The monetary effects arising from stochastic resource revenues and the subsidization of financial intermediation in resource rich developing economies

by

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1.   Introduction

In this paper we develop a simple macro model to analyze a set of monetary issues that can arise when monetary, fiscal, and development policies become integrated. This is done for the specific case where a government finances a significant portion of its spending from resource revenues that are subject to external shocks and where the ability to alter both spending and taxes is limited in the short run. One concrete example is that of oil rich developing economies that frequently finance both government operations and development plans through the sale of oil on world markets (subject to stochastic price and/or exchange rate shocks). Here monetary consequences arise through the government budget constraint and to the extent that the central bank manages its exchange rate (Obstfeld, 1982). A second way that monetary policy becomes intermingled with government policy is when a country feels that its growth or development potential is held back by imperfectly functioning internal capital markets (see Levine, 1997). In such cases, the central bank may choose to supplement internal capital markets by monetizing the loans made by the government to encourage higher levels of private or quasi-private domestic investment. These two issues are explored for their effects on price level and inflation rate stability.

To analyze the conditions underlying monetary stability, the classic paper of Leeper (1991) is modified to allow the government to own the revenue stream associated with the natural resource and to use this revenue to fund some portion of government services. Both to simplify presentation and set the stage for later application, we characterize the resource revenue as oil revenue. In addition to analyzing the effects that stochastic oil revenues may create for the government's budget and balance of payments

positions, we consider the monetary consequences arising from underwriting private investment. To focus on these issues, the model abstracts from population growth and technological change.

2. The Model

2.1 The Representative Household

The representative household in a community of size $N_t = N$ is assumed to face the following maximization problem:

$$Max \ E_0 \sum_{t=0}^{\infty} \beta^t [\log(c_t) + \theta \log(m_t) + \kappa \log(g_t)] \tag{1}$$

$$s.t. \quad c_t + m_t + b_t^p + \tau_t = y + \frac{m_{t-1}}{\Pi_t} + R_{t-1} \frac{b^p_{t-1}}{\Pi_t} \tag{2}$$

where respectively $c_t = C_t/N_t$, $g = G/N_t$, $m_t = M_t/P_t N_t$, and $b_t^p = B_t^p/P_t N_t$ are real per capital levels of private and public consumption, money and government bond holdings; $R_t = 1 + i_t$, and $\Pi_t = 1 + \pi_t$ are gross nominal interest and inflation rates; θ and κ are the utility weights on real balances and government output and β is the household's subjective time discount rate. P_t is the price of both private and public consumption. For simplicity we normalize constant population size to $N = 1$ and abstract from changes in y and g through time. We then suppose that while government spending provides utility to consumers, households view its level as determined exogenously, as are period specific lump-sum tax payments, τ_t. The separable form of the utility function means that changes in government spending have no direct effect on the optimal levels of consumption or money holdings. Oil is assumed to be owned by the government and its revenues used to fund some part of government expenditure. Hence for the representative household g will

not equal τ_t. The community as a whole, however, is still subject to an aggregate resource constraint that takes the form:

$$c_t + g = y \tag{3}$$

The resource constraint together with the assumed constancy of y and g implies that $c_t = c_{t+1} = c$.

Finally, the maximization problem in (1) – (2) is subject also to the initial conditions, $M_t = M_0$ and $B_t^p = B_0^p$ at t = 0 and the transversality conditions for real money balances and government bonds. The latter requires the net present value of government debt to equal zero.

The first order conditions for the constrained intertemporal maximization problem described above can be written as:

$$\begin{cases} \dfrac{1}{R_t} = \beta E_t[\dfrac{1}{\Pi_{t+1}}] & (4) \\[2mm] \dfrac{M_t}{P_t} = m_t = c\theta(\dfrac{R_t}{R_t - 1}) = c\theta(\dfrac{1+i_t}{i_t}) & (5) \end{cases}$$

where (4) is a version of the Fisher equation, $R_t - 1 \equiv i_t = \rho + \pi_t$, where $\beta = \dfrac{1}{1+\rho}$ (and ρ is the rate of time preference and steady state real rate of interest). Equation (5) implies that the demand for money varies inversely with the nominal rate of interest $\left(\dfrac{i_t}{1+i_t}\right)$.

