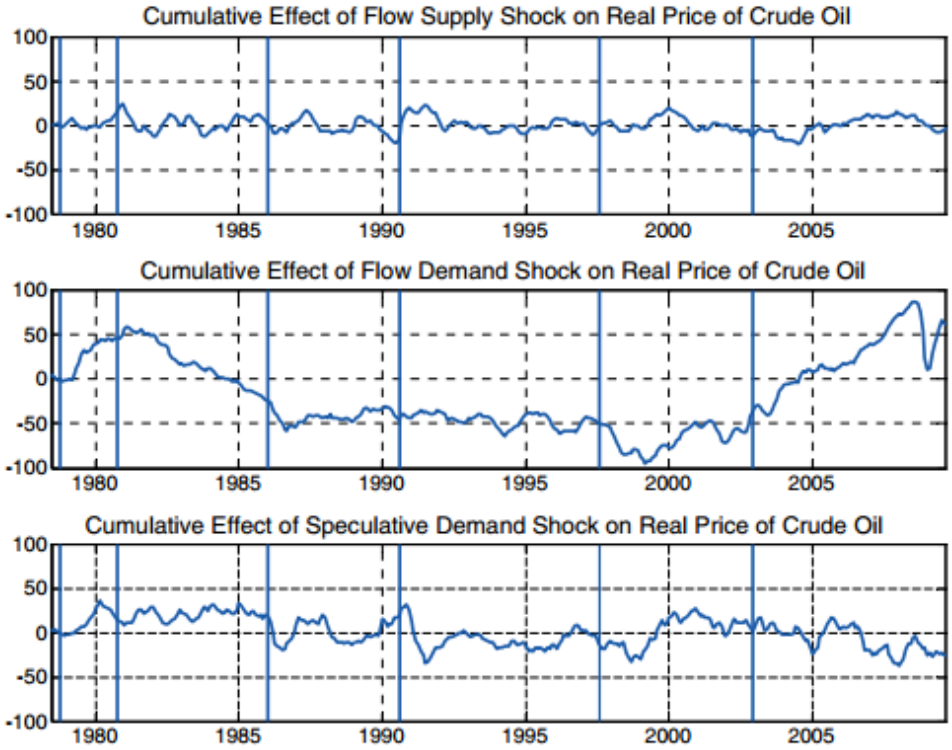
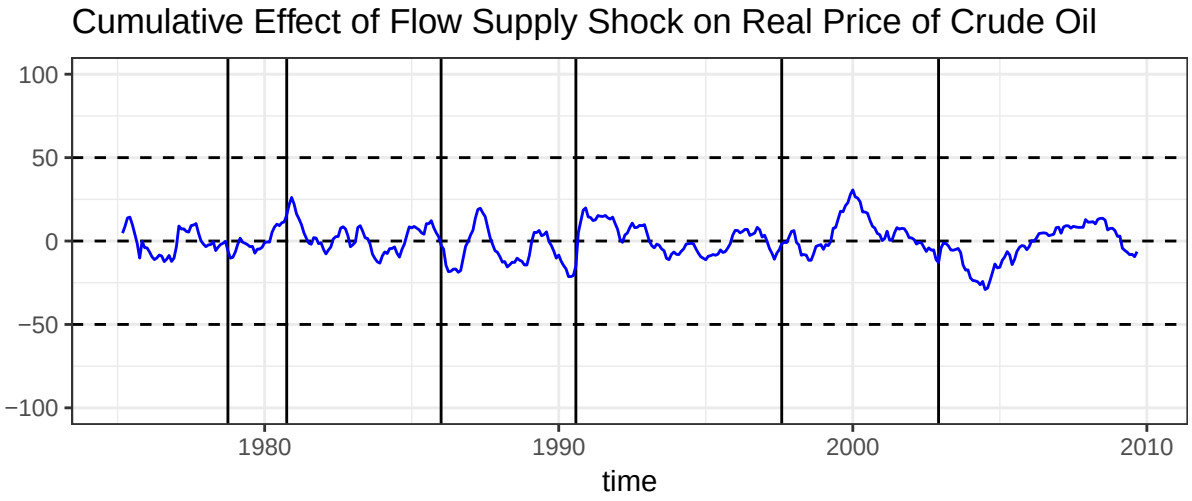


