Preliminary and Incomplete

Rapidly Rising Energy Prices: Does the Driver of the Energy Market Imbalance Matter?

by Jared Bebee and Ben Hunt

Abstract

This paper uses a variant of the IMF 's Global Economy Model (GEM) to examine the macroeconomic impact on the major industrial countries of the rise in energy prices since the end of 2003. The analysis illustrates how the impact varies across industrial countries based on their level of energy use and energy production. In addition, the analysis considers how the macroeconomic implications depend on the factors driving higher energy prices. If labor supply and tradable sector productivity increases in emerging Asian economies are an important factor driving energy price increases, then industrial countries receive some positive terms-of-trade effects coming through non-energy tradable goods that offset some of the negative implications of permanently higher real energy prices. The stronger are the industrial countries' trade links with emerging Asia, the larger will be the offsets.

1.0 Introduction

The rise in energy prices since the beginning of 2004 has had an important impact on the large industrial countries. Inflation, which had long been subdued, even during the high-tech boom years of the late 1990s, has accelerated in most industrial countries. GDP growth, while still healthy in most industrial countries, has slowed relative to expectation. In this paper, a variant of the IMF's Global Economy Model (GEM) is used to estimate the contribution of rising energy prices to these developments. The paper also considers whether the source of the imbalance in the energy market that has driven energy prices higher has implications for the macroeconomic consequences.

The model incorporates energy (oil and natural gas) as a final consumption good as well as a primary input in the production process. Because energy enters the consumption basket directly, increases in energy prices quickly affect household welfare through their impact on the level of consumer prices and thus households' real wage. With energy entering the production process, increases in energy costs affect overall aggregate supply capacity as firms reduce output and factor utilization rates given the real increase in their costs structures. Because there is a complete market for energy in the model, the analysis can consider how the source of the imbalance between energy supply and demand influences the macroeconomic consequences.

The analysis of the impact of higher energy prices focuses on four key issues: the likely implications for the level of economic activity; the magnitude of the direct impact on headline inflation; the mechanisms through which permanently higher energy prices could lead to persistently high inflation; and how the source of the energy market imbalance affects the macroeconomic implications. Some of the analysis is based on the rise in oil prices that has occurred since the end of 2003. To attempt to adequately capture the important role played by expectations, a multi-period shock is implemented that uses futures market data to proxy for how model agents' expectations about the permanent component of the shock evolved over that period.

The simulation results suggest that the long-run implications for GDP in most industrial countries except Canada, depends of the factors underlying higher energy prices. Because of its large net export position in energy, Canadian GDP will likely rise no matter what is the source of higher energy prices is. For all countries, the resulting rise in headline CPI inflation reflects the energy intensity of final consumption. This rise in inflation can be persistent if labor suppliers resist the required declines in their real wages and monetary authorities underestimate the supply side implications of higher energy prices. Alternatively, if higher energy prices are being driven by non-energy sector supply factors in emerging Asia for example, the simulation results suggest that the inflation effects could be persistent even in the absence of policy errors or inappropriate adjustment in real wages.

The remainder of the paper is structured as follows. In section 2 a brief, non-technical outline of GEM is presented focusing on how energy is integrated into the model's structure. The calibration of the model is also outlined in this section. A technical description of the incorporation of energy into GEM is presented in the Appendix. Section 3 presents the simulation results for industrial countries of an increase in energy prices that mimics the increase that has occurred in oil prices since the beginning of 2004 using futures prices to guide the evolution about the shocks expected persistence. The implications of some alternative responses of the monetary authority and wage bargainers in the U.K. economy are examined section 4. Section 5 considers the implications of the source of the energy market imbalance for the macroeconomic consequences using the Euro Area. Some conclusions are offered in section 6.

2.0 The Global Economy Model - GEM

GEM is a large multi-country macroeconomic model derived completely from optimizing foundations. The version used here characterizes the behavior of two countries, home and foreign. The home country is alternatively calibrated to represent the major industrial economies, the United Kingdom, the Euro Area, the United States, Japan and Canada. In each case, the foreign country represents the rest of the world. The model describes the behavior of three types of agents: households; firms; and government. Below, only a brief overview of GEM is presented and the interested reader can look to Laxton and Pesenti (2003) and Hunt and Rebucci (2005) for a more detailed description of the model's structure and properties.