2.2   The Government Sector

To simplify our analysis we assume that while the real output of the oil sector is constant through time, oil export revenues are received in U.S. dollars. Hence oil revenues in domestic currency, OR_t, can be written as

$$OR_t = e_t P_t^o y_o \tag{6}$$

where, y_0 is the constant level of oil production, e_t is exchange rate (the number of units of domestic currency per U.S. dollar), and P_t^o is the oil price in U.S. dollars. Real oil revenues are then

$$or_t = \frac{OR_t}{P_t} = \left(\frac{e_t P_t^o}{P_t} \right) y_o. \tag{7}$$

We now suppose that real oil revenues fluctuate through time because of stochastic changes in either the U.S. price of oil or the exchange rate. Moreover, we assume that these external shocks result in oil revenues following an AR(1) process:

$$\ln(or_t) = \rho_o \ln(or_{t-1}) + \varepsilon_t \tag{8}$$

where ε_t is a white noise disturbance reflecting random oil price and/or exchange rate shocks and ρ_0 reflects their persistence over time. Written in terms of deviations from steady state values, this becomes:

$$\hat{or}_t = \rho_o \hat{or}_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{9}$$

Next we incorporate oil revenues as a revenue source into the government budget constraint. Grouping terms so that the left hand side represents the real value of government's current deficit, d_t,

$$d_t = g + \frac{i_{t-1} b_{t-1}^p}{\Pi_t} - or_t - \tau_t \tag{10}$$

where $\frac{i_{t-1} b_{t-1}^p}{\Pi_t}$ is the current real value of the interest paid on the stock of government debt in the hands of the public at time t-1 and τ_t is the real value of non-inflationary taxes collected. Then whatever spending cannot be financed by oil revenues and lump-sum taxes must be financed through new government borrowing. That is,

$$D_t = P_t(g - \tau_t) + i_{t-1} B_{t-1}^p - OR_t \tag{11}$$

is the amount of new government borrowing needed for budgetary purposes, embodied in a new issuance of government bonds, B_t. These, in turn, must be held by either the central bank, ΔB_t^{cb}, or the public, ΔB_t^{p}, such that in the aggregate $B_t = B_t^{cb} + B_t^{p}$. For individuals to hold government debt willingly, the transversality condition must hold. This implies that at time t = 0,

$$b_0^p = \frac{B_0^p}{P_0} = \sum_{i=0}^{\infty}\left(\prod_{j=0}^{i}\Pi_{j+1}R_j^{-1}\right)\left[\tau_{i+1} + or_{i+1} - g + \frac{\Delta B_{i+1}^p}{P_{i+1}}\right], \tag{12}$$

so that any new bond financed government deficit must be fully repaid (in present value terms) through higher taxes, oil revenues and/or money creation sometime in the future.

Finally we allow for the possibility that there may exist a positive level of privately held real government debt, $(b^p)^{ss} \geq 0$ and a positive rate of inflation, π^{ss} in the steady state. The later yields the government a constant revenue stream of $\frac{\pi^{ss}}{1+\pi^{ss}}h^{ss}$.[1] Hence in the steady state, the government will set lump-sum non-inflation tax collections such that government expenditures not covered by either oil revenues or inflation taxes are fully funded, i. e.,

$$\tau^{ss} = g + \frac{i^{ss}(b^p)^{ss}}{\Pi^{ss}} - or^{ss} - \left(\frac{\pi^{ss}}{1+\pi^{ss}}\right)h^{ss}, \tag{13}$$

where $or^{ss} = \left(\frac{eP^0}{P}\right)^{ss}y_o$, and h^{ss} represents the real value of high powered money, $\frac{H_t}{P_t}$, and $\left(\frac{\pi^{ss}}{1+\pi^{ss}}h^{ss}\right)$ represents the level of seigniorage revenue all in the steady state.

In what follows we restrict our attention to cases where the steady state rates of expected and actual inflation are equal and constant. In such states the nominal supply of high powered money and the price level will be growing at the same constant rate and

under flexible exchange rates, the exchange rate will be adjusting proportionally. With the money supply multiplier set equal to one so that $M_t = H_t$, it follows from (4) and (5) that the real stock of money is

$$m^{ss} = \left(\frac{H}{P}\right)^{ss} = c\theta(\frac{1+i^{ss}}{i^{ss}}) \quad . \tag{14}$$

This implies that the steady state level of real balances will vary inversely with the expected rate of inflation (since c, θ, and ρ are constant across steady state rates of inflation). Then to the extent that transitory changes in oil revenues produce budget surpluses and deficits that are at least partially monetized, transitory changes in the money supply will produce transitory changes in the actual rate of inflation about its steady state level.

Finally, the steady state real exchange rate is determined by the market clearing condition in the foreign exchange market when oil revenues are or^{ss} and other variables take their steady state values. Transitory changes oil revenues will then generate offsetting transitory changes in the exchange rate if the central bank does not intervene in the foreign exchange market. To the extent that the central bank does intervene, there will be concomitant changes in the money supply.

