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Oil Price Shocks: Can They Account for the Stagflation in the 1970s?

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Oil Price Shocks: Can They Account for the Stagflation in the 1970s?

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Abstract

Using a variant of the IMF's Global Economy Model (GEM), featuring energy as both an intermediate input into production and a final consumption good, this paper examines the macroeconomic implications of large increases in the price of energy. Within a fully optimizing framework with nominal and real rigidities arising from costly adjustment, large increases in energy prices can generate an inflation response similar to that seen in the 1970s if the monetary authority misperceives the economy's supply capacity and workers resist the erosion in their real consumption wages resulting from the price increase. In the absence of either of these two responses, the model suggests that energy price shocks cannot generate the type of stagflation witnessed in the 1970s. Further, even allowing for these two effects, the results do not suggest that the increase in the price of oil in late 1973 and early 1974 can fully explain the extent of the slowing in real activity or the magnitude of the acceleration in inflation experienced in the United States in 1974 and 1975.

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I. INTRODUCTION

In the early1970s, a sharp spike in the world price of oil was followed by a period of significant economic dislocation in many industrial countries. There were dramatic slowdowns in real activity and accelerations in inflation. Although there were several other factors—such as prior overheating in many economies, accelerations in other commodity prices and a significant slowing in productivity growth—that certainly contributed to these developments, the large increase in the price of oil was certainly a major contributing factor. The subsequent taming of inflation in the early 1980s required a significant tightening in monetary policy and sharp and severe recessions in many industrial countries. Whenever oil prices rise sharply, memories of the experience with inflation in the 1970s and the significant economic costs that were incurred in the early 1980s to tame the high inflation inevitably generate worries of a repeat performance. This paper uses a version of the International Monetary Fund's new Global Economic Model (GEM) to consider when such worries may be justified.

The version of GEM that is used for the analysis incorporates four types of goods, a traded primary input, hereafter referred to as energy, a traded intermediate good, a nontraded intermediate good, and a nontraded final good. The traded energy input is used along with capital and labor in the production of both the traded and nontraded intermediate goods. The traded energy good is also a direct component of the final nontraded good. Through its use in the production of intermediate goods, shocks to the price of energy affect the supply capacity and output prices in the traded and nontraded intermediate goods sectors. Because the traded energy good is consumed directly in the final nontraded good, energy price shocks quickly affect household welfare through their impact on the consumer price level and thus households' real consumption wages. A two-country representation with this structure is calibrated to represent the United States as the Home country and the rest of the world as the Foreign country. This two-country setup is then used to consider how much of the macroeconomic developments in the United States in the 1970s can be explained by the sharp increase in oil prices and alternative responses of the monetary authority and labor suppliers.

The analysis suggests that if the monetary authority underestimates the negative impact of the shock on the economy's supply capacity and labor suppliers attempt to resist declines in their real wages, energy price increases can result in significant disruptions to real activity and persistent inflation. An important point that the analysis brings out is the possible interaction between workers’ response to the decline in their real wages and the extent to which the policymaker overestimates the level of the economy's potential output. If, as is generally believed, policymakers viewed the evolution of potential output as a deterministic process, the more aggressive the resistance on the part of workers to the declines in their real wages, the larger would have been the gap between the economy's true level of potential output and the policymakers' estimate. The policymaker’s larger estimate of excess supply would have led to easier policy settings that would have generated additional demand-side pressures. This, in turn, would have provided an environment that both facilitated and fueled labor suppliers’ wage demands. However, even allowing for these two possible responses, the simulation results do not suggest that the oil price shock alone can account for the extent of the slowing in real activity and the acceleration in inflation that occurred in the United States in 1974 and 1975.

The remainder of the paper is structured as follows. A brief overview of GEM is presented in Section II. The extensions to the model and the structure critical for understanding the role of energy are presented in Section III. Section IV presents the calibration, solution, and properties of the model. The model's response to an energy price shock of roughly the same magnitude as the first oil shock in the 1970s is contained in Section V. This section also considers the implications of alternative responses of the monetary authority and wage bargainers to the large increase in energy prices. Section VI offers some conclusions.

II. AN OVERVIEW OF GEM WITH ENERGY

The version of GEM used in this paper is an extended version of the structure presented in detail in Laxton and Pesenti (2003), and Hunt and Rebucci (2005). For the sake of brevity, only an overview of the complete model is presented below. It is worth noting that although in this paper the primary input is considered to be energy, specifically oil and natural gas, this structure can be used for a broader classification of commodities that share similar supply and demand characteristics. The model user, through the calibration/estimation process, can choose either a very broad classification or a very narrow classification, depending on the question at hand.

In the version of GEM used here, the world economy consists of two countries, Home (identified with the US in this application) and Foreign (identified with the rest of the world). Foreign variables are indexed with a star. In each country there are households, firms, and a government.

Each household is infinitely lived, consumes the nontradable final goods, and is the monopolistic supplier of a differentiated labor input to all domestic firms. Households exhibit habit persistence in their consumption behavior (real rigidities). Wage contracts are subject to adjustment costs (nominal wage rigidities).

Households owns all domestic firms and the domestic capital stock, which they rent to domestic firms. The market for capital is competitive, but capital accumulation is subject to adjustment costs (real rigidities). Labor and capital are immobile internationally. Households trade short-term nominal bonds, denominated in Foreign currency, and issued in zero net supply worldwide. There are intermediation costs for Home households entering the international bond market. No other asset is traded internationally.

Firms produce a continuum of nontradable final goods, a continuum of differentiated nontradable intermediate goods, a continuum of differentiated tradable intermediate goods, a continuum of tradable primary inputs (in this application energy consisting of oil and natural gas) and provide distribution and financial intermediation services.

The final good is produced by perfectly competitive firms that use the following intermediate goods as inputs: nontradable goods; domestic tradable and/or imported tradable; and domestic and/or imported energy. The final good can be consumed by domestic households or the government, or used for investment.

Intermediate goods and energy are produced by firms under conditions of monopolistic competition. Firms in the intermediate goods sectors combine capital, labor and the energy input under CES technology. Prices of intermediate goods are subject to adjustment costs (nominal price rigidities). Firms in the energy sector combine capital, labor and a fixed factor, land, under CES technology to produce the energy input. Each nontradable intermediate good is either used directly in the production of the nontradable final good or used indirectly in the distribution sector to make tradable intermediate goods available to firms producing the final good and to make the energy input available to firms producing the intermediate goods and the final good. Each tradable intermediate good is used either in the production of the domestic nontradable final good or in the production of the foreign nontradable final good.

Firms in the distribution sector operate under perfect competition. They purchase tradable intermediate goods and energy worldwide (at the producer price), and distribute them to firms producing the final good (at the consumer price). They also distribute energy goods to the intermediate goods producers. Local nontradables are the only input in the provision of distribution services.

Government spending falls exclusively on the final nontradable good. Government spending is financed through tax and seigniorage revenues. The government controls the national short-term nominal interest rate. Monetary policy is specified in terms of interest rate rules.

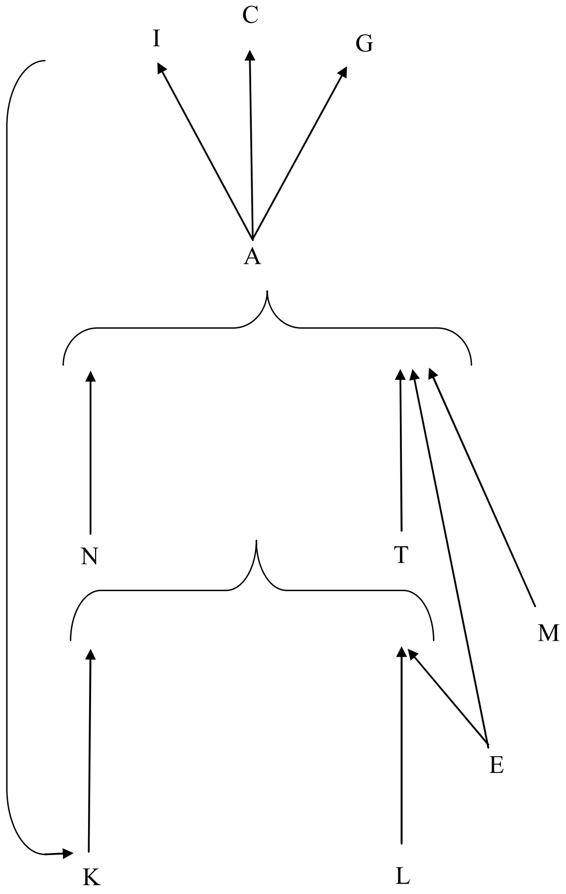
Figure1 contains a simplified representation of the model's structure that illustrates how energy enters into the production process and into the final consumption basket in a single country.

III. ENERGY IN GEM

This section details the extensions to GEM and the structure critical for understanding the role of energy. The focus is on demand, prices and production. The remaining model structure not presented below is contained in Appendix I.

The major extensions to GEM for this application include the introduction of energy directly into the production of the final nontradable good, and the introduction of monopolistic competition and distribution in the energy sector. In each country there is a continuum of symmetric firms producing a nontradable final good under perfect competition. Home firms producing the good are indexed by $x \in [0, s]$, where $0 < s < 1$ is a measure of country size. World size is normalized to 1, and Foreign firms producing the Foreign final good are indexed by $x^* \in (s, 1]$.

Figure 1. Simplified GEM Structure



I - Investment
C - Private Consumption
G - Government Consumption
A - Final Nontradable Good
N - Intermediate Nontraded Good
T - Intermediate Tradable Good
M - Imported Intermediate Tradable Good
E - Energy: Domestically Produced and Imported
K - Capital
L - Labor

A. Demand for Energy in Final Good

The integral of the Home final goods producing firms output at time (quarter) t is denoted A_t and can be thought of as capturing Home preferences over the range of goods available for consumption.[2] The final good is produced with the following CES technology:

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[2] The convention throughout the model is that variables which are not explicitly indexed (to firms or households) are expressed in per-capita (average) terms. For instance, $A_t = (1/s)_o^s A_t(x)\, d_x$

$$
\begin{aligned}
A_t = \Bigg\{ & (1-\gamma)^{\frac{1}{\varepsilon}} N_{N,t}^{1-\frac{1}{\varepsilon}} + \gamma^{\frac{1}{\varepsilon}} \Bigg[(1-\gamma_{OA})^{\frac{1}{\varepsilon_{OA}}} \left(\nu^{\frac{1}{\varepsilon_{QM}}} Q_t^{1-\frac{1}{\varepsilon_{QM}}} + (1-\nu)^{\frac{1}{\varepsilon_{QM}}} \left[M_t \left(1-\Gamma_{M,t}\right)\right]^{1-\frac{1}{\varepsilon_{QM}}} \right)^{\left(\frac{\varepsilon_{QM}}{\varepsilon_{QM}-1}\right)\left(1-\frac{1}{\varepsilon_{OA}}\right)} \\
& + \gamma_{OA}^{\frac{1}{\varepsilon_{OA}}} \left(\nu_O^{\frac{1}{\varepsilon_{QMOA}}} Q_{OA,t}^{1-\frac{1}{\varepsilon_{QMOA}}} + (1-\nu_O)^{\frac{1}{\varepsilon_{QMOA}}} M_{OA,t}^{1-\frac{1}{\varepsilon_{QMOA}}} \right)^{\left(\frac{\varepsilon_{QMOA}}{\varepsilon_{QMOA}-1}\right)\left(1-\frac{1}{\varepsilon_{OA}}\right)} \Bigg]^{\left(\frac{\varepsilon_{OA}}{\varepsilon_{OA}-1}\right)\left(1-\frac{1}{\varepsilon}\right)} \Bigg\}^{\left(\frac{\varepsilon}{\varepsilon-1}\right)}
\end{aligned}
\tag{1}
$$

Three intermediate goods and two energy goods are used in the production of the final good A: a basket N_N of domestically-produced nontradables, a basket Q of domestically-produced intermediate tradable goods, a basket M of imported intermediate tradable goods, a basket Q_{OA} of domestically-produced energy goods and a basket M_{OA} of foreign-produced energy goods. The elasticity of substitution between tradable and nontradable goods is $\varepsilon > 0$. The elasticity of substitution between the tradable intermediate good and the tradable energy good is $\varepsilon_{OA} > 0$. The elasticity of substitution between the domestic and foreign tradable intermediate good is $\varepsilon_{QM} > 0$ and $\varepsilon_{QMOA} > 0$ is the elasticity of substitution between the domestic and foreign energy good. The parameters γ and $\gamma_{OA} \in (0,1)$ are the weights on tradable goods and energy respectively in the production of the final good. The parameters v and $v_O \in (0,1)$ are the weights on the domestically-produced tradable intermediate good and energy in the final good. These parameters are measures of home bias in consumption. Imports of intermediate goods are subject to adjustment cost $\Gamma_{M,t}$.