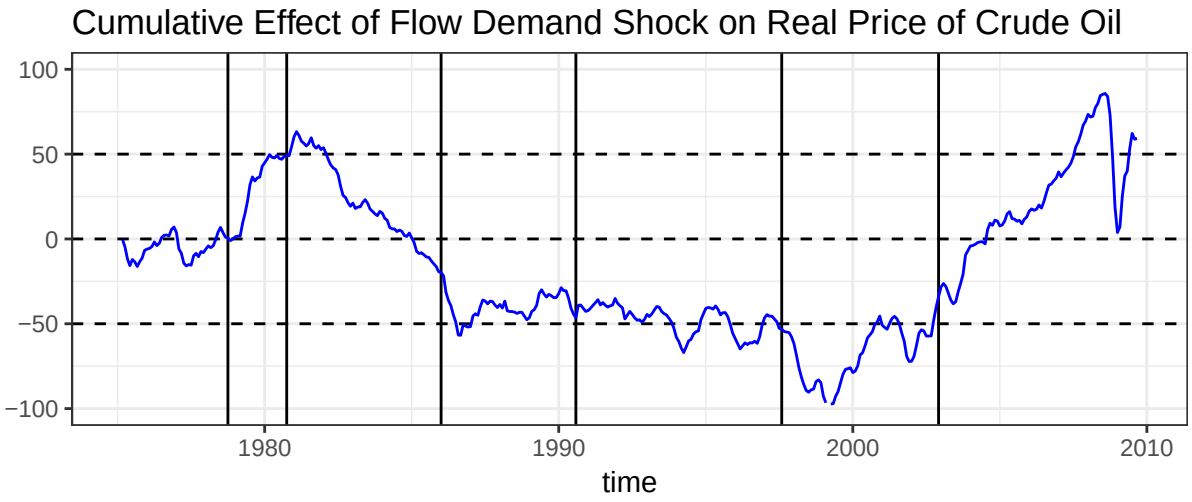
Figure 2. Historical decompositions for 1978:6–2009:8. Based on benchmark estimate as in Figure 1. The vertical bars indicate major exogenous events in oil markets, notably the outbreak of the Iranian Revolution in 1978:9 and of the Iran–Iraq War in 1980:9, the collapse of OPEC in 1985:12, the outbreak of the Persian Gulf War in 1990:8, the Asian Financial Crisis of 1997:7, and the Venezuelan crisis in 2002:11, which was followed by the Iraq War in early 2003. In constructing the historical decomposition we discard the first five years of data in an effort to remove the transition dynamics

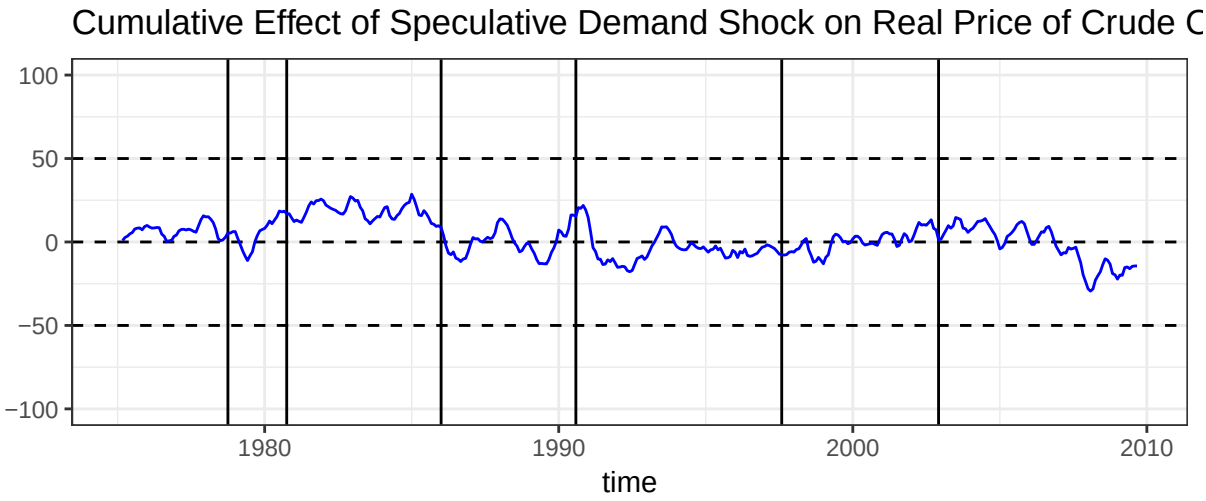
Figure 2:

Replicated Figure 2: Historical Decompositions

```
grid.arrange(grobs=list(g1,g2,g3), nrow=3)
```


Cumulative Effect of Flow Supply Shock on Real Price of Crude Oil
100
50
0
−50
−100
1980
1990
2000
2010
time


Cumulative Effect of Flow Demand Shock on Real Price of Crude Oil
100
50
0
−50
−100
1980
1990
2000
2010
time


Cumulative Effect of Speculative Demand Shock on Real Price of Crude C
100
50
0
−50
−100
1980
1990
2000
2010
time

The paper offers explanations for several historical price shocks. In particular, its conclusions on the 2003-08 oil price shock run counter to the prevailing explanations at the time the paper was written; the paper discounts the suggestions that "peak oil" theory, OPEC supply, or speculation by oil traders were responsible for the oil price increase. Instead, the paper claims there is strong evidence that a booming world economy was the cause.

The paper offers three policy conclusions:

1. Increased regulation of oil traders will not keep the real price of oil down.
2. Increased domestic oil production in the U.S. will not lower the real price of oil materially.
3. Efforts to revive the world economy will cause the real price of oil to recover.