2.3   Policy considerations

Even though the transversality and the no ponzi game condition require the government to repay all new borrowings from the public over the long run, it remains possible, and possibly desirable, for the government to issue new government debt in the short run to smooth spending and/or taxes intertemporally (á la Barro). Thus if monetary

policy is set independently to stabilize prices each period, either the private holding of government debt or lump-sum taxes must respond to altered current circumstances. Alternatively, should fiscal tax plans be set independent of current budget outcomes (for example, if taxes were unalterable and additional private holdings of government debt not feasible), then changes in money would be needed to offset external changes in the government's budget. Implicitly, an inflation tax is needed to finance desired expenditures. Hence for the model to be uniquely determinate (in Leeper's sense), one policy must accommodate the other. Only then can one of the policies be truly independent of current conditions.

We close the model by specifying the two policy instruments used by government. Here monetary policy could be modeled by having the central bank set either the interest rate or the quantity of high powered money; while fiscal policy requires the government to set the level of g and the intertemporal timing of taxes. Because we are interested in how external oil revenue shocks can spillover into money supply changes, we focus on high powered money as the central bank's policy instrument.

Beginning with the stock of high powered money issued by the central bank, the real value of its supply at any point in time is,

$$\frac{H_t^s}{P_t} \equiv \frac{B_t^{cb}}{P_t} + \frac{FA_t}{P_t}$$

and the real value of its change between points in time is

$$\frac{\Delta H_t^s}{P_t} = \frac{\Delta B_t^{cb}}{P_t} + \frac{\Delta FA_t}{P_t} \quad \Rightarrow \quad h_t - \frac{h_{t-1}}{\Pi_t} = b_t^{cb} - \frac{b_{t-1}^{cb}}{\Pi_t} + fa_t - \frac{fa_{t-1}}{\Pi_t}$$

where b_t^{cb} is the real value of the stock of government bonds held by the central bank at time t and fa_t is the real value of foreign assets held by the bank (essentially foreign

exchange). It follows that the real stock of high powered money can change for two reasons that might be affected by stochastic changes in natural resource revenue — the changes oil revenues produce in the government's current budget deficit and the changes they produce in the country's balance of payments position.

Somewhat more generally, the nominal supply of money will increase (decrease) whenever the central bank purchases (sells) government bonds. This can happen in our economy for three different reasons. First the central bank may purchase (and so monetize) some proportion, α, of the bond issue used to fund the current operating deficit, d_t. Second, the central bank may purchase the government bonds issued to supplement financially constrained quasi-private institutions and organizations. These are often asset transactions not included as part of the government's flow budget position. Nevertheless, whenever the central bank purchases the government bonds issued to fund these loans, the central bank both monetizes the debt while supplementing the level of liquidity in domestic financial markets. In what follows we assume that the central bank underwrites a constant real level of replacement investment, μy. Finally, the central bank may itself engage in open market operations to counter expected inflation and hence actively pursue an inflation target. To counter excess expected inflation the central bank will sell some proportion, γ, of its holdings of government debt to reduce the stock of high powered money in circulation (so increasing the stock of government debt held by the public). Putting these three points together we have

$$\frac{\Delta B_t^{cb}}{P_t} = \alpha\, d_t + \mu\, y - \gamma(\pi_t^e - \pi^{ss})\frac{b_{t-1}^p}{\Pi_t} \tag{15}$$

where $1 \geq \alpha, \mu, \gamma \geq 0$. Then substituting for d_t from (10), we find,

$$\frac{\Delta B_t^{cb}}{P_t} = \alpha \left(g + \frac{i_{t-1} b_{t-1}^p}{\Pi_t} - or_t - \tau_t \right) + \mu y - \gamma(\pi_t^e - \pi^{ss}) \frac{b_{t-1}^p}{\Pi_t},$$

$$= \alpha(g - or_t - \tau_t) + [\alpha i_{t-1} - \gamma(\pi_t^e - \pi^{ss})] \frac{b_{t-1}^p}{\Pi_{t-1}} + \mu y. \tag{16}$$

As we saw earlier, the supply of money also changes whenever the central bank intervenes in the foreign exchange market and buys or sells foreign exchange to prevent full exchange rate adjustment. Then given that stochastic changes in oil revenue generate excess supplies and demands for foreign exchange at current market rates, the money supply changes to the extent that the central bank intervenes to prevent full exchange rate adjustment (Kouri and Porter 1986, Kamas 1986, and Kim 1995). Hence, assuming that some such intervention takes place,

$$\frac{\Delta FA_t}{P_t} = \psi(or_t - or^{ss}), \tag{17}$$

where $1 \geq \psi \geq 0$ is the portion of the balance of payments shock that is monetized, equaling zero if the central bank doesn't intervene in the foreign exchange market.