Taking prices as given, cost minimization in Home final good production yields the demands for tradable goods and energy as follows:

$$
Q_t^D = \gamma(1-\gamma OA)^v \left(\frac{P_{Q,t}}{P_t}\right)^{-\varepsilon_{QM}} \left(\frac{P_{X,t}}{P_t}\right)^{\varepsilon_{QM}-\varepsilon_{OA}} \left(\frac{P_{T,t}}{P_t}\right)^{\varepsilon_{OA}-\varepsilon} A_t \tag{2}
$$

$$M_t^D = \gamma\left(1-\gamma_{OA}\right)\left(1-v\right)\left(\frac{P_{M,t}}{P_t}\right)^{-\varepsilon_{QM}}\left(\frac{P_{X,t}}{P_t}\right)^{\varepsilon_{QM}-\varepsilon_{OA}}\left(\frac{P_{T,t}}{P_t}\right)^{\varepsilon_{OA}-\varepsilon} A_t$$

$$*\frac{\left[1-\Gamma_{M,t}-\phi_M\left(\frac{M_t}{A_t}\Big/\frac{M_{t-1}}{A_{t-1}}-1\right)\left(\frac{M_t}{A_t}\Big/\frac{M_{t-1}}{A_{t-1}}\right)\right]^{\varepsilon_{QM}}}{1-\Gamma_{M,t}} \tag{3}$$

$$Q_{OA,t}^D = \gamma\gamma OA^{v_O}\left(\frac{P_{QOA,t}}{P_t}\right)^{-\varepsilon_{QMOA}}\left(\frac{P_{OA,t}}{P_t}\right)^{\varepsilon_{QMOA}-\varepsilon_{OA}}\left(\frac{P_{T,t}}{P_t}\right)^{\varepsilon_{OA}-\varepsilon} A_t\text{, and} \tag{4}$$

$$M_{OA,t}^D = \gamma\gamma OA\left(1-v_O\right)\left(\frac{P_{MOA,t}}{P_t}\right)^{-\varepsilon_{QMOA}}\left(\frac{P_{OA,t}}{P_t}\right)^{\varepsilon_{QMOA}-\varepsilon_{OA}}\left(\frac{P_{T,t}}{P_t}\right)^{\varepsilon_{OA}-\varepsilon} A_t \tag{5}$$

Relative prices faced by the final goods firms are given by:

$$\frac{P_{OA,t}}{P_t} = \left(v_O\left(\frac{P_{QOA,t}}{P_t}\right)^{1-\varepsilon_{QMOA}} + \left(1-v_O\right)\left(\frac{P_{MOA,t}}{P_t}\right)^{1-\varepsilon_{QMOA}}\right)^{\frac{1}{1-\varepsilon_{QMOA}}}, \tag{6}$$

$$\frac{P_{QOA,t}}{P_t} = \left(\frac{\bar{P}_{QOA,t}}{P_t} + \eta_{OA}\frac{P_{N,t}}{P_t}\right)\left(1+tax_{OA}\right), \tag{7}$$

$$\frac{P_{MOA,t}}{P_t} = \left(\frac{\bar{P}_{MOA,t}}{P_t} + \eta_{OA}\frac{P_{N,t}}{P_t}\right)\left(1+tax_{OA}\right)\text{, and} \tag{8}$$

$$\frac{P_{T,t}}{P_t} = \left(\left(1-\gamma_{OA}\right)\left(\frac{P_{X,t}}{P_t}\right)^{1-\varepsilon_{OA}} + \gamma_{OA}\left(\frac{P_{OA,t}}{P_t}\right)^{1-\varepsilon_{OA}}\right)^{\frac{1}{1-\varepsilon_{OA}}}, \tag{9}$$

where the relative prices of the home-produced, $P_{Q,t}$, and foreign-produced, $P_{M,t,}$ tradable intermediate goods, and the overall relative price of the tradable intermediate good, $P_{X,t}$ are as given in Laxton and Pesenti (2003) and can be found in Appendix I. Also, $\overline{P}$ denotes the wholesale or producer price, η_{OA} represents the number of units of the nontradable good required to distribute a unit of the energy good to the final goods producer, and tax_{OA} is the rate at which the government taxes the energy good used in final goods production.

There are several important features of this structure worth noting. First, because energy enters the final good directly, energy price shocks will have an immediate impact on headline inflation. However, the presence of a distribution sector in energy, based on Corsetti and Dedola (2002),[3] mutes the impact of changes in the producer price of energy on the final consumption price. In this application, these distribution services represent things like transportation and refining. The more important are these services in the final energy good, the more muted will be the impact of changes in producer prices on final energy prices. Finally, the structure allows for government to tax energy goods. The specification above implies an ad valorem tax, however, alternative formulations which lead to government tax policy muting the impact of changes in the producer price of energy can be easily implemented.

B. Demand for Energy in Intermediate Goods Production

The CES production technologies in the tradable, T, and nontradable, N, intermediate goods sectors are given by:

$$T_t = Z_{T,t}\left[\left(1-\alpha_T-\gamma_T\right)^{\frac{1}{\xi_T}} \ell_{T,t}^{1-\frac{1}{\xi_T}} + \alpha_T^{\frac{1}{\xi_T}} K_{T,t}^{1-\frac{1}{\xi_T}} + \gamma_T^{\frac{1}{\xi_T}}\left[\left(1-\Gamma_{OT,t}\right)O_{T,t}\right]^{1-\frac{1}{\xi_T}}\right]^{\frac{\xi_T}{\xi_T-1}}, \text{ and} \tag{10}$$

$$N_t = Z_{N,t}\left[\left(1-\alpha_N-\gamma_N\right)^{\frac{1}{\xi_N}} \ell_{N,t}^{1-\frac{1}{\xi_N}} + \alpha_N^{\frac{1}{\xi_N}} K_{N,t}^{1-\frac{1}{\xi_N}} + \gamma_N^{\frac{1}{\xi_N}}\left[\left(1-\Gamma_{ON,t}\right)O_{N,t}\right]^{1-\frac{1}{\xi_N}}\right]^{\frac{\xi_N}{\xi_N-1}}, \tag{11}$$

where Z denotes the level of productivity, ℓ the labor input, K the capital input, O the energy input, ξ the constant elasticity of input substitution, γ and α are the parameters that determine the shares of energy, and capital respectively and Γ_O is the cost of adjusting the energy input. Taking input prices as given, solving the intermediate goods firms' cost minimization problem yields demands for the energy input given by:

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[3] See also Burstein, Neves, and Rebelo (2000).

$$Q_{ON,t}^{D} = v_{ON}\left(\frac{P_{QO,t}}{P_{ON,t}}\right)^{-\varepsilon_{ON}} O_{N,t}\,, \tag{12}$$

$$Q_{OT,t}^{D} = v_{OT}\left(\frac{P_{QO,t}}{P_{OT,t}}\right)^{-\varepsilon_{OT}} O_{T,t}\,, \tag{13}$$

$$M_{ON,t}^{D} = \left(1 - v_{ON}\right)\left(\frac{P_{MO,t}}{P_{ON,t}}\right)^{-\varepsilon_{ON}} O_{N,t}\,, \tag{14}$$

$$M_{OT,t}^{D} = \left(1 - v_{OT}\right)\left(\frac{P_{MO,t}}{P_{OT,t}}\right)^{-\varepsilon_{OT}} O_{T,t}\,, \tag{15}$$

$$O_{N,t} = \gamma_N\left(\frac{P_{ON,t}/P_t}{Z_{N,t}MC_{N,t}/P_t}\right)^{-\xi_N}\frac{N_t}{Z_{N,t}} \\ * \frac{\left[1 - \Gamma_{OT,t} - \phi_{OT}\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}} - 1\right)\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}\right)\right]^{\xi_T}}{1 - \Gamma_{OT,t}} \text{, and} \tag{16}$$

$$O_{T,t} = \gamma_T\left(\frac{P_{\;OT,t}/P_t}{Z_{T,t}MC_{T,t}/P_t}\right)^{-\xi}\frac{T_t}{Z_{T,t}} \\ * \frac{\left[1 - \Gamma_{OT,t} - \phi_{OT}\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}} - 1\right)\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}\right)\right]^{\xi_T}}{1 - \Gamma_{OT,t}}\,, \tag{17}$$

where the parameters v_{ON} and v_{OT} denote the degree of home bias in energy demand in the nontradable and tradable intermediate good sectors and the parameters ε_{ON} and ε_{OT} denote the elasticities of substitution between domestic and foreign energy in nontradable and tradable intermediate good sectors respectively.

The relative prices faced by the intermediate goods producers are given by:

$$\frac{P_{ON,t}}{P_t} = \left(v_{ON} \left(\frac{P_{QO,t}}{P_t} \right)^{1-\varepsilon_{ON}} + \left(1 - v_{ON}\right) \left(\frac{P_{MO,t}}{P_t} \right)^{1-\varepsilon_{ON}} \right)^{\frac{1}{1-\varepsilon_{ON}}}, \tag{18}$$

$$\frac{P_{OT,t}}{P_t} = \left(v_{OT} \left(\frac{P_{QO,t}}{P_t} \right)^{1-\varepsilon_{OT}} + \left(1 - v_{OT}\right) \left(\frac{P_{MO,t}}{P_t} \right)^{1-\varepsilon_{OT}} \right)^{\frac{1}{1-\varepsilon_{OT}}}, \tag{19}$$

$$\frac{P_{QO,t}}{P_t} = \left(\frac{\overline{P}_{QO,t}}{P_t} + \eta_O \frac{P_{N,t}}{P_t} \right) \left(1 + tax_O\right), \text{ and} \tag{20}$$

$$\frac{P_{MO,t}}{P_t} = \left(\frac{\overline{P}_{MO,t}}{P_t} + \eta_O \frac{P_{N,t}}{P_t} \right) \left(1 + tax_O\right), \tag{21}$$

where tax_O is the rate at which the government taxes energy used as an intermediate input, and η_O represents the number of units of the nontradable good required to distribute a unit of the energy good to the intermediate goods firms.

As was the case with the final consumption price of energy, the existence of distribution services in energy used in the production of intermediate goods will mute the impact of changes in the producer price of energy on the prices paid by intermediate goods producers. There is also a role for government tax policy. The level of distribution services and government tax policy can be different in energy used in the production of intermediate goods and energy used directly in the final good. Unlike the case of energy price effects in the final good, the existence of adjustment costs in intermediate goods price setting implies that changes in the price of energy inputs will only be passed slowly into intermediate goods prices. Further, because it is costly for intermediate goods producers to adjust the quantity of energy used in production, the short-run elasticity of substitution between energy and the other two inputs, can be significantly below ξ_N and ξ_T.

C. Energy Production

The CES production technology for energy is given by:

$$T_{O,t}=Z_{O,t}\left[\left(1-\alpha_O-\gamma_O\right)^{\frac{1}{\xi_O}}\ell_{O,t}^{1-\frac{1}{\xi_O}}+\alpha_O^{\frac{1}{\xi_O}}K_{O,t}^{1-\frac{1}{\xi_O}}+\gamma_O^{\frac{1}{\xi_O}}LAND_t^{1-\frac{1}{\xi_O}}\right]^{\frac{\xi_O}{\xi_O-1}}, \tag{22}$$

where $Z_{O,t}$ denotes the level of productivity, $\ell_{O,t}$ denotes the labor input, $K_{O,t}$ denotes the capital input, $LAND_t$ denotes the fixed factor land, $\gamma_O and \alpha_O$ are the parameters that determine the shares of land and capital respectively, and ξ_O is the elasticity of input substitution.

Taking input prices as given, the solution to the energy producer's cost minimization problem yields real marginal cost in energy production as:

$$\frac{MC_{QO}}{P_t}=\frac{\left[\varphi_O\left(W_t/P_t\right)^{1-\xi_O}+\alpha_O\left(R_t/P_t\right)^{1-\xi_O}+\gamma_O\left(P_{L,t}/P_t\right)^{1-\xi_O}\right]^{\frac{1}{1-\xi_O}}}{Z_{O,t}}, \tag{23}$$

where $\varphi_O=\left(1-\alpha_O-\gamma_O\right), W_t/P_t$ is the real wage, R_t/P_t is the real user cost of capital, and $P_{L,t}/P_t$ is the real price of land.

In the presence of a distribution sector in energy and monopolistic competition, the producer or wholesale prices of the energy good are given by the following markups over marginal cost:

$$\frac{\overline{P}_{QOA,t}}{P_t}=\left(\frac{1}{\theta_O-1}\right)\eta_{OA}\frac{P_{N,t}}{P_t}+\left(\frac{\theta_O}{\theta_O-1}\right)\frac{MC_{QO}}{P_t} \tag{24}$$

$$\frac{\overline{P}_{MOA,t}}{P_t}=\left(\frac{1}{\theta_O^*-1}\right)\eta_{OA}\frac{P_{N,t}}{P_t}+\left(\frac{\theta_O^*}{\theta_O^*-1}\right)\frac{MC_{QO}^*}{P_t}\left(\frac{\varepsilon_t P_t^*}{P_t}\right), \tag{25}$$

$$\frac{\overline{P}_{QO,t}}{P_t}=\left(\frac{1}{\theta_O-1}\right)\eta_O\frac{P_{N,t}}{P_t}+\left(\frac{\theta_O}{\theta_O-1}\right)\frac{MC_{QO}}{P_t}, \text{ and} \tag{26}$$

$$\frac{\overline{P}_{MO,t}}{P_t} = \left(\frac{1}{\theta_O^* - 1}\right)\eta_O \frac{P_{N,t}}{P_t} + \left(\frac{\theta_O^*}{\theta_O^* - 1}\right)\frac{MC_{QO}^*}{P_t}\left(\frac{\varepsilon_t P_t^*}{P_t}\right), \tag{27}$$

where ε_t is the nominal exchange rate and θ_O is the elasticity of input substitution (the lower is the elasticity of input substitution, the greater is the energy producers' market power and the larger is the markup over marginal cost in energy prices).