2.1 Households

Households are infinitely lived, consume a bundle of goods, are the monopolistic suppliers of differentiated labor inputs to all domestic firms, and own the capital stock. Households exhibit habit persistence in their consumption behavior contributing to real rigidities in economic adjustment. Monopoly power in labor supply implies that the wages households receive contain a markup over the marginal rate of substitution between consumption and leisure. Because wage contracts are subject to adjustment costs, aggregate nominal rigidities arise through the wage bargaining process. Households rent the capital stock to firms in a competitive market. Capital accumulation is subject to adjustment costs that contribute to gradual economic adjustment. Capital and labor are immobile internationally and households only trade short-term nominal bonds internationally.

Households consume energy goods directly along with other tradable and nontradable goods. Households' final consumption bundle is given by:

$$A = f(N, Q, M, Q_E, M_E), \qquad (1)$$

where A is the bundle of final goods consumed by households, N represents nontradable goods, Q represents domestically produced tradable goods, M represents imported tradable goods, Q_E represents domestically produced energy goods, and M_E represents imported energy goods. The function, f, is a nested constant elasticity of substitution (CES) aggregator.

2.2 Firms

Firms produce three types of goods: nontradable goods, non-energy tradable goods, and a tradable energy good. Goods are assumed to be differentiated giving rise to market power that enables firms to charge a markup over the marginal cost of production. Non-energy goods prices are subject to adjustment costs that along with slowly adjusting wages give rise to the gradual adjustment of intermediate goods prices in response to economic disturbances.

Firms combine capital, labor, and energy to produce the tradable and nontradable goods. The production process is given by:

$$Y = f(K, L, Q_E, M_E), \tag{2}$$

where Y denotes the output of tradable and nontradable goods (N, Q), K is the capital input, L is the labor input, Q_E is the domestically produced energy input, and M_E is the imported energy input. The production technology, f, embodies constant elasticity of substitution, however, firms face adjustment costs in both capital and energy that reduce the short-run elasticity of substitution below the long-run elasticity.

Energy producing firms combine capital, labor, and land to produce the tradable energy good. The production technology is given by:

$$Q_E = f(K, L, Land), \tag{3}$$

where Q_E is domestically produced energy, K represents the capital input, L denotes the labor input, and $Land$ is the known available reserve of energy. The production technology, f, embodies constant elasticity of substitution.

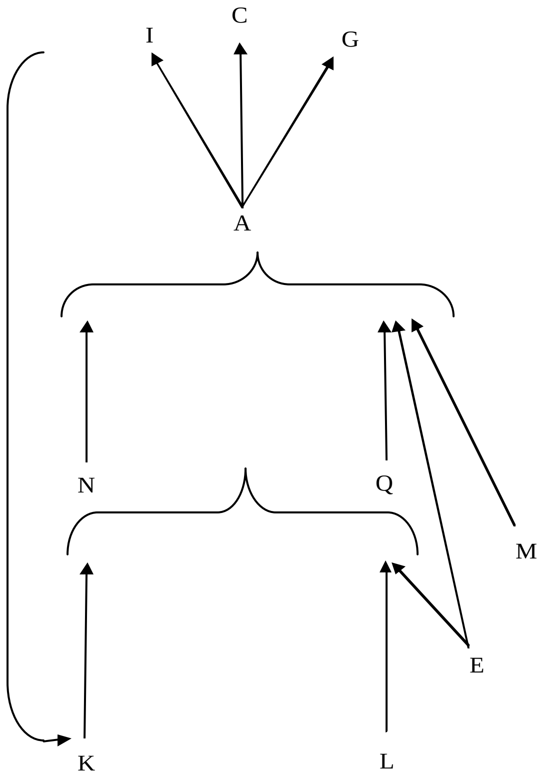
2.3 Government

Government consumes a bundle of goods identical to that consumed by households. Government spending is financed through a non-distorting tax. The government controls the national short-term interest rate with the objective of providing a nominal anchor for the economy, which here is assumed to be the rate of CPI inflation. The monetary policy reaction function is given by:

$$i_t = w_1 \bullet i_{t-1} + (1 - w_1)\left[\bar{i}_t + w_2 \bullet E_t\left(p_t - \Pi_t\right) + w_3\left(outputgap\right)\right], \tag{4}$$

where i_t is the annualized short-term nominal interest rate, $\bar{i}_t$ is the equilibrium nominal interest rate, E_t denotes an expectations operator, p_t denotes year-over-year CPI inflation, Π_t is the target rate of inflation, and *outputgap* is the difference between the level of output and potential output. The $w_i s$ represent response coefficients. Equation (4) in its general form represents the familiar Taylor (1993) policy rule.

Figure 1. Simplified GEM Structure



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

2.4 Calibration[1]

Energy is assumed to represent oil and natural gas. The historical correlation of these two energy prices presented in Figure 2 suggests that this is appropriate. The main focus of the calibration has been to achieve two key properties in energy prices: home and foreign energy prices moving together; and energy prices that are considerably more volatile over the business cycle than other prices.

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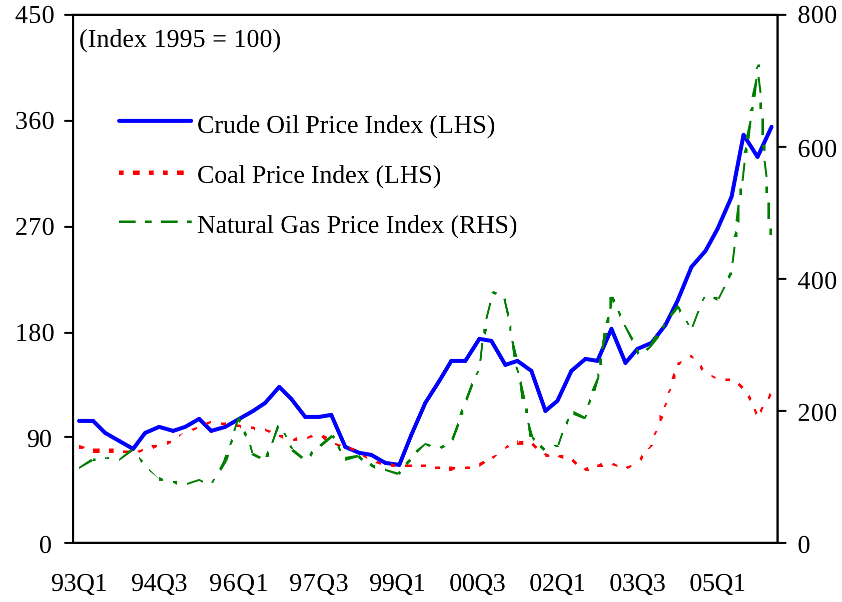
[1] A more detailed discussion of the calibration of the energy structure in GEM can be found in Hunt (2005).

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; and World Bank.

The elasticities of substitution play a central role in achieving the desired properties. The elasticity of substitution between home and foreign produced energy in both consumption and production is calibrated to be high to ensure the that home and foreign energy prices move together. The calibration of three elasticities of substitution and the importance of the fixed factor in energy production contribute to the desired cyclical volatility in energy prices. First, a relatively low elasticity of substitution between energy and non-energy tradable goods in consumption. Second, standard unitary elasticity of substitution among capital, labor and energy in non-energy goods production (Cobb Douglas) combined with costly adjustment. Third, a low elasticity of substitution among the fixed factor (*Land)*, labor, and capital in the production of the energy good in industrial countries.[2] Further, the fixed reserve of energy, *Land*, is assumed to be the most significant input into energy production.

The energy intensities, valued at producer prices, of the major industrial countries have been calibrated to match their levels as of end-2003. The energy intensities that the model has been calibrated to replicate are presented in Table 1. A number of points are worth noting. First, the United Kingdom and Canada are net exporters of energy. Second, for some countries it was necessary to make assumptions about the split between energy as a primary

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[2] Cobb Douglas technology is assumed in energy production in the foreign sector.

input into production and energy consumed directly by households because of data limitations. Third, the model has not been calibrated to replicate the exact treatment of energy taxes. Value added taxes, however, are important because they affect the transmission of energy price shocks into the CPI. Consequently, for the United Kingdom, a value added tax of 17.5 percent has been included.