Combining these reasons, the change in the stock of money [from (14)] becomes

$$\frac{\Delta H_t^s}{P_t} = \alpha(g - \tau_t) + [\alpha i_{t-1} - \gamma(\pi_t^e - \pi^{ss})] \frac{b_{t-1}^p}{\Pi_t} - \alpha or_t + \mu y + \psi(or_t - or^{ss})$$

$$= [\alpha(g - \tau_t) + \mu y] + [\alpha i_{t-1} - \gamma(\pi_t^e - \pi^{ss})] \frac{b_{t-1}^p}{\Pi_t} + (\psi - \alpha) or_t - \psi or^{ss}. \tag{18}$$

The assumptions made to describe the change in high powered money also imply changes in the real values of both the total stock of government bonds and the proportion held by the public. Moreover, in addition to the influences just discussed, the government's fiscal strategy may involve an active strategy of deliberately adjusting non-inflation taxes to repurchase outstanding government debt to maintain the real value of government debt. In doing so the government alters the intertemporal timing of its non-

inflation taxes. Hence if we add the possibility of active fiscal intervention, so that the government chooses to repurchase some proportion, φ, of the discrepancy between the outstanding stock of privately held government debt and its steady state level, then

$$\frac{\Delta B_t^p}{P_t} = (1-\alpha)d_t + \gamma\left(\pi_t^e - \pi^{ss}\right)\frac{b_{t-1}^p}{\Pi_t} - \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right)$$
(19)

and substituting in for d_t,

$$\frac{\Delta B_t^p}{P_{t-1}} = (1-\alpha)\left[g - \tau_t + \frac{i_{t-1}b_{t-1}^p}{\Pi_t} - or_t\right] + \gamma\left(\pi_t^e - \pi^{ss}\right)\frac{b_{t-1}^p}{\Pi_t} - \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right)$$

$$= (1-\alpha)[g - \tau_t - or_t] + \left[(1-\alpha)i_{t-1} + \gamma\left(\pi_t^e - \pi^{ss}\right)\right]\frac{b_{t-1}^p}{\Pi_t} - \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right)$$
(20)

Finally, fiscal choices are often constrained by political and technical considerations that result in expenditure commitments and non-inflation taxes being fixed in the short run. We represent this as,

$$\tau_t = \tau^{ss} + \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi^{ss}}\right)$$

$$= g + \frac{i^{ss}(b^p)^{ss}}{\Pi^{ss}} - or^{ss} - \left(\frac{\pi^{ss}}{1+\pi^{ss}}\right)h^{ss} + \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right).$$
(21)

Implicitly non-inflation tax levels are set to cover the steady state expenditures that cannot be financed by steady state oil revenues and (expected) inflation taxes and are assumed to have limited ability to respond to current deficits. That is, non-inflation taxes cannot respond to the current state of the budget and thus the problems created this period by stochastic oil revenues. Rather it can respond only with a lag to the consequences these stochastic changes have on the outstanding stock of government bonds held by the public.

Finally, by substituting the tax policy in (21) back into (20) we can solve for the change in the stock of government debt held privately as

$$\frac{\Delta B_t^p}{P_t} = (1-\alpha)\left(\frac{i_{t-1}b_{t-1}^p - i^{ss}(b^p)^{ss}}{\Pi_t} - \left(or_t - or^{ss}\right) + \frac{\pi^{ss}}{\Pi^{ss}}h^{ss}\right) + \gamma(\pi_t^e - \pi^{ss})\frac{b_{t-1}^p}{\Pi_t} - (2-\alpha)\varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right) \quad (22)$$

It follows from (22) that $\frac{\Delta B_{t-1}^p}{P_t} = (1-\alpha)\left(\frac{\pi^{ss}}{\Pi^{ss}}\right)h^{ss}$ if all endogenous values

converge on their steady states, and since $\frac{\Delta B_{t-1}^p}{P_t} = b_t^p - b_{t-1}^p + \left(\frac{\pi_t}{\Pi_t}\right)b_t^p$, then in the steady

state, $\frac{\Delta(B^p)^{ss}}{P} = \left(\frac{\pi^{ss}}{\Pi^{ss}}\right)(b^p)^{ss}$. This in turn implies that $(b^p)^{ss} = (1-\alpha)h^{ss}$.