Given this structure, the producer price of energy is endogenously determined in GEM. The structure can be calibrated so that the supply of energy is very inelastic and small changes in demand yield large changes in prices. Alternatively, changes on the supply side to either the quantity of land available for energy production or energy producers' markup over marginal cost can also lead to sharp changes in energy prices.

D. Nontradable Good Resource Constraint

The resource constraint in the nontradable intermediate good N_t is given by:

$$N_t = N_{N,t} + \eta(Q_t + M_t) + \eta_O\left(Q_{ON,t} + Q_{Pt,t} + M_{ON,t} + M_{OT,t}\right) + \eta_{OA}\left(Q_{OA,t} + M_{OA,t}\right) \tag{28}$$

In addition, with imports of the intermediate input now going into the production of the final nontraded good, the equations for imports, exports, the trade balance, the current account and the exchange rate must all be modified slightly to account for this (Appendix I). There is also a symmetric set of equations added or modified as outlined above for the foreign sector.

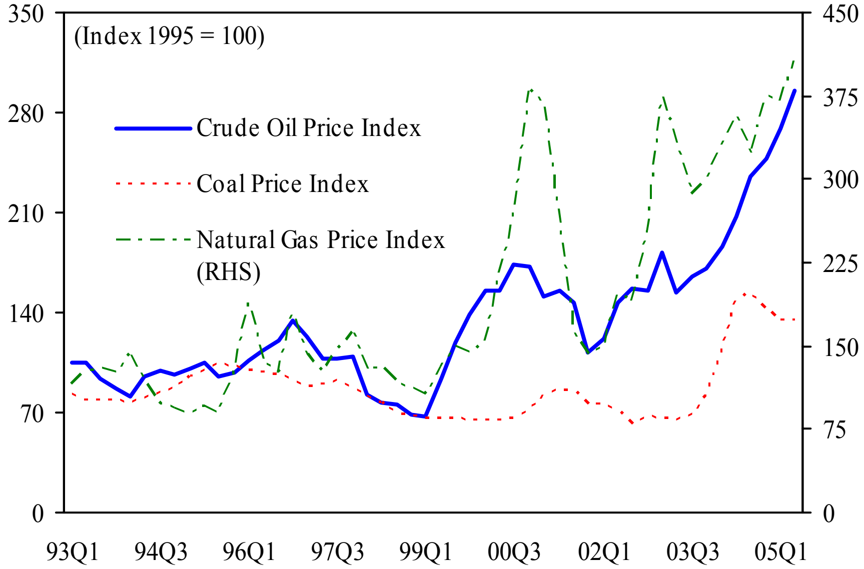
IV. MODEL CALIBRATION, SOLUTION, AND PROPERTIES

A. Calibration

This structure is calibrated to represent the United States as the Home country and the rest of the world as the Foreign country. To the extent possible, the calibration of the two regions is kept symmetric, with many parameters calibrated as in Hunt and Rebucci (2005). The discussion below focuses primarily on the calibration of energy supply and demand.

Energy is assumed to represent oil and natural gas. The historical correlation of these two energy prices presented in Figure 1 suggests that this is appropriate. The shares in GDP of the consumption and production of energy valued at real producer prices are initially calibrated to their levels prior to the first oil price shock in the early 1970s. At that time in the United States, the consumption of oil and gas represented roughly 1.7 percent of GDP with production representing 0.9 percent of GDP. For the rest of the world, the consumption of oil and gas represented 1.3 percent of GDP with production at 1.7 percent of GDP. These shares are calibrated based on a real US dollar price of oil of roughly 0.4, its level prior to 1973. Consistent with Blinder (1979), energy demand is calibrated so that in the United States, roughly half is used by the final good producers with the other half going into intermediate goods production. In the rest of the world, it is assumed that roughly one third is used by the final good producers with the remaining two thirds used by intermediate goods producers.[4]

Figure 2. Energy Prices



Source: Data Compiled by the IMF Commodities Unit of the Research Department based on data from: International Petroleum Exchange, London; New York Mercantile Exchange, New York; Henry Hub, Louisiana; World Bank.

The calibration of the production of energy assumes that land is the primary input. The parameter that determines the share of land in production, γ_O, is set to 0.96. The parameter determining capital's share, α_O, is set at 0.025. This results in a labor's share parameter of 0.015. In the United States, it is assumed that in energy production it is difficult to substitute among inputs, with the elasticity of substitution, ξ_O, set at 0.2. In the rest of the world it is assumed that there are more substitution possibilities and production is Cobb Douglas, $\xi_O^* = 1.0$. This calibration results in United States oil production that is not highly sensitive to changes in either rest of world oil production or the real price of oil, consistent with the evidence presented in Backus and Crucini (2000). The production of intermediate goods is also assumed to be Cobb Douglas, $\xi_N = \xi_T = \xi_N^* = \xi_T^* = 1.0$, however, because it is costly to adjust the amount of energy used in production, the short-run elasticity of substitution can be calibrated to be significantly below unity. The parameters $\phi_{ON}, \phi_{OT}, \phi_{ON}^*$, and ϕ_{OT}^* are set at 200 to achieve an evolution in energy's share of GDP in United States similar to that witnessed after the oil price shock in 1973 given the calibration of the demand for oil by final goods producers outlined below. This calibration will yield short-run properties similar to those in Kim and Loungani (1992) and Backus and Crucini (2000) where the focus is on

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[4] This precise calibration choice is somewhat arbitrary, but reflects the fact that, on average, final consumption in the United States is more energy intensive than in the rest of the world.

business cycle dynamics. It also yields long-run properties like those in Atkenson and Kehoe (1994) where the focus is on secular changes in energy use. In the absence of costly adjustment of energy in final goods production, it is assumed that the elasticity of substitution between energy and tradable intermediate goods, ε_{OA} is quite low, 0.175.[5]

To ensure that both the United States and the rest-of-world prices of energy move in tandem when there are shocks that affect the rest-of-world price, the elasticity of substitution between domestic and imported energy in intermediate goods production is set to 100 and in final goods production it is set at 10. These values for the elasticities of substitution, interacting with the calibration of the production of energy ensure that the United States and the rest-of-world prices of energy move in parallel. Further, the calibration ensures that over the business cycle, the relative price of energy will exhibit considerable variability, consistent with the data.

In the model's baseline, the parameters θ_O and θ_O^* are set to 100, implying virtually no markup in the price of oil above marginal cost. The oil price shocks considered in the paper are then generated by increasing the markup charged by rest-of-world energy producers. All the parameter values influencing energy demand and supply are presented in Table 1 with all the model's remaining parameter values presented in Table 2.

B. Solution

The steady state of the non-linear model is solved numerically in Troll by using an algorithm designed to deal with large, non-linear models. The routine breaks a large non-linear simulation problem into a number of smaller steps and applies the Newton-Raphson algorithm iteratively to each step.[6] Breaking down the large, non-linear problem into smaller steps allows the algorithm to treat the sub-problems as approximately linear without breaking down. A variant of this algorithm is also relied on to compute the forward-looking solution of the non-linear dynamic model under perfect foresight about the underlying realizations of the stochastic forcing processes.[7]

C. Model Properties

To provide a flavor of the model's dynamic adjustment properties, responses to two monetary policy shocks in the Home country are presented in Figures 2 and 3. Figure 2 contains the

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[5] Ideally it should be costly to adjust the use of the intermediate input in final goods production and this extension is planned for the future.

[6] These algorithms were programmed in portable TROLL by Susanna Mursula, at the IMF.

[7] For a discussion of the efficiency and robustness properties of these latter algorithm see Armstrong and others (1998) and Juillard and others (1998).

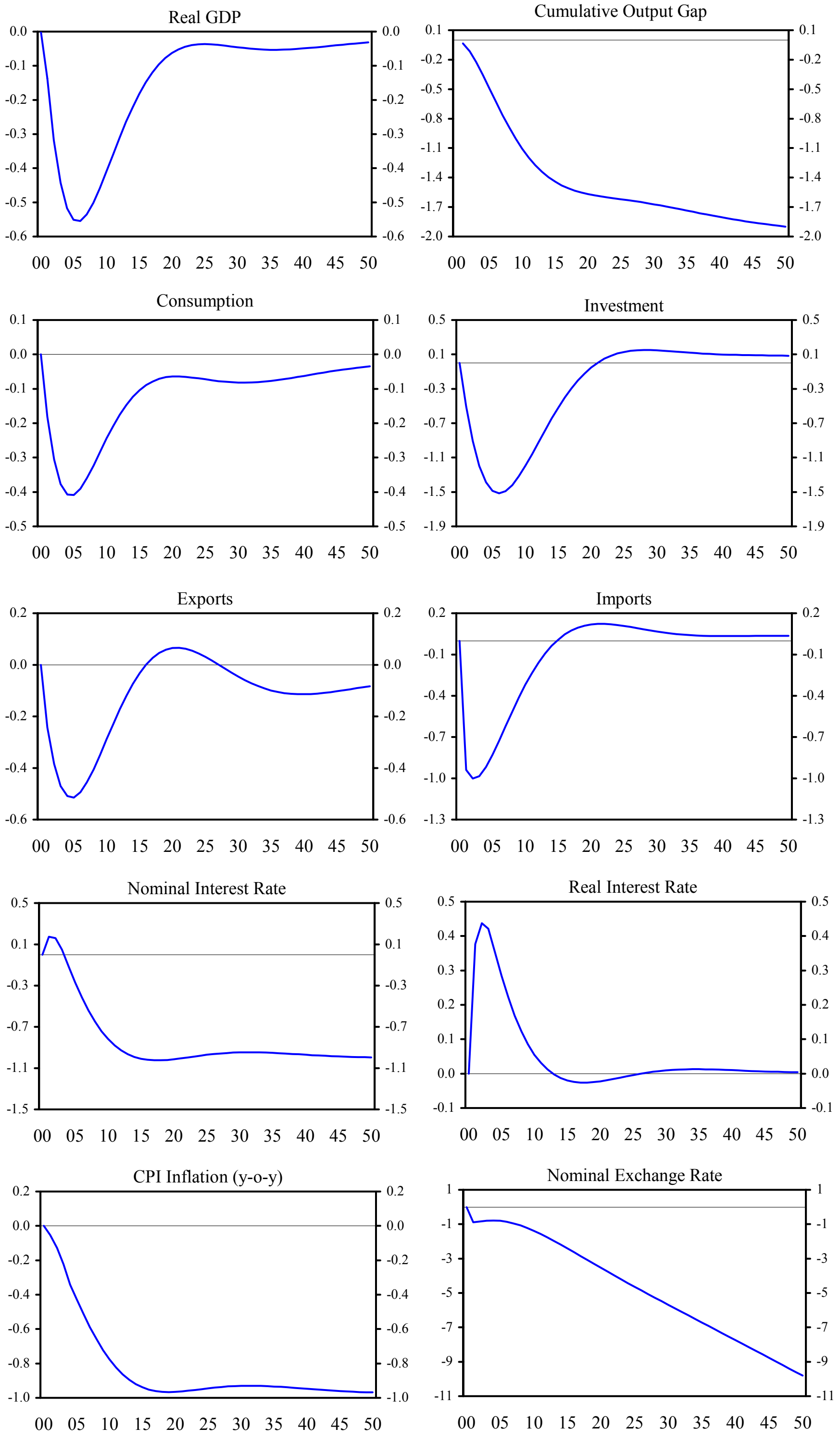
Table 1. Key Oil Demand and Supply Parameters

Parameters	U.S.	Row
Nontradable production, elasticity of substitution ξ_N	1.00	1.00
Tradable production, elasticity of substitution ξ_T	1.00	1.00
Oil production, elasticity of substitution ξ_O	0.20	1.00
Production parameter that determines capital's share α_N	0.29	0.29
Production parameter that determines capital's share α_T	0.35	0.35
Production parameter that determines capital's share α_O	0.025	0.02
Production parameter that determines energy's share γ_N	0.01	0.014
Production parameter that determines energy's share γ_T	0.01	0.008
Production parameter that determines land's share γ_O	0.96	0.96
Elasticity of substitution, domestic and foreign energy ε_{ON}	100.00	100.00
Elasticity of substitution, domestic and foreign energy ε_{OT}	100.00	100.00
Home bias in nontradable production energy demand v_{ON}	0.70	1.00
Home bias in tradable production energy demand v_{OT}	0.70	1.00
Elasticity of substitution, energy and tradables ε_{OA}	0.17	0.17
Elasticity of substitution, home and foreign energy ε_{QMOA}	10.00	10.00
Parameter determining share of energy in final good γ_{OA}	0.03	0.01
Home bias in energy in final good v_O	0.54	1.00
Adjustment cost parameter on energy in production ϕ_{ON}	200.00	200.00
Adjustment cost parameter on energy in production ϕ_{OT}	200.00	200.00
Elasticity of input substitution θ_O	100.00	100.00
Distribution of energy to intermediate good producers η_O	0.33	0.33
Distribution of energy to final good producers η_{OA}	0.33	0.33