Table 1.Energy Intensities of the Major Industrial Countries

Expressed as a share of nominal GDP (oil and natural gas valued at producer prices)

	United Kingdom	*Euro Area*	*United States*	*Canada*	*Japan*
Production	2.23	0.16	1.50	6.80	0.02
Imports	0.71	1.60	1.26	1.22	1.38
Total Available	2.94	1.76	2.76	8.02	1.40
Total Use	1.94	1.76	2.72	4.05	1.40
Input	1.15	1.02	1.23	2.23	0.70
Consumption	0.79	0.73	1.49	1.82	0.70
Net Exports	0.29	-1.60	-1.22	2.75	-1.38

Source: OECD, IEA Database; and IMF Staff estimates.

3.0 Energy Price Shocks

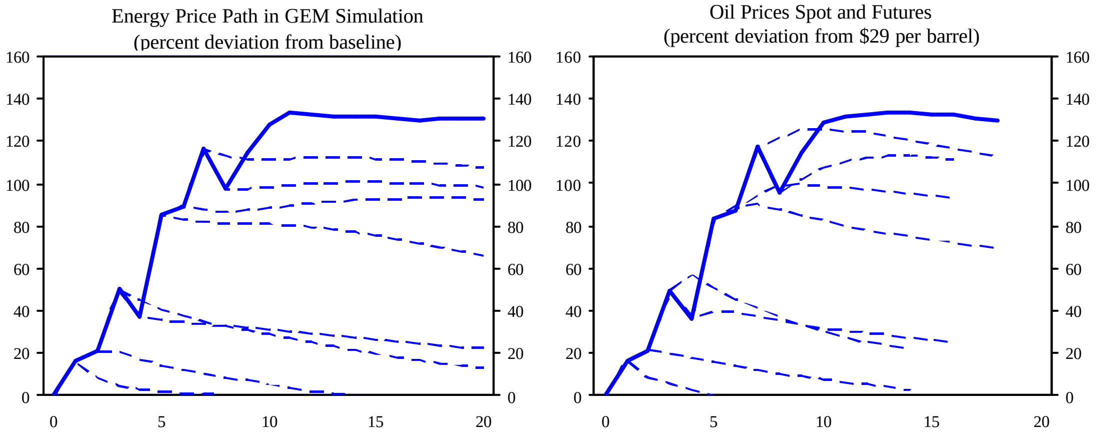
Given the complete market for energy in GEM, the price of energy is the result of the interaction of supply and demand factors. To implement an increase in the price of energy in this section, factors on the supply side are altered. These factors could be either the markup demanded by the monopolistic suppliers of energy or the available reserve of energy (*Land*). Comparisons indicates that the macroeconomic implications are independent of the factor altered. The increases in energy prices in the 1970s are generally interpreted to have arisen because of the actions of energy producers restricting the supply. The implementation of the shock in this section is consistent with this. However, the increase in energy prices that has occurred recently is, in part, interpreted as the outcome of the demand for energy increasing faster than available supply. Faster than expected growth in energy demand in emerging Asian economies is cited as a key factor reflecting rapid expansion in their production of tradable goods. The implications of this are examined in section 5 because of its potentially important impact on the major industrial countries.

3.1 The Increase in Energy Prices Since End-2003

Since end-2003, oil prices have increased by over 100 percent. To examine the implications for the major industrial countries, an energy price increase that broadly matches that seen in oil prices over the 2004Q1 to 2006Q1 period is simulated. One important feature of the recent energy price increase has been the gradual evolution of expectations regarding its persistence. Looking at futures' market prices, it appears that at the beginning of 2004, the increase in the price of oil above the 30 dollars a barrel level was thought to be temporary. As prices accelerated throughout the year and into 2005, it appears that expectations of the price rise's persistence increased. To capture the impact of gradually evolving expectations, the simulations that follow are built up, quarter by quarter, with an energy price shock that matches that seen in the data both in terms of its magnitude and its expected persistence. The left-hand panel in Figure 2 presents the energy price shock considered. The solid line denotes the increase in energy price that occurred between 2004Q1 and 2006Q1 and its expected persistence as of 2006Q1. The dashed lines denoted the persistence of the shock in each quarter of the multi-period simulation. In each period in the simulation experiment, agents' expectation of the shock's persistence broadly matches the expected path for oil prices as suggested by futures market prices. The right-hand panel in Figure 2 illustrates the actual increase in oil prices and the futures' market path.