Similarly, we can substitute (21) back into (18) to find the change in the stock of

(high-powered) money as,

$$\frac{\Delta H_t^s}{P_t} = \mu y + \alpha\left[-\frac{i^{ss}(b^p)^{ss}}{\Pi^{ss}} + or^{ss} + \left(\frac{\pi^{ss}}{\Pi^{ss}}\right)h^{ss} - \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right)\right] + \left[\alpha i_{t-1} - \gamma(\pi_t^e - \pi^{ss})\right]\frac{b_{t-1}^p}{\Pi_t}$$
$$+ (\psi - \alpha)or_t - \psi\, or^{ss} \quad (23)$$
$$= \mu y + \alpha\left(\frac{\pi^{ss}}{\Pi^{ss}}\right)h^{ss} + \alpha\left[\frac{i_{t-1}b_{t-1}^p - i^{ss}(b^p)^{ss}}{\Pi^{ss}} - \varphi\left(\frac{b_{t-1}^p - (b^p)^{ss}}{\Pi_t}\right)\right] + (\psi - \alpha)\left(or_t - or^{ss}\right) - \gamma(\pi_t^e - \pi^{ss})\frac{b_{t-1}^p}{\Pi_t}$$

Here we see that even if all variables converge to their steady state values, the change in

the money supply will not equal zero. Rather, $\frac{\Delta H}{P_t} = \mu y + \left(\frac{\alpha\pi^{ss}}{\Pi^{ss}}\right)h^{ss} > 0$, so that (using

footnote 1) we can solve for the steady state value as $h^{ss} = \frac{\mu y \Pi^{ss}}{(1-\alpha)\pi^{ss}}$.[2] Hence in this

economy, the steady state will be characterized by a constant steady state rate of inflation

tied to the government's use of money creation to fund a portion of state (or quasi-

private) investment and its role as a tax source in the budget. To the extent that income

growth was present in the model, say due to a positive rate of technical change, the

inflation rate would be proportionately lower.

The more general point is that neither the use of the inflation tax nor the

monetization of government lending in support of efforts to speed development by

underwriting private finance need necessarily cause instability. Rather, a higher inflation tax and/or a higher subsidy rate will result in a higher steady state rate of inflation but this need not imply accommodization by the central bank nor an accelerating rate of inflation.

3. Linearization about the steady state

After linearizing our four equation model (equations (4), (5), (22) and (23)) about its steady state, the motion of the system can be reduced to the following two equations:

$$\hat{\pi}^e_{t+1} = \left(\frac{c\theta(1-\alpha) - \mu y [\Pi^{ss}(\alpha-\gamma)(1-\alpha) - 1 - \alpha(1-\alpha)i^{ss}]}{c\theta(1-\alpha)} \right)\left(\frac{1}{\Pi^{ss}} \right)\hat{\pi}_t$$
$$- \left(\frac{\mu y \alpha(i^{ss} - \varphi)}{c\theta\pi^{ss}} \right)\hat{b}^p_{t-1} + (\alpha - \psi)\left(\frac{or^{ss}}{c\theta} \right)o\hat{r}_t.$$

(24)

$$\hat{b}^p_t = \left(\frac{1 + (1-\alpha)i^{ss} - (2-\alpha)\varphi}{\Pi^{ss}} \right)\hat{b}^p_{t-1} + \left(\frac{(1-\alpha+\gamma)\Pi^{ss} - [1 + (1-\alpha)i^{ss}]}{\Pi^{ss}} \right)\left(\frac{\pi^{ss}}{\Pi^{ss}} \right)\hat{\pi}_t$$
$$- \left(\frac{(1-\alpha)\pi^{ss}or^{ss}}{\Pi^{ss}\mu y} \right)o\hat{r}_t.$$

(25)

Note that the effect of a positive oil shock on expected future inflation [in (24)] is ambiguous at impact, depending on the size of the parameter governing monetization through the government budget constraint, α, relative to the size of the parameter describing the central bank's unwillingness to let the exchange rate fully adjust to changes in the balance of payments position, ψ. On the other hand, the impact effect of an oil shock on the outstanding stock of government debt (held by the public) [in (25)] is straightforward--a positive oil shock is used to reduce the outstanding stock of privately held government debt.

To examine the full general equilibrium consequences of oil shocks we follow Ireland (2004) and set up our system as a DSGE model and apply the Blanchard-Kahn (1980) method. In our case, this rewrites the above equations in state space form as:

$$\begin{bmatrix} \hat{b}_t^p \\ \hat{or}_{t+1} \end{bmatrix} = \begin{bmatrix} S_3 & S_4 \\ 0 & \rho_o \end{bmatrix} \begin{bmatrix} \hat{b}_{t-1}^p \\ \hat{or}_t \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} \varepsilon_{t+1} \tag{26}$$

in combination with the observation equation:

$$[\hat{\pi}_t] = [S_1 \quad S_2] \begin{bmatrix} \hat{b}_{t-1}^p \\ \hat{or}_t \end{bmatrix}. \tag{27}$$

The S_i parameters in (26) and (27) represent combinations of the deep parameters of the model.[3] The state and observation equations are then used in conjunction with the set of calibrated parameter values presented below to investigate the impulse response of inflation to oil shocks across different policy periods in Iran's recent history. Looking across these divergent historical periods, we seek to explain the different ways that oil shocks have impacted domestic money prices and inflation rates.