Table 2. Remaining Model Parameters

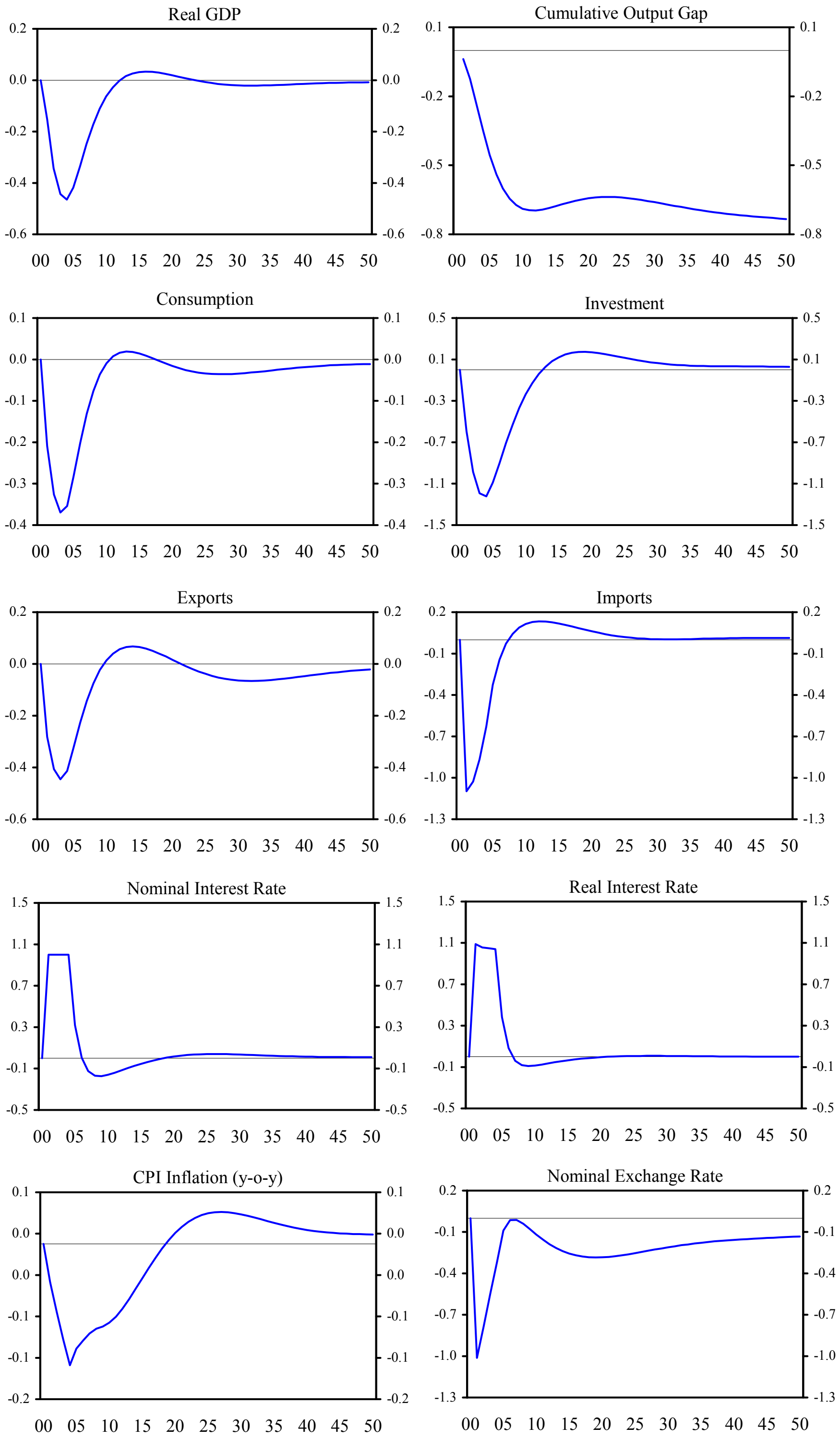
Parameters	U.S.	Row
Country size s	0.25	(1-s)
Home bias in non-energy tradables in final good v	0.78	0.75
Parameter that determines share of tradables in final good γ	0.67	0.67
Elasticity of substitution, tradables and nontradables ε	0.44	0.44
Elasticity of substitution, home and foreign tradables ε_{QM}	3.00	3.0
Elasticity of input substitution θ_N	6.00	6.0
Elasticity of input substitution θ_T	6.00	6.0
Elasticity of substitution among labor inputs ϕ	6.00	6.0
Intertemporal elasticity of substitution $1/\sigma$	1.00	1.0
Inverse of the Frisch elasticity of labor supply ξ	3.00	3.0
Habit persistence parameter b	0.80	0.80
Discount rate β	$1.03^{-0.25}$	$1.03^{-0.25}$
Depreciation rate on capital δ	0.02	0.025
Adjustment cost parameter for investment ϕ_{I1}	60.00	60.0
Adjustment cost parameter for investment ϕ_{I2}	5.00	5.0
Adjustment cost parameter for imports ϕ_M	5.00	5.0
Adjustment cost parameter for imports of energy $\phi_{M1,}\phi_{M2}$	0.00	0.0
Adjustment cost parameter nontradable prices ϕ_{N2}	3,042.00	3042.0
Adjustment cost parameter tradable prices ϕ_{Q2}	3,042.00	3042.0
Adjustment cost parameter wages ϕ_{W2}	3,042.00	3042.0
Adjustment cost parameter on bonds $\phi_{B1,}\phi_{B2}$	0.01	0.01
Adjustment cost parameter consumption ϕ_{S1}	0.011	0.011
Adjustment cost parameter consumption ϕ_{S2}	0.075	0.075
Adjustment cost parameter $\phi_{N1,}\phi_{Q1,}\phi_{W1}$	0.0	0.0
Distribution of intermediate goods η	0.33	0.33
Policy rule parameter on lagged interest rate ω_1	0.5	0.5
Policy rule parameter on inflation gap ω_2	0.5	0.5
Policy rule parameter on output gap ω_3	0.0	0.0

Figure 3. Effects of a One Percentage Point Reduction in Target Rate of Inflation
(percent or percentage point deviation from baseline)



Source: GEM Simulation

Figure 4. Effects of a Temporary 100 Basis Point Increase in Short-Term Interest Rate
(percent or percentage point deviation from baseline)



Source: GEM Simulation

response to a one-percentage-point permanent reduction in the target rate of inflation and Figure 3 contains the response to a one-year, 100 basis point increase in the short-term nominal interest rate. The inflation target shock illustrates that the nominal frictions in the model have been calibrated to yield a sacrifice ratio of roughly 2 percent. The temporary increase in interest rates illustrates that the trough in real activity occurs after roughly 4 quarters and investment is approximately three times as volatile as consumption. While many of these characteristic are consistent with more econometrically-based models of the U.S. economy, such as FRB/US, the speed of adjustment is still somewhat faster.

V. OIL PRICE SHOCKS

Given the structure of energy production, supply shocks to the price of energy can arise from two sources, changes in the markup or changes in the quantity of the fixed factor, land. Some preliminary work suggests that the impact is identical from either of these two sources. However, it is easier to achieve a desired path for the endogenous real producer price of oil using changes in the markup and in the simulation results presented below changes in the markup are used to generate shocks to the real producer price of oil. The first shock we consider is calibrated to match the path of the real producer price over the 1973 to 1978 period. The shock to the markup results in an initial 300 percent increase in the real producer price of energy which then decays slowly. After five years, the real producer price of energy has declined to roughly 150 percent above its initial level. The shock is simulated under a simple inflation targeting monetary policy rule given by:

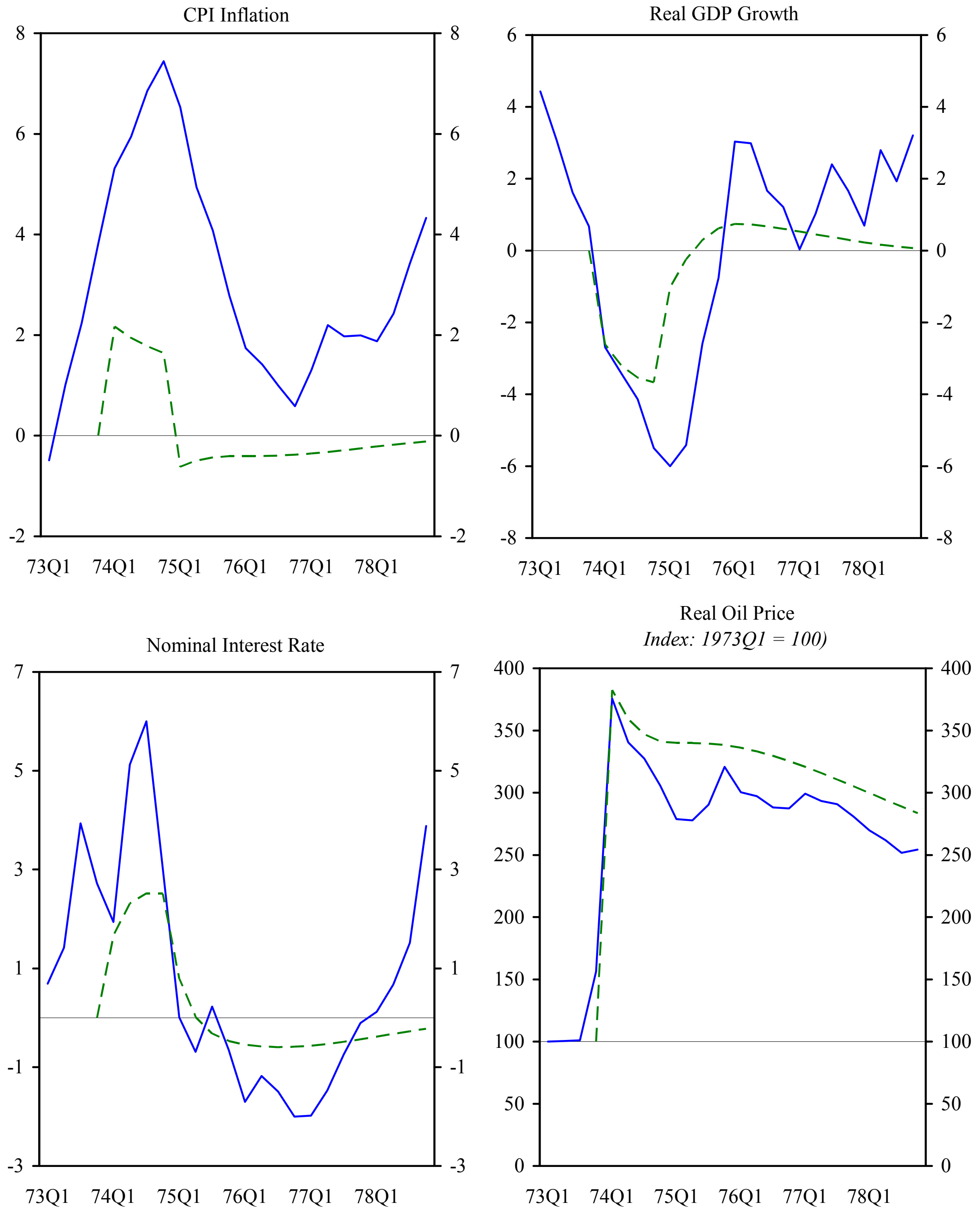
$$i_{t+1} = \omega_1 \bullet i_t + (1-\omega_1)\left[\overline{i_{t+1}} + \omega_2 \bullet E_t(\pi_t - \Pi_{t+1})\right], \qquad (29)$$

where i_t is the annualized short-term nominal interest rate, $\overline{i}_{t+1}$ is the equilibrium nominal interest rate, E_t denotes an expectations operator, π_t denotes year-over-year CPI inflation, Π_{t+1} is the target rate of inflation, the parameter on the lagged interest rate, ω_1, is set to 0.5 and the parameter on the inflation gap, ω_2, is set to 0.5.

The dashed lines in Figure 4 trace out the model's response to this shock under the inflation targeting policy rule. The solid lines graphed in the figure are the de-trended responses in the United States data over the 1973 to 1978 period. The trend is the 1968 to 1972 average. The first point to note is that the simulated acceleration in inflation is considerably less than that in data and there is no persistence. Real growth slows, although not as significantly as in the data. The increase in the short-term nominal interest rate is also considerably less than that contained in the data. These results suggest that under the base-case assumptions about behavior in GEM, it is quite difficult to explain the broad macroeconomic features of the 1974 to 78 period in the US with an increase in energy prices similar to that which occurred at the end of 1973 and the beginning of 1974.

Figure 5. Base-Case Energy Price Shock

Solid = U.S. stylized facts - difference from average of 1968-72.
Dashed = GEM simulation path - deviation from baseline.


CPI Inflation

Real GDP Growth

Nominal Interest Rate

Real Oil Price
Index: 1973Q1 = 100)

Source: GEM Simulation, U.S. Bureau of Economic Analysis.

It is interesting to consider how these base-case GEM results compare to those obtained from macroeconomic models that were state-of-the-art in the late 1970s. Results presented in Mork and Hall (1980) compared the impact of the 1973–74 energy price shock on several well respected macroeconomic models. In Table 3, the results from the DRI, FRB, and MPS models along with Mork and Hall's own model are compared to the base-case GEM results. Although the GEM results in the first year of the shock are quite comparable to those from the other models, the second year effects are quite different. There is no persistence in the increase in inflation in GEM and output moves back toward baseline in the second year rather than further away as it does in all the other models. Two common themes emerge from the explanations advanced about why the oil price shock in the 1970s resulted in such large and persistence effects that might help explain the difference. The first is the response of wage earners to the decline in their real wages as outlined in Bruno and Sachs (1985). The second, and not unrelated theme, is the response of monetary policy as Bernanke (2003) notes that poor monetary policies both facilitated the rise in oil prices and exacerbated their effects. Estimated reduced-form macroeconomic models would likely capture some of these effects, largely through their ad hoc lag structures which were motivated by empirical fit. However, GEM's rational expectations, choice-theoretic framework, anchored with an inflation forecasting monetary policy rule does not allow for these possibilities.

Table 3. Impact of 1973–74 Energy Price Shock in Several Models

Inflation – percentage point deviation from baseline

	DRI*	FRB*	MPS*	Mork&Hall*	GEM
1974	1.6	1.3	2.6	4.1	1.7
1975	2.0	0.8	0.0	1.8	-0.4

Output – percentage deviation from baseline

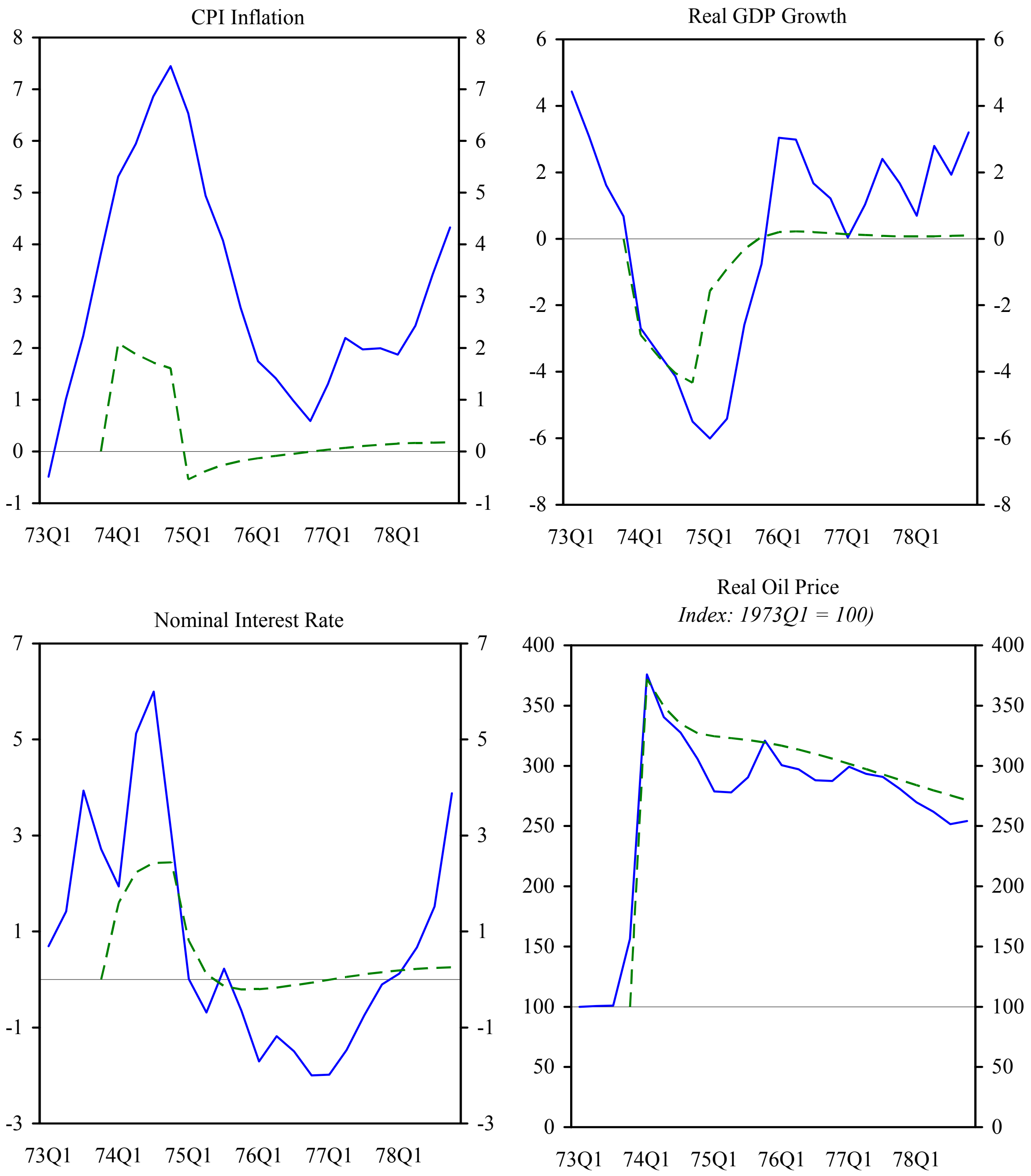
	DRI	FRB	MPS	Mork&Hall	GEM
1974	-3.1	-2.0	-1.1	-2.4	-3.7
1975	-5.2	-3.0	-2.7	-5.4	-3.1

* Source: Mork and Hall (1980)

In GEM, the wage bargaining process embodies nominal frictions. Under this specification, the sharp rise in consumer prices resulting from the energy price shock drives the real consumption wage down by roughly two percent. Forward-looking rational labor suppliers recognize the permanent change in relative prices and simply accept this lower real wage. As shown in Hunt, Isard and Laxton (2002), if workers do not attempt to resist this decline in their real wage, then oil price shocks will not result in persistent inflation even if policymakers completely accommodate the impact of the shock on the price level. In GEM it is possible to allow workers to resist the decline in their real wage by temporarily increasing the markup in the real wage. Calibrating the temporary increase in the markup so that workers are able to temporarily recover 50 percent of the decline in their real wage yields the simulation paths presented in Figure 5. The initial acceleration in inflation is almost identical to the case with no change in the markup, although, the subsequent path for inflation is marginally higher. Tighter monetary policy prevents the behavior of workers from generating

Figure 6. Energy Price Shock with a Temporary Increase in Markup

Solid = U.S. stylized facts - difference from average of 1968-72.
Dashed = GEM simulation path - deviation from baseline.



Source: GEM Simulation, U.S. Bureau of Economic Analysis.

a persistent increase in inflation. This is reflected in part by the larger decline in real growth than in the case with no change in the markup. This suggests that with monetary policy focused on controlling inflation, resistance on the part of labor suppliers to the decline in their real wage cannot generate persistent inflation.

Turning to the response of monetary policy, one way to characterize more accommodative monetary policy is to include a measure of real activity in the policy response function. Adding the output gap to the inflation targeting rule above yields the familiar Taylor (1993) policy rule given by:

$$i_{t+1} = \omega_1 \bullet i_t + (1-\omega_1)\left[\overline{i_{t+1}} + \omega_2 \bullet E_t(\pi_t - \Pi_{t+1}) + \omega_3(outputgap)\right], \tag{30}$$

where ω_3 is the response coefficient on the output gap which is the difference between the level of output and potential output. One measure of potential output to consider would be the model-consistent level that would be obtained in the absence of nominal frictions, the flexible-price level of output. Setting $\omega_3 = 1$ and using the model-consistent, flexible-price level of output to calculate the output gap yields the solution paths given by the dashed lines in Figure 6.[8] The parameters ω_1 and ω_2 continue to be set at 0.5.

Relative to the results under inflation targeting, inflation initially rises by a little more and output declines by less if the policymaker targets the flexible-price level of output, but there are no persistent inflation effects. However, assuming that policymakers can calculate the true flexible-price solution to use as their estimate of potential output is an heroic assumption. In practice, potential output is unobservable and policymakers must estimate it with very incomplete information sets. Consequently, policymakers' estimates embody a great deal of uncertainty and undergo substantial revision through time as information sets improve. This suggest that using the flexible-price level of output as the estimate of potential output, while informative, probably does not yield a realistic characterization of policymakers' view of the extend of excess supply in the economy following the first oil price shock in the 1970s.

The real-time estimates of potential output used by policymakers in the 1970s presented in Orphanides (2000) suggest that the level of potential output was consistently overestimated throughout this period. An alternative estimate of potential output that is readily available in GEM is the equilibrium level of output that reflects only the long-run impact of the permanent component of the increase in energy prices. Under the calibration of the energy

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[8] To generate flexible-price output, the complete model is replicated with all the parameters determining the nominal adjustment cost set to zero. This structure is simulated simultaneously with the sticky-price structure and the flexible-price level of GDP is used as the policymaker's estimate of potential output in the computation of the output gap entering the policy rule.

shock considered here, the long-run permanent decline in real GDP is roughly 1 percent. This compares to a decline in the flexible-price level of output that is in the range of 2.5 percent over the first five years of the shock (in the absence of a change in the markup in wages).[9] Consequently, using the long-run level of output to calculate the output gap would results in an overestimate of the extend of excess supply by roughly 1.5 percentage points if labor suppliers don't resist the decline in their real wage. Although this is still considerably less than the extent of the overestimation of excess supply suggested in Orphanides (2000), it is a convenient, model-consistent measure that embodies an error with the appropriate sign. Simulating the energy price shock using the Taylor rule given above that temporarily puts a weight of unity $\left(\omega_3 = 1\right)$ on this estimate of the output gap results in the simulation paths given by the dotted line in Figure 6. The parameter ω_3 is set equal to one for the first five years of the simulation and is then reduced gradually over the subsequent three years to zero. This reflects the notion that policymakers would eventually have learned that this estimate of the output gap was leading to unexpectedly high inflation and they would have eventually ceased to respond to it, or revised their technique for estimating potential output. Monetary policy attempting to support output above the flexible-price level results in an initially larger spike in inflation followed by a mild secondary cycle in persistent inflation. Although, this is suggestive of the response of inflation in the data, the secondary cycle is much smaller. However, larger output gap errors could clearly have resulted in a much larger secondary burst of persistent inflation.

One reason for the large errors in the estimation of potential output in the 1970s arose from the general view that an economy's supply capacity evolved at a constant known rate.[10] The average real growth rates experienced in the 1950s and 60s were simply extrapolated into the future. Given this determinist view of the evolution of potential output, it is interesting to see how the oil price shock and the response of workers could have contributed to the overestimation of potential output resulting in a secondary burst of persistent inflation. This is illustrated by the dotted lines in Figure 7 that trace the response of the model to the oil price shock when policymakers use the long-run level of real output as the estimate of potential output and labor suppliers temporarily resist the decline in their real wages. Here, in addition to a larger initial spike in inflation, there is a very large secondary cycle in persistent inflation, which is starting to broadly match the secondary acceleration in inflation in the data. When workers are able to temporarily resist the decline in their real wage, firms want to employ less capital and labor and the flexible-price level of output in the economy declines.