4. Calibrating the model

In this section we describe how the magnitudes of the various structural and policy parameters of the model were determined using data from post-revolutionary Iran, our example of a resource intensive emerging economy. In undertaking this calibration, we have found that there are three distinct policy periods: first, the period immediately following the Iranian revolution and lasting through the war with Iraq (from 1979-1988); second, the period following the Iraqi War and before the government sanctioned the

issuance of government debt (1989-1993); and finally the most recent time period (from 1994-2006) where the government's ability to issue new government bonds (to the outside public) allowed the nonmonetary financing of government deficits.[4] These differences across periods suggest to us that policy response to government budget and balances of payments deficits and surpluses have been somewhat asymmetric.[5] Whatever the reason, by adapting the model to these distinct periods, we can allow the model to illustrate the distinct effects that different active and passive government policy responses to the problems created by stochastic oil revenues have had on inflation.

With this background, we began by using the data from the entire 1979-2006 time interval (to maximize our degrees of freedom) to model the oil shocks impacting the economy. The AR(1) oil revenue process was then derived by first deflating oil values by the CPI to find real oil revenues and then detrending the logarithmic value of real oil revenues by regressing it on a constant and time. The residual from this regression became the stochastic deviation of real oil revenues from their long run value. By estimating an AR(1) process on these residuals we found the values for ρ_o and σ_o presented in Table 1. Implicitly we are assuming that the outside stochastic process underlying oil revenues stayed constant for our entire period (unlike the changes in policy regime).

Then to calibrate the portion of the natural resource shock that is monetized through intervention in the foreign exchange market, ψ, we first took the residual of the AR(1) process for the stochastic part of real oil revenues for the entire 1979-2006 period. Then we calculated the ratio of the net change in the foreign assets held by the central bank to those residuals. In the early parts of our time period, the values of ψ were close to

zero while in the latter stages, the ratio sometimes exceeded one. Since our ratio is bounded by one and zero, the upper bound was adopted when the ratio exceeded one. With these adjustments, the value used in each period was the period average. The large value of this parameter in the later period reflects the inability of the central bank to sterilize the huge flow of oil revenues that arose more recent time periods.

To calibrate α, the parameter describing the proportion of the deficit that is monetized, we faced the problem of not having independent data on the size of the government deficit. Hence to approximate its size, we added to the government's net borrowing from the central bank a set of other government off-budget revenue sources not accounted for directly in the government's flow deficit (for example, the net receipt of interest on foreign loans, the sale of government assets, etc.). To do this we then added net government borrowing from the outside public. This last term was relevant only for the 1994 to 2006 time period--before 1994 outside government borrowing was not used. This proxy for the size of the government deficit was then divided into the government's net borrowing from the central bank to derive a value of α for each year. Its average value in each of our three periods was the calibrated value of α used for that time period.[6]

For the role played by the central bank in supplementing financial intermediation, the parameter μ was calculated as the change in net public corporation and agency debt to the central bank as a ratio of GDP. Its average value in each of the three periods was the value of μ used for that time period. In Iran, the inability of the central bank to sell either its own bonds or Iranian government bonds prior to 1994 means that γ will have equaled zero. In the period following 1994, and particularly between 2000 and 2006, the central

bank does appear to have issued its own debt, so re-absorbing high powered money. The value of gamma used in the latest time period then reflects the average value of the ratio of new central bank debt to GDP in this period.

As P´erez and Hiebert (2004) among others have shown, some parameters in the fiscal rule will be determined by the requirement that the stability condition for the Blanchard Kahn method can be satisfied. In our case, the policy parameter φ is not always observed (separately) and needs to be set so that the model can converge to its steady state. Hence the imposing of stability on the analysis generates a domain of values for consistent with that requirement. Recognizing that government bonds were not used before 1994, the coefficient value for government bond repurchases to keep stable the size of the national debt, φ, was zero for the first two periods and then chosen to be relatively small at 0.05 for the third.

Lastly we assigned to β the value of 0.99 and to θ, the weight given to (the log of) real money holdings relative to consumption in the utility function, the value 0.04. The former is traditional for the literature and corresponds to a steady state (annual) real interest rate of about 4%, while the latter was chosen primarily to avoid the problem of sunspots.[7] The full set of calibrated values are summarized in Table 1 below.

Insert Table 1 about here

Finally, the values used for steady state per capita real GDP, per capita consumption, inflation, the interest rate and real oil revenues relative to GDP were calculated as the average value of these variables in each of the specified periods. Table 2 reports these values.