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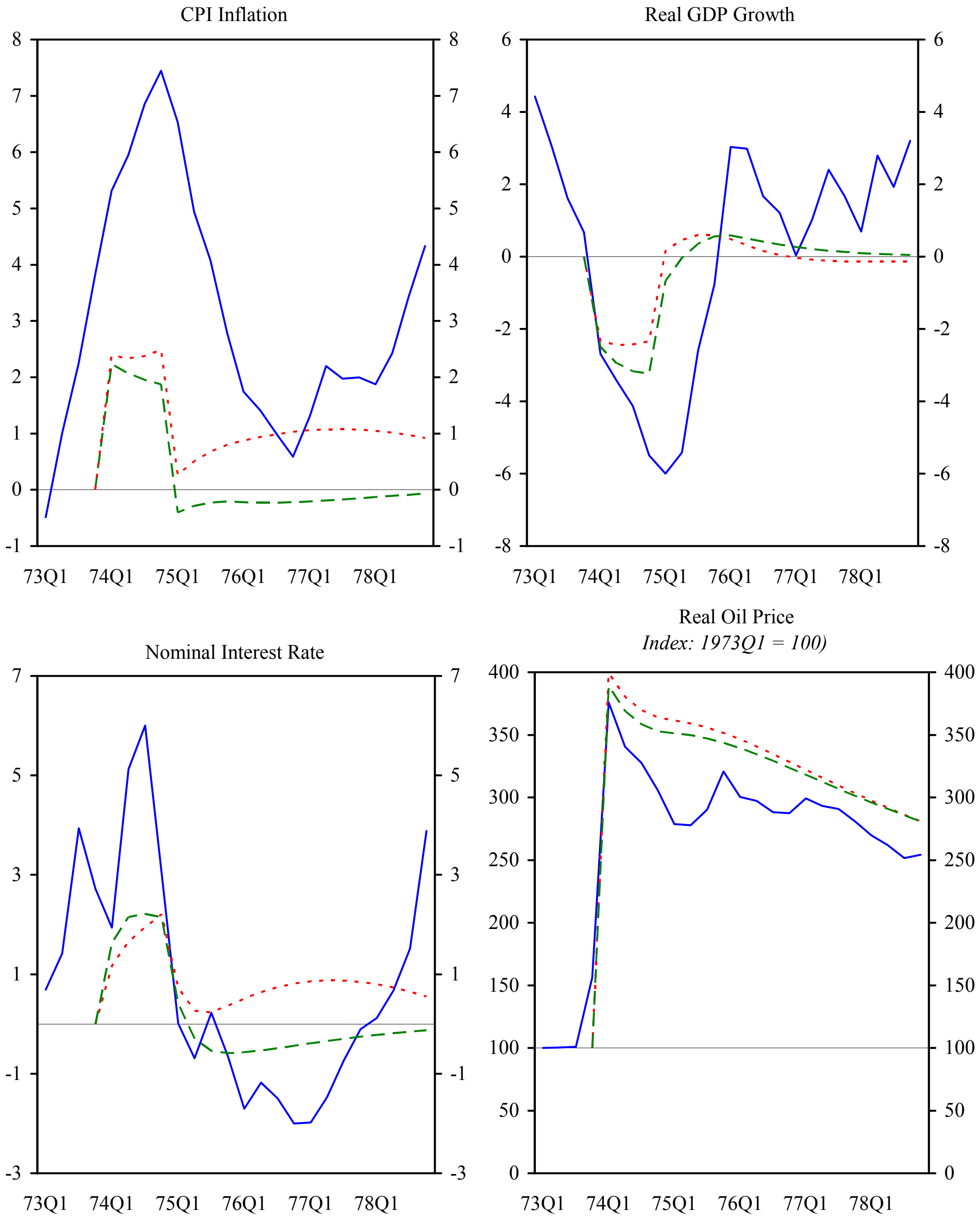
[9] In the short-run the flexible price level of potential output falls much more than the long-run level for two reasons. First, initially real energy price rise by almost 300 percent, but in the long-run are up by under 100 percent, Second, adjustment cost in intermediate goods production imply that the short-run elasticity of substitution between energy and capital and labor is lower than in the long-run, which is calibrated to be Cobb Douglas.

[10] For an informative discussion of the evolution of techniques for estimating potential output see Laxton and Tetlow (1992).

Figure 7. Energy Price Shock with Output Gap Entering Policy Rule

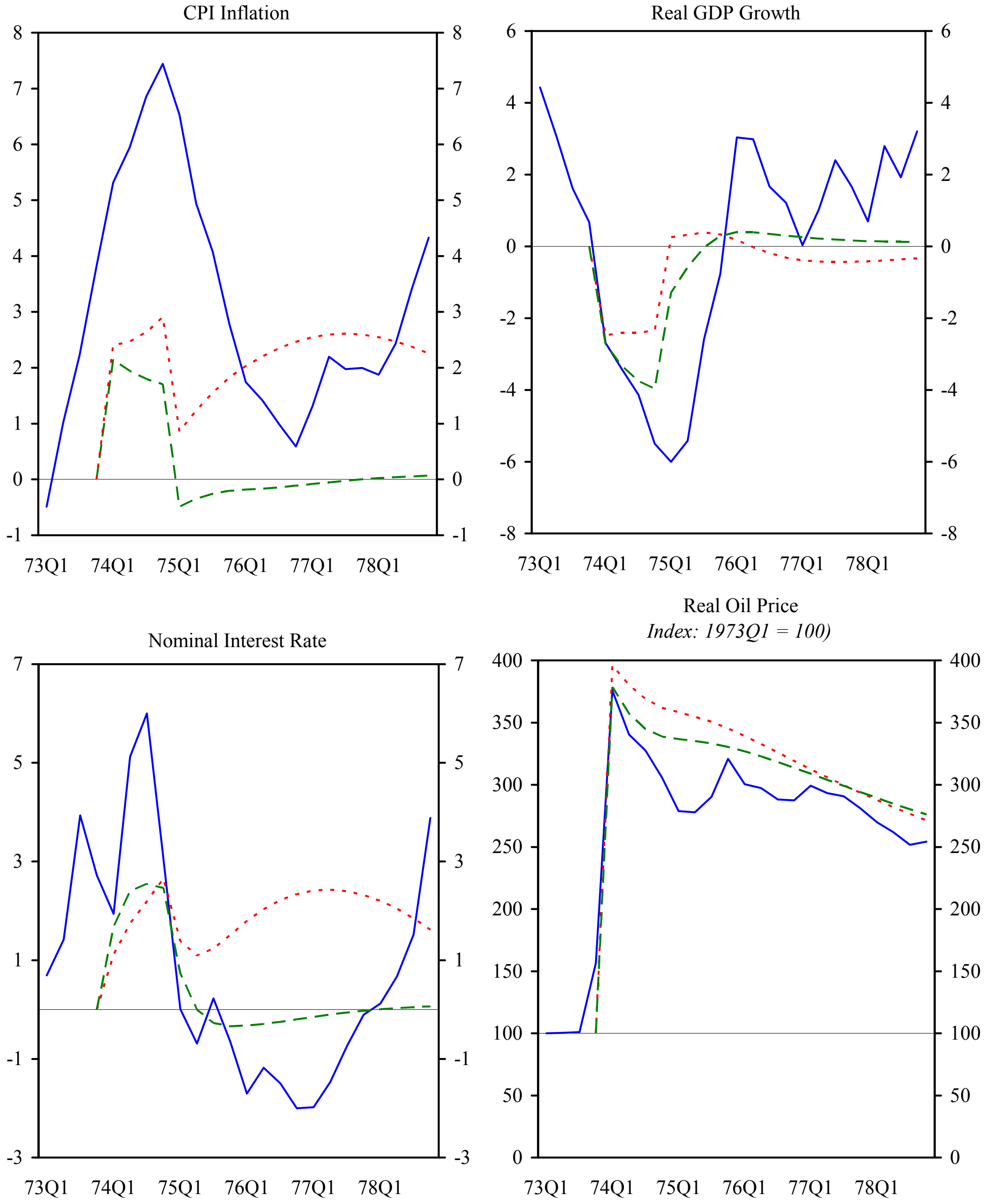
Solid = U.S. stylized facts - difference from average of 1968-72.
Dotted = GEM simulation path: Long-run potential output - deviation from baseline.
Dashed = GEM simulation path: Flexible-price potential output - deviation from baseline.



Source: GEM Simulation, U.S. Bureau of Economic Analysis.

Figure 8. Energy Price Shock with a Temporary Increase in Markup and Output Gap Entering Policy Rule

Solid = U.S. stylized facts - difference from average 1968-72.
Dotted = GEM simulation path: Long-run potential output - deviation from baseline.
Dashed = GEM simulation path: Flexible-price potential output - deviation from baseline.



Source: GEM Simulation, U.S. Bureau of Economic Analysis.

Policymakers with a more naive process for estimating potential output would not recognize this and would try to support output at a level that generates considerably more demand-side inflationary pressure. This is effectively illustrated by the dashed lines in Figure 7 that trace out the response when workers resist the decline in their real wage and policymakers respond to the flexible-price output gap. Output is initially lower and there is no secondary burst of inflation.

The simulation results for inflation and output from Figures 4 through 7 are summarized in Table 4. There are several reasons why these GEM simulations of the 1973–74 energy price shock fail to capture the burst of inflation that followed immediately after. Blinder (1979) provides a detailed decomposition that attributes the 1974–75 acceleration in inflation to four factors: prior overheating of the economy; removal of wage and price controls; an increase in food prices; and the increase in energy prices. Blinder's allocation of 2.5 percentage points of the acceleration in inflation in 1974 to energy price rises is consistent with these GEM results. In addition to being consistent with this estimate of energy's direct effect, adding plausible responses of the monetary authority and labor suppliers to the simulation allows the model to capture the broad pattern in the data where an initial transitory spike in inflation is followed by a secondary persistent acceleration.

Table 4. GEM Simulation Results

Inflation – percentage point deviation from baseline

	Base Case	**Markup**	**FPP**	**LRP**	**Markup+LRP**	**Markup+FPP***
1974	1.7	1.6	1.9	2.5	2.9	1.7
1975	-0.4	-0.2	-0.2	0.8	1.8	-0.2
1976	-0.4	0.0	-0.2	1.0	2.5	-0.1
1977	-0.2	0.1	-0.1	1.1	2.6	0.0
1978	-0.1	0.2	-0.1	0.9	2.3	0.1

Output – percent deviation from baseline

	Base Case	**Markup**	**FPP**	**LRP**	**Markup+LRP**	**Markup+FPP***
1974	-3.7	-4.3	-3.2	-2.3	-2.3	-4.0
1975	-3.1	-4.3	-2.7	-1.8	-2.0	-3.7
1976	-2.5	-4.2	-2.4	-1.7	-2.3	-3.4
1977	-2.2	-4.0	-2.2	-1.8	-2.7	-3.2
1978	-2.1	-3.9	-2.2	-2.0	-3.1	-3.1

Markup – Temporary increase in the markup in wages.

FPP – Output gap using flexible-price output as estimate of potential in policy rule $\left(\omega_3 = 1\right)$

LRP – Output gap using long-run output as estimate of potential in policy rule $\left(\omega_3 = 1\right)$

Markup+LRP – Temporary increase in markup and LRP output gap $\left(\omega_3 = 1\right)$

Markup+FPP – Temporary increase in markup with FPP output gap $\left(\omega_3 = 1\right)$

* It was necessary to slightly reduce the scale of the increase in the markup to solve.

Table 5. Estimates of Output Gap Entering Policy Rule When ω_3=1

	FPP	**LRP**	**Markup+LRP**	**Markup+FPP***
1974	-0.8	-1.3	-1.3	-0.2
1975	-0.3	-0.7	-1.0	-0.1
1976	-0.1	-0.7	-1.3	0.0
1977	0.0	-0.8	-1.7	0.0
1978	0.0	-0.9	-2.0	0.0

FPP – Using flexible-price output as estimate of potential
LRP – Using long-run output as estimate of potential
Markup+LRP – Temporary increase in markup using LRP as estimate of potential
Markup+FPP – Temporary increase in markup using FPP as estimate of potential

VI. CONCLUSION

The oil price shocks of the 1970s are often cited as the culprits responsible for the stagflation experienced in many industrial countries in that decade. In this paper the IMF's new Global Economic Model (GEM) has been used to examine the validity of such claims. Unlike many of the macroeconomic models used in the past to consider this question, GEM is a structural model based fully on a choice theoretic framework. Further, GEM models both the supply of, and demand for, energy in a realistic manner that captures all the major economic channels through which energy influences economic behavior. The simulation results suggest that the acceleration in energy prices alone cannot account for the stagflation widely experienced throughout the 1970s. However, if households resisted the decline in their real incomes arising from the increase in energy costs and the monetary authority facilitated that resistance with accommodative policy because it was overestimating the level of potential output, then energy prices could have been the spark that ignited the stagflation.

An interesting point that emerges from the analysis is the possible interaction between labor suppliers' response to the decline in their real wages and the magnitude of the errors in the policymaker's estimates of the output gap. If, as is generally accepted, policymakers viewed the evolution of potential output at the time as a relatively deterministic process, the more aggressively workers resisted the declines in their real wages, the lower would have been the economy's true supply capacity (the flexible-price level of potential output) and the larger would been the policymaker's error in its estimation of the output gap (see Table 5). Consequently, if policy was set in a fashion consistent with a Taylor-type reaction function, the resulting magnitude of the excess easing in policy in response to the estimate of the output gap would have depended on workers' responses to their real wage declines. Had workers resisted those declines, excessively easy policy could have generated demand pressures on prices, which, coupled with the direct wage pressures on prices, could have generated the significant secondary burst of persistent inflation.

I. Dynamic Model Equations

Country Specific Equations

$\boxed{\ell_{N,t}}$ Labor in nontradable sector

$$N_t = Z_{N,t}\left[\left(1-\alpha_N-\gamma_N\right)^{\frac{1}{\xi_N}}\ell_{N,t}^{1-\frac{1}{\xi_N}}+\alpha_N^{\frac{1}{\xi_N}}K_{N,t}^{1-\frac{1}{\xi_N}}+\gamma_N^{\frac{1}{\xi_N}}\left[\left(1-\Gamma_{ON,t}\right)O_{N,t}\right]^{1-\frac{1}{\xi_N}}\right]^{\frac{\xi_N}{\xi_N-1}}$$

$\boxed{\ell_{T,t}}$ Labor in tradable sector

$$T_t = Z_{T,t}\left[\left(1-\alpha_T-\gamma_T\right)^{\frac{1}{\xi_T}}\ell_{T,t}^{1-\frac{1}{\xi_T}}+\alpha_T^{\frac{1}{\xi_T}}K_{T,t}^{1-\frac{1}{\xi_T}}+\gamma_T^{\frac{1}{\xi_T}}\left[\left(1-\Gamma_{OT,t}\right)O_{T,t}\right]^{1-\frac{1}{\xi_T}}\right]^{\frac{\xi_T}{\xi_T-1}}$$

$\boxed{\ell_{O,t}}$ Labor in intermediate input sector

$$T_{O,t} = Z_{O,t}\left[\left(1-\alpha_O-\gamma_O\right)^{\frac{1}{\xi_O}}\ell_{O,t}^{1-\frac{1}{\xi_O}}+\alpha_O^{\frac{1}{\xi_O}}K_{O,t}^{1-\frac{1}{\xi_O}}+\gamma_O^{\frac{1}{\xi_O}}L_t^{1-\frac{1}{\xi_O}}\right]^{\frac{\xi_O}{\xi_O-1}}$$

$\boxed{K_{N,t}}$ Capital in nontradable sector

$$k_{N,t}=\frac{K_{N,t}}{\ell_{N,t}}$$

$\boxed{K_{T,t}}$ Capital in tradable sector

$$k_{T,t}=\frac{K_{T,t}}{\ell_{T,t}}$$

$\boxed{K_{O,t}}$ Capital in intermediate input sector

$$k_{o,t}=\frac{K_{O,t}}{\ell_{O,t}}$$

$\boxed{Q_t}$ Home country demand for the Home tradable good

$$Q_t = \gamma v \left(\frac{P_{Q,t}}{P_t} \right)^{-\varepsilon_{QM}} A_t \left(\frac{P_{X,t}}{P_t} \right)^{\varepsilon_{QM}-\varepsilon}$$

$\boxed{M_t}$ Home country demand for the Foreign tradable intermediate good

$$M_t = \gamma (1-v) \left(\frac{P_{M,t}}{P_t} \right)^{-\varepsilon_{QM}} \left(\frac{P_{X,t}}{P_t} \right)^{\varepsilon_{QM}-\varepsilon} A_t$$

$$* \frac{\left[1-\Gamma_{M,t} - \phi_M \left(\frac{M_t}{A_t} / \frac{M_{t-1}}{A_{t-1}} - 1 \right) \left(\frac{M^t}{A_t} / \frac{M_{t-1}}{A_{t-1}} \right) \right]^{\varepsilon_{QM}}}{1-\Gamma_{M,t}}$$

$\boxed{\Gamma_{M,t}}$ Adjustment cost on imports of intermediate good

$$\Gamma_{M,t} = \frac{\phi_M}{2} \left(\frac{M_t}{A_t} / \frac{M_{t-1}}{A_{t-1}} - 1 \right)^2$$

$\boxed{N_{N,t}}$ Demand for the nontradable intermediate good

$$N_{N,t} = (1-\gamma) \left(\frac{P_{N,t}}{P_t} \right)^{-\varepsilon} A_t$$

$\boxed{\Gamma_{ON,t}}$ Cost of adjusting the quantity of the intermediate input used in nontradable good production

$$\Gamma_{ON,t} = \frac{\phi_{ON}}{2} \left(\frac{O_{N,t}}{N_t} / \frac{O_{N,t-1}}{N_{t-1}} - 1 \right)^2$$

$\boxed{\Gamma_{OT,t}}$ Cost of adjusting the quantity of the intermediate input used in tradable good production

$$\Gamma_{OT,t} = \frac{\phi_{OT}}{2} \left(\frac{O_{T,t}}{T_t} / \frac{O_{T,t-1}}{T_{t-1}} - 1 \right)^2$$

$\boxed{k_{N,t}}$ Capital-to-labor ratio in nontradable sector

$$k_{N,t} = \frac{\alpha_N}{1-\alpha_N-\gamma_N}\left(\frac{W_t / P_t}{R_t / P_t}\right)^{\xi_N}$$

$\boxed{k_{T,t}}$ Capital-to-labor ratio in tradable sector

$$k_{T,t} = \frac{\alpha_t}{1-\alpha_T-\gamma_T}\left(\frac{W_T / P_t}{R_t / P_t}\right)^{\xi_T}$$

$\boxed{k_{O,t}}$ Capital-to-labor ratio in tradable intermediate input sector

$$k_{O,t} = \frac{\alpha_O}{1-\alpha_O-\gamma_O}\left(\frac{W_t / P_t}{R_t / P_t}\right)^{\xi_O}$$

$\boxed{\frac{P_{Q,t}}{P_t}}$ Relative consumer price of Home country tradable good

$$\frac{P_{Q,t}}{P_t} = \frac{\overline{P}_{Q,t}}{P_t} + \eta\frac{P_{N,t}}{P_t}$$

$\boxed{\frac{\overline{P}_{Q,t}}{P_t}}$ Relative producer price of Home country tradable good

$$0 = \left(1-\Gamma_{PQ,t}\right)\frac{\overline{P}_{Q,t} / P_t}{P_{Q,t} / P_t}\left(\frac{\overline{P}_{Q,t}}{P_t}\left(1-\theta_T\right) + \eta\frac{P_{N,t}}{P_t} + \theta_T\frac{MC_{T,t}}{P_t}\right)$$

$$-\left(\frac{\overline{P}_{Q,t}}{P_t} - \frac{MC_{T,t}}{P_t}\right)\left(\frac{\phi_{Q1^{\overline{\pi}}Q,t}}{\pi}\left(\frac{\overline{\pi}_{Q,t}}{\pi}-1\right) + \frac{\phi_{Q2^{\overline{\pi}}Q,t}}{\overline{\pi}_{Q,t-1}}\left(\frac{\overline{\pi}_{Q,t}}{\overline{\pi}_{Q,t-1}}-1\right)\right)$$

$$+E_t D_{t,t+1}\left(\frac{\overline{P}_{Q,t\_1}}{P_{t+1}} - \frac{MC_{T,t+1}}{P_{t+1}}\right)\pi_{t+1}\frac{Q_{t+1}}{Q_t}\left(\frac{\phi_{Q1}\pi_{Q,t+1}}{\pi}\left(\frac{\overline{\pi}_{Q,t+1}}{\pi}-1\right) + \frac{\phi_{Q2}\pi_{Q,t+1}}{\overline{\pi}_{Q,t}}\left(\frac{\overline{\pi}_{Q,t+1}}{\overline{\pi}_{Q,t}}-1\right)\right)$$

$\boxed{\frac{MC_{T,t}}{P_t}}$ Real marginal cost in tradable goods sector

$$\frac{MC_{T,t}}{P_t} = \frac{1}{Z_{T,t}}\left(\left(1-\alpha_T-\gamma_T\right)\left(\frac{W_t}{P_t}\right)^{1-\xi_T} + \alpha_T\left(\frac{R_t}{P_t}\right)^{1-\xi_T}\right.$$

$$\left. +\gamma_T \frac{P_{OT,t}}{P_t}^{1-\xi_T}\left[1-\Gamma_{OT,t}-\phi_{OT}\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}-1\right)\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}\right)\right]^{\xi_T-1}\right)^{\frac{1}{1-\xi_T}}$$

$\boxed{\Gamma_{PQ,t}}$ Cost of adjusting prices in tradable goods sector

$$\Gamma_{PQ,t} = \frac{\phi_{Q1}}{2}\left(\frac{\overline{\pi}_{Q,t}}{\pi}-1\right)^2 + \frac{\phi_{Q2}}{2}\left(\frac{\overline{\pi}_{Q,t}}{\overline{\pi}_{Q,t-1}}-1\right)^2$$

$\boxed{\frac{P_{X,t}}{P_t}}$ Relative consumer price of tradable goods

$$\frac{P_{X,t}}{P_t} = \left(v\left(\frac{P_{Q,t}}{P_t}\right)^{1-\varepsilon_{QM}} + \left(1-v\right)\left(\frac{P_{M,t}}{P_t}\right)^{1-\varepsilon_{QM}}\right.$$

$$\left. *\left[1-\Gamma_{M,t}-\phi_M\left(\frac{M_t}{A_t}/\frac{M_{t-1}}{A_{t-1}}-1\right)\left(\frac{M_t}{A_t}/\frac{M_{t-1}}{A_{t-1}}\right)\right]^{\varepsilon_{QM}-1}\right)^{\frac{1}{1-\varepsilon_{QM}}}$$

$\boxed{\frac{P_{M,t}}{P_t}}$ Relative consumer price of imports of intermediate goods

$$\frac{P_{M,t}}{P_t} = \frac{\overline{P}_{M,t}}{P_t} + \eta\frac{P_{N,t}}{P_t}$$

$\boxed{\Gamma_{PM,t}}$ Cost of adjusting the quantity of import of intermediate goods

$$\Gamma_{P,M,t} = \frac{\phi_{M1}}{2}\left(\frac{\overline{\pi}_{M,t}}{\pi}-1\right)^2 + \frac{\phi_{M2}}{2}\left(\frac{\overline{\pi}_{M,t}}{\overline{\pi}_{M,t-1}}-1\right)^2$$

$\boxed{\frac{P_{N,t}}{P_t}}$ Relative consumer price of nontradable goods

$$0 = \left(1-\Gamma_{PN,t}\right)\left(\left(1-\theta_N\right)\frac{P_{N,t}}{P_t} + \theta_N\frac{MC_{N,t}}{P_t}\right)$$

$$-\left(\frac{P_{N,t}}{P_t}-\frac{MC_{N,t}}{P_t}\right)\left(\frac{\theta_{N1}\pi_{N,t}}{\pi}\left(\frac{\pi_{N,t}}{\pi}-1\right)+\frac{\theta_{N1}\pi_{N,t}}{\pi_{N,t-1}}\left(\frac{\pi_{N,t}}{\pi_{N,t-1}}-1\right)\right)$$

$$+E_tD_{t,t+1}\left(\frac{P_{N,t+1}}{P_{t+1}}-\frac{MC_{N,t+1}}{P_{t+1}}\right)\pi_{t+1}\frac{N_{t+1}}{N_t}\left(\frac{\theta_{N1}\pi_{N,t+1}}{\pi}\left(\frac{\pi_{N,t+1}}{\pi}-1\right)+\frac{\theta_{N2}\pi_{N,t+1}}{\pi_{N,t}}\left(\frac{\pi_{N,t+1}}{\pi_{N,t}}-1\right)\right)$$

$\boxed{\frac{MC_{N,t}}{P_t}}$ Real marginal cost in nontradable goods sector

$$\frac{MC_{N,t}}{P_t}=\frac{1}{Z_{N,t}}\Bigg(\left(1-\alpha_N-\gamma_N\right)\left(\frac{W_t}{P_t}\right)^{1-\xi_N}+\alpha_N\left(\frac{R_t}{P_t}\right)^{1-\xi_N}$$

$$+\gamma_N\left(\frac{P_{ON,t}}{P_t}\right)^{1-\xi_N}\left[1-\Gamma_{ON,t}-\phi_{ON}\left(\frac{O_{N,t}}{N_t}/\frac{O_{N,t-1}}{N_{t-1}}-1\right)\left(\frac{O_{N,t}}{N_t}/\frac{O_{N,t-1}}{N_{t-1}}\right)\right]^{\xi_{N-1}}\Bigg)^{\frac{1}{1-\xi_N}}$$

$\boxed{\Gamma_{PN,t}}$ Cost of adjusting prices in nontradable goods sector

$$\Gamma_{PN,t}=\frac{\phi_{N1}}{2}\left(\frac{\pi_{N,t}}{\pi}-1\right)^2+\frac{\phi_{N2}}{2}\left(\frac{\pi_{N,t}}{\pi_{N,t-1}}-1\right)^2$$

$\boxed{\frac{W_t}{P_t}}$ Real consumer wage

$$\frac{W_t}{P_t}=\left(\frac{\phi V_t^{\iota}}{U_t^{\iota}}\right)\Big[(\phi-1)\left(1-\Gamma_{W,t}\right)$$

$$+\frac{\phi_{W1}\pi_{W,t}}{\pi}\left(\frac{\pi_{W,t}}{\pi}-1\right)+\frac{\phi_{W2}\pi_{W,t}}{\pi_{W,t-1}}\left(\frac{\pi_{W,t}}{\pi_{W,t-1}-1}\right)$$

$$-E_tD_{t,t+1}\pi_{W,t+1}\frac{\ell_{t+1}}{\ell_t}\left(\frac{\phi_{W1}\pi_{W.t+1}}{\pi}\left(\frac{\pi_{W,t+1}}{\pi}-1\right)+\frac{\phi_{W2}\pi_{W,t+1}}{\pi_{W,t}}\left(\frac{\pi_{W,t+1}}{\pi_{W,t}}-1\right)\ \ \right)\ \Big]^{-1}$$

$\boxed{U_t^l}$ Marginal utility of consumption

$$U_t^l=Z_{U,t}\left(C_t-bC_{t-1}\right)^{-\sigma}$$

$\boxed{V_t^l}$ Marginal disutility of labor

$$V_t^l = Z_{V,t} \ell_t^{\xi}$$

$\boxed{\Gamma_{W,t}}$ Cost of adjusting the nominal wage

$$\Gamma_{W,t} = \frac{\phi_{W1}}{2}\left(\frac{\pi_{W,t}}{\pi} - 1\right)^2 + \frac{\phi_{W2}}{2}\left(\frac{\pi_{W,t}}{\pi_{W,t-1}} - 1\right)^2$$

$\boxed{\frac{R_t}{P_t}}$ Real rental rate on capital

$$\frac{1}{\Psi_t^l} = E_t\left(D_{t,t+1}\pi_{t+1}\left(\frac{R_{t+1}}{P_{t+1}} + \frac{1}{\Psi_{t+1}^l}\right)\left[1 - \delta + \Psi_{t+1}\left(1 - \frac{\Psi_{t+1}^l}{\Psi_{t+1}}\frac{I_{t+1}}{K_{t+1}}\right)\right]\right) \quad)$$