Insert Table 2 about here
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5.   Simulation Results

Using these values in the DGSE model of equations (25) and (26), we show in Figure 1 below the impulse responses of inflation to a positive one standard deviation oil shock that are implied for each of our three time periods. Given these calibrated values, the results show a remarkable difference in policy response across the three periods. In all three periods there is an expansionary effect on the money supply and thus inflation following a positive oil shock. This has arisen in the first and third periods from the central bank's unwillingness to let the exchange rate float and an inability to sterilize foreign oil revenues under a positive oil shock. In the middle period, the same type of inflationary response has arisen rather from the monetization of budget deficits following a series of negative oil shocks.

Insert Figure 1 about here

The more important point, however, is that implicitly or explicitly the economic policies adopted in the most recent time period have made the inflation rate in the Iranian economy increasingly susceptible to oil price shocks. While the economy has not become any less quick in its adjustment to oil shocks, reflected in the almost proportional adjustment of inflation in the post 2000 time period, the impact effect itself is now considerably stronger than in any of the earlier time periods. In our simulations, the response is between three and five times larger than it was over the $1979 - 1993$ time period. Explained in terms of our model, this dramatic response reflects a changed approach to exchange rate policy (a rapid rise in the parameter φ) that now exhibits much greater resistance to exchange rate movements. This resistance, together with cumulative impact of much larger sized positive oil shocks in this period, has had a significant effect

on the size of the balance of payments effects that have arisen in recent periods. Together they have made the Iranian economy not only more susceptible to higher rates of inflation but more prone to extended variations in its level.

6.   Conclusion

In this paper we have developed a simple DSGE model to illustrate how those economies that face restrictions in their ability to alter government spending and taxation in the short run and cannot borrow easily (perhaps because of incompletely developed internal capital markets) can find external fluctuations in resource revenues producing unexpected variations in their internal money supply and ultimately in their inflation rate. The main channels for these effects run through the government budget constraint and through the country's balance of payments position (should the country choose to suppress exchange rate movements).

While these general circumstances are likely to be relevant to a large number of countries, we have chosen to apply our structure to the Iranian economy over the 1979 - 2006 time period. To do so we calibrated the model for three somewhat separate policy regimes in Iran's recent past. After doing so we were able to illustrate how the different policy choices made (as embodied in the different calibrated values of our analysis) have produced quite different inflationary responses to external oil shocks. Perhaps most dramatically, our calibrated values in the third period imply that the central bank's inability to sterilize foreign oil revenues more than compensates for the contractionary effects that would arise from budget surpluses being used to pay-off government debt with the central bank. In turn this implies a significant increase in the impulse that oil

shocks have given to Iranian inflation. It is this dramatic change in the central bank's

ability to sterilize accumulated foreign dollars from oil price increases together with the

dramatic recent rise in oil prices that has resulted in the large inflationary effect that is the

striking feature of our final period.

Figure 1

The response of inflation to a one standard error oil shock in the three periods
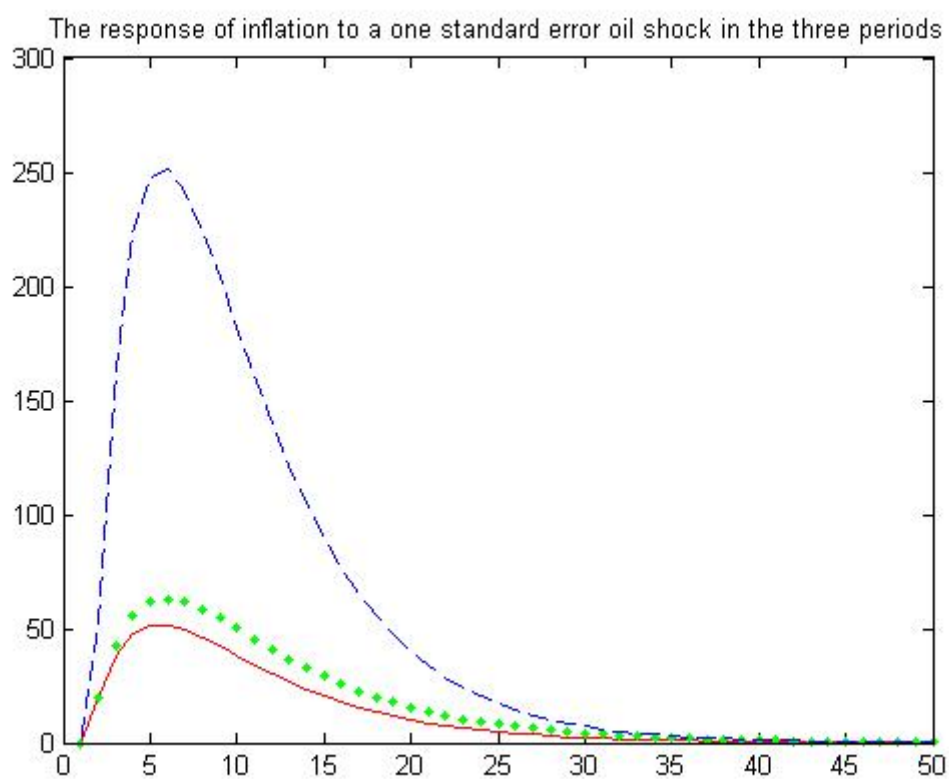
The solid impulse response line applies to 1979-1988