$\boxed{\Psi_t}$ Investment-to-capital ratio net of adjustment costs

$$K_t = K_{t-1}\left(1 - \delta\right) + \Psi_{t-1}K_{t-1}$$

$\boxed{I_t}$ Investment

$$\Psi_t = \frac{I_t}{K_t} - \frac{\phi_{I1}}{2}\left(\frac{I_t}{K_t} - \delta\left(1 + Z_{I,t}\right)\right)^2 - \frac{\phi_{I2}}{2}\left(\frac{I_t}{K_t} - \frac{I_{t-1}}{K_{t-1}}\right)^2$$

$\boxed{\Psi_t^l}$

$$\Psi_t^l = 1 - \phi_{1I}\left(\frac{I_t}{K_t} - \delta\left(1 + Z_{I,t}\right)\right) - \varphi_{I2}\left(\frac{I_t}{K_t} - \frac{I_{t-1}}{K_{t-1}}\right)$$

P_L Price of Land

$$LAND_t = \gamma_O\left(\frac{P_{L,t}/P_t}{Z_{O,t}P_{O,t}/P_t}\right)^{-\xi_O}\frac{T_{O,t}}{Z_{O,t}}$$

$\boxed{\frac{\overline{P}_{O,t}}{P_t}}$ Real producer price of oil

$$\frac{\overline{P}_{O,t}}{P,t} = \omega_O\frac{\overline{P}_{QOA,t}}{P_t} + \left(1 - \omega_O\right)\frac{\overline{P}_{QO,t}}{P_t}$$

$\boxed{\pi_t}$ Consumer price inflation

$$D_{t,t+1} = \frac{\beta}{\pi_{t+1}} \frac{U^l_{t+1}}{U^l_t} \frac{1+\Gamma_{S,t} + \Gamma^l_{S,t^{V_t}}}{1+\Gamma_{S,t+1} + \Gamma^l_{S,t+1^{V_{t+1}}}}$$

$\boxed{\Gamma_{S,t}}$ Adjustment costs in consumption (shopping technology)

$$\Gamma_{S,t} = \phi_{S1^{V_t}} + \frac{\phi_{S2}}{v_t} - 2\sqrt{\phi_{S1}\phi_{S2}}$$

$\boxed{\Gamma^l_{S,t}}$

$$\Gamma^l_{S,t} = \phi_{S1} - \frac{\phi_{S2}}{v_t^2}$$

$\boxed{\frac{M_t}{P_t}}$ Real money balances

$$v_t = \frac{C_t}{M_t / P_t}$$

$\boxed{D_{t,t+1}}$ Stochastic one-period discount rate (pricing kernel)

$$1 = \left(1 + i_{t+1}\right) E_t D_{t,t+1}$$

$\boxed{v_t}$ Money velocity

$$E_t D_{t,t+1} = 1 - \Gamma^l_{S,t^{v_t^2}}$$

$\boxed{i_{t+1}}$ Interest rate reaction function

$$\left(1 + i_{t+1}\right)^4 - 1 = \omega_1 \left[\left(1 + i_t\right)^4 - 1\right]$$

$$+\left(1-\omega_1\right)\left[\left(1+\bar{i}_{t+1}\right)^4 - 1\right] + \omega_2 E_t\left[\pi_{t+\tau}\pi_{t+\tau-1}\pi_{t+\tau-2}\pi_{t+\tau-3} - \Pi_{t+\tau}\right] + \omega_3\left(outputgap\right)$$

$\boxed{\bar{i}_{t+1}}$ Equilibrium nominal interest rate

$$\left(1+\bar{i}_{t+1}\right)^4 = E_t \frac{\pi_{t+\tau}\pi_{t+\tau-1}\pi_{t+\tau-2}\pi_{t+\tau-3}}{\beta^4}$$

$\boxed{C_t}$ Consumption

$$A_t = C_t\left[1+\Gamma_{S,t}\right]+G_{A,t}+I_t$$

K_t Total capital stock

$$K_t = K_{N,t}+K_{T,t}+K_{O,t}$$

$\boxed{\ell_t}$ Total labor input

$$\ell_t = \ell_{N,t}+\ell_{T,t}+\ell_{O,t}$$

Equations involving both Home-and Foreign-related terms

$\boxed{\dfrac{\bar{P}_{M,t}}{P_t}}$ Home producer price of imported intermediate tradable good

$$0=\left(1-\Gamma_{PM,t}\right)\frac{\bar{P}_{M,t}/P_t}{P_{M,t}/P_t}\left(\frac{\bar{P}_{M,t}}{P_t}\left(\frac{\varepsilon_t P_t^*}{P_t}\right)^{-1}\left(1-\theta_T^*\right)+\eta\frac{P_{N,t}}{P_t}\left(\frac{\varepsilon_t P_t^*}{P_t}\right)^{-1}+\theta_T^*\frac{MC_{T,t}^*}{P_t^*}\right)$$

$$-\left(\frac{\bar{P}_{M,t}}{P_t}\left(\frac{\varepsilon_t P_t^*}{P_t}\right)^{-1}-\frac{MC_{T,t}^*}{P_t^*}\right)\left(\frac{\phi_{M1}\bar{\pi}_{M,t}}{\pi}\left(\frac{\bar{\pi}_{M,t}}{\pi}-1\right)+\frac{\phi_{M2}\bar{\pi}_{M,t}}{\bar{\pi}_{M,t-1}}\left(\frac{\bar{\pi}_{M,t}}{\bar{\pi}_{M,t-1}}-1\right)\right)$$

$$+E_t D_{t,t+1}^*\left(\frac{\bar{P}_{M,t+1}}{P_{t+1}}\left(\frac{\varepsilon_{t+1}P_{t+1}^*}{P_{t+1}}\right)^{-1}-\frac{MC_{T,t+1}^*}{P_{t+1}^*}\right)\pi_{t+1}^*\frac{M_{t+1}}{M_t}$$

$$*\left(\frac{\phi_{M1}\pi_{M,t+1}}{\pi}\left(\frac{\bar{\pi}_{M,t+1}}{\pi}-1\right)+\frac{\phi_{M2}\bar{\pi}_{M,t+1}}{\bar{\pi}_{M,t}}\left(\frac{\bar{\pi}_{M,t+1}}{\bar{\pi}_{M,t}}-1\right)\right)$$

$\boxed{\dfrac{\bar{P}_{M,t}^*}{P_t^*}}$ Foreign producer price of imported intermediate tradable good

$$0=\left(1-\Gamma^*_{PM,t}\right)\frac{\overline{P}^*_{M,t}/P^*_t}{P^*_{M,t}/P^*_t}\left(\frac{\overline{P}^*_{M,t}}{P^*_t}\frac{\varepsilon_t P^*_t}{P_t}\left(1-\theta_T\right)+\eta^*\frac{P^*_{N,t}}{P^*_t}\frac{\varepsilon_t P^*_t}{P_t}+\theta_T\frac{MC_{T,t}}{P_t}\right)$$

$$-\left(\frac{\overline{P}^*_{M,t}}{P^*_t}\frac{\varepsilon_t P^*_t}{P_t}-\frac{MC_{T,t}}{P_t}\right)\left(\frac{\phi^*_{M1}\pi^*_{M,t}}{\pi^*}\left(\frac{\overline{\pi}^*_{M,t}}{\pi^*}-1\right)+\frac{\phi^*_{M2}\pi^*_{M,t}}{\overline{\pi}^*_{M,t-1}}\left(\frac{\overline{\pi}^*_{M,t}}{\overline{\pi}^*_{M,t-1}}-1\right)\right)$$

$$+E_tD_{t,t+1}\left(\frac{\overline{P}^*_{M,t+1}}{P^*_{t+1}}\frac{\varepsilon_{t+1}P^*_{t+1}}{P_{t+1}}-\frac{MC_{T,t+1}}{P_{t+1}}\right)\pi_{t+1}\frac{M^*_{t+1}}{M^*_t}$$

$$*\left(\frac{\phi^*_{M1}\pi^*_{M,t+1}}{\pi^*}\left(\frac{\overline{\pi}^*_{M,t+1}}{\pi^*}-1\right)+\frac{\phi^*_{M2}\overline{\pi}^*_{M,t+1}}{\overline{\pi}^*_{M,t}}\left(\frac{\overline{\pi}^*_{M,t+1}}{\overline{\pi}^*_{M,t}}-1\right)\right)$$

$\boxed{T_t}$ Tradable intermediate good consumption in Home country.

$$sT_t=sQ_t+\left(1-s\right)M^*_t$$

$\boxed{T^*_t}$ Tradable intermediate good consumption in Foreign country

$$\left(1-s\right)T^*_t=\left(1-s\right)Q^*_t+sM_t$$

$\boxed{T_{O,t}}$ Tradable intermediate input consumption in Home country

$$sT_{O,t}=sQ_{ON,t}+sQ_{OT,t}+sQ_{OA,t}+\left(1-s\right)M^*_{ON,t}+\left(1-s\right)M^*_{OT,t}+\left(1-s\right)M^*_{OA,t}$$

$\boxed{T^*_{O,t}}$ Tradable intermediate input consumption in Foreign country

$$\left(1-s\right)T^*_{O,t}=\left(1-s\right)Q^*_{ON,t}+\left(1-s\right)Q^*_{OT,t}+\left(1-s\right)Q^*_{OA,t}+sM_{ON,t}+sM_{OT,t}+sM_{OA,t}$$

$\boxed{\frac{B^*_{H,t+1}}{P^*_t}}$ Bonds

$$\Gamma_{B,t+1}=\phi_{B1}\frac{\exp\left\{\phi_{B2}\frac{B^*_{H,t+1}}{P^*_t}\frac{\varepsilon_t P^*_t}{}\right\}-1}{\exp\left\{\varphi_{B2}\frac{B^*_{H,t+1}}{P^*_t}\frac{\varepsilon_t P^*_t}{P_t}\right\}+1}+Z_{B,t}$$

$\boxed{\Gamma_{B,t+1}}$ Adjustment cost on bonds

$$1=\left(1+i_{t+1}^{*}\right)\left(1-\Gamma_{B,t+1}\right)E_t\left(D_{t,t+1}\Delta_{t+1}\right)$$

$\boxed{\Delta_t}$ Nominal exchange rate depreciation

$$\Delta_t=\frac{\varepsilon_t P_t^*}{P_t}\left(\frac{\varepsilon_{t-1}P_{t-1}^*}{P_{t-1}}\right)^{-1}\frac{\pi_t}{\pi_t^*}$$

$\boxed{\frac{F_t}{P_t}}$ Financial wealth

$$\frac{F_t}{P_t}=\left(1+i_t^*\right)\left(1-\Gamma_{B,t}\right)\frac{1}{\pi_t^*}\frac{\varepsilon_t P_t^*}{P_t}\frac{B_{H,t}^*}{P_{t-1}^*}$$

$\boxed{\frac{\varepsilon_t P_t^*}{P_t}}$ Real exchange rate

$$E_t D_{t,t+1}\frac{F_{t+1}}{P_{t+1}}\pi_{t+1}=\frac{F_t}{P_t}+\left(1+i_t^*\right)\frac{\Gamma_{B,t}}{\pi_t^*}\frac{B_{H,t}^*}{P_{t-1}^*}\frac{\varepsilon_t P_t^*}{P_t}$$

$$+\frac{1-s}{s}\frac{\varepsilon_t P_t^*}{P_t}\left(\frac{\bar{P}_{M,t}^*}{P_t^*}M_t^*+\frac{\bar{P}_{MO,t}^*}{P_t^*}\left(M_{ON,t}^*+M_{OT,t}^*\right)+\frac{\bar{P}_{MOA,t}}{P_t^*}M_{OA,t}^*\right)$$

$$-\frac{\bar{P}_{M,t}}{P_t}M_t-\frac{\bar{P}_{MO,t}}{P_t}\left(M_{ON,t}+M_{OT,t}\right)-\frac{\bar{P}_{MA,t}}{P_t}M_{OA,t}$$

Other Useful equations

Aggregate current account

$$CUR_t=sE_tD_{t,t+1}\frac{F_{t+1}}{P_{t+1}}\pi_{t+1}-s\frac{F_t}{P_t}=\left(1-s\right)\frac{\varepsilon_t P_t^8}{P_t}\left(\frac{\bar{P}_{M,t}^*}{P_t^*}M_t^*+\frac{\bar{P}_{MO,t}}{P_t^*}\left(M_{ON,t}^*+M_{OT,t}^*\right)+\frac{\bar{P}_{MOA,t}^*}{P_t^*}M\right.$$

$$-s\frac{\bar{P}_{M,t}}{P_t}M_t-s\frac{\bar{P}_{MO,t}}{P_t}\left(M_{ON,t}+M_{OT,t}\right)-\frac{\bar{P}_{MA,t}}{P_t}M_{OA,t}+s\left(1+i_t^*\right)\frac{\Gamma_{B,t}}{\pi_t^*}\frac{B_{H,t}^*}{P_{t-1}^*}\frac{\varepsilon_t P_t^*}{P_t}$$

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