The dotted impulse response function applies to 1989-1993

The dashed response curve represents 1994-2006

Table1

Calibrated values for the parameters of the model

Parameters	1979-1988	1989-1993	1994-2006
β	0.99	0.99	0.99
θ	.04	.04	.04
ρ_o	0.71	0.71	0.71
σ_o	0.4	0.4	0.4
α	0.74	0.52	0.34
μ	0.013	0.01	0.004
Γ	0	0	0.074
Φ	0	0	0.05
Ψ	0.12	0.01	0.48

Table 2
Steady State Values

Variables	1979-1988	1989-1993	1994-2006
$y(ss)$	4.4	4.2	5.22
$c(ss)$	3.3	2.8	3.4
$\pi(ss)$	0.1718	0.1712	0.1785
or(ss)	0.109	0.091	0.137
i(ss)	0.082	0.082	0.115

Endnotes

1. Note that since $\frac{\Delta H_t^s}{P_t} = h_t - h_{t-1} + \left(\frac{\pi_t}{1+\pi_t}\right)h_t$, it follows that, $\left(\frac{\Delta H}{P}\right)^{ss} = \left(\frac{\pi^{ss}}{1+\pi_{ss}}\right)h^{ss}$ which in turn would equal zero if $\pi^{ss} = 0$.

2. This implies that $(b^p)^{ss} = \frac{\mu y \Pi^{ss}}{\pi^{ss}}$.

3. A set of detailed notes outlining the specifics of the derivations is available upon request.

4. In the first year, these bonds were issued to finance some of the investment projects undertaken by government associations.

5. One interpretation of the asymmetry in policy across this period lies in the political incentives faced by government. That is, when a negative oil shock generates a short run budget deficit requiring borrowing (for a government with little short run tax flexibility), the government may find it considerably easier politically to borrow from the central bank than from the outside public. On the other hand, when the shock is positive, the resulting budget surplus is more likely to be seen as an opportunity to pay off external public borrowing. Hence a negative oil shock is more likely to be associated with a rise in the money supply through the government budget constraint than is the corresponding positive shock likely to be associated with a decline. Inversely, the delayed effect of money supply increases on prices (and the positive stimulus this provides to output) makes the government more likely to resist the fall in the exchange rate following a positive oil shock. The contractionary pressures associated with a negative shock make the government more likely to acquiesce in the rise in the exchange rate.

6. From equation (24) it apparent that increasing the size of theta will decrease the size of all coefficients. This leads to both eigenvalues falling below one so generating the sunspot issue.

7. The calibrated values reflect the policy asymmetry mentioned above. That is, the positive oil shocks in years 2000/1 and 2004/6 did not result in an overall demonetization from the implied government budget surplus.

References

Blanchard, O.J. and Kahn, C.M, 1980, "The solution of linear difference equations under rational expectations", *Econometrica* 48 (5), 1305-11.

Ireland, P., 2004, "A Method for taking models to the Data", *Journal of Economic Dynamics and Control* 28, 1205-1226.

Kamas, L., 1986, "The Balance of Payments Offset to Monetary Policy: Monetarist, Portfolio Balance, and Keynesian Estimates for Mexico and Venezuela", *Journal of Money Credit and Banking*, 18 (4), 467-481.

Kim, G., 1995, exchange Rate Constraints and Money Control in Korea", *Federal Reserve Bank of St. Louis Working Paper Series*, 1995-011A, http://research.stlouisfed.org/wp/1995/95-011.pdf.

Kouri, J.K. and M.G. Porter, 1974, "International Capital Flows and Portfolio Equilibrium", *Journal of Political Economy*, 82 (3), 443-467.

Leeper, E. M., 1991, Equilibria under 'active' and 'passive' monetary and fiscal policy, *Journal of Monetary Economics*, 27, 129-147.

Levine, R., 1997, "Financial development and economic growth: Views and agenda." *Journal of Economic Literature*, 35, 688-726.

Obstfeld, M., 1982, "Can we Sterilize? Theory and Evidence", *American Economic Review,* 72 (2), 45-50.

Pasula, K., 1994, "Sterilization, Ricardian Equivalence and Structural and Reduced-Form Estimates of the Offset Coefficient", *Journal of Macroeconomics*, 16 (4), 683-99.

P´erez , J. & Hiebert , B. (2004). "Identifying endogenous fiscal policy rules for macroeconomic models". *Journal of Policy Modeling* 26, (2004) 1073–1089.