Figure 2. Energy Prices - Simulation and Data

Solid Line - represents actual path and expected path beyond quarter 9.
Dashed Line - represents expected path at each quarter prior to quarter 9.


Energy Price Path in GEM Simulation
(percent deviation from baseline)

Oil Prices Spot and Futures
(percent deviation from $29 per barrel)

Source: Bloomberg and GEM Simulations.

These simulations are done assuming that monetary policy follows the standard inflation-forecast-targeting rule presented early and given by:

$$i_t = w_1 \bullet i_{t-1} + (1-w_1)\left[\bar{i}_t + w_2 \bullet E_t(p_t - \Pi_t) + w_3(outputgap)\right], \qquad (4)$$

where i_t is the annualized short-term nominal interest rate, $\bar{i}_t$ is the equilibrium nominal interest rate, E_t denotes an expectations operator, p_t denotes year-over-year CPI inflation, Π_t

is the target rate of inflation, and *outputgap* is the difference between the level of output and potential output. The $w_i s$ represent response coefficients. For these simulations $?_1 = 0.5$, $?_2 = 0.5$, and $?_3 = 0$.[3] The simulation is run assuming no change in nominal interest rates in the first nine quarters of the shock. Since energy prices started to rise in early 2004, there has been little evidence that monetary authorities have been raising policy rates in response. Further, the impact of higher energy prices in the absences of policy response to the first-round affect is an interesting starting point for the analysis. Given that the endogenous policy rule used in the simulations would lead to an increase in the nominal rate as current inflation increases, the interest rate is temporarily fixed at baseline at the start of each of the iterative simulations. The final outcome is that interest rates remain at baseline for the first nine quarters. Beyond that horizon, the endogenous policy rule switches back on.

The simulated responses of the key macroeconomic variables in the United Kingdom, the Euro Area and the United States to the multi-period energy price increase are presented in Figure 3. Figure 4 presents the results for Japan and Canada. The peak effect on year-over-year CPI inflation ranges from just over 1 percentage point in Canada to roughly ½ percentage point in Japan reflecting the energy intensities of final consumption. The peaks occur in the fifth quarter. Beyond that horizon, the impact on inflation moderates. Assuming oil prices follow the futures market path as of end-March 2006, the impact on year-over-year CPI inflation turns negative before returning toward baseline. Because of the model's structure, the direct impact of energy price changes are reflected immediately in the CPI. In reality, this pass-through is likely slower and, consequently, the precise quarterly dynamics should not be interpreted too literally.[4]

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[3] GEM's representative agent structure combined with the assumption that domestic households own all the capital stock has some important implications under energy price shocks that must be considered carefully. Households in energy producing countries receive a positive wealth shock from the increased returns in energy production when real energy prices rise. The structure of the model is such that households consume out of that wealth with their standard propensities. However, the increased returns in the energy sector are probably not widely spread and the propensity to consume out of the increase in wealth is likely much lower than average. To more accurately portray the likely impact on U.K. GDP, an additional temporary shock to household preferences is include so that in the near-term, U.K. consumption behaves similarly to consumption in the Euro Area. Although this a factor in Canada as well, (and could be a factor for the U.S. because of the level of energy production there) no additional shock has been included. Consequently, the near-term positive impact on GDP in Canada is likely to be more subdued than these results suggest. This is an area that will be addressed more carefully in future work.

[4] Because of the model's complete choice theoretic framework, there is no scope for making ad hoc changes to the dynamic adjustment properties to more closely match the pass-through properties in the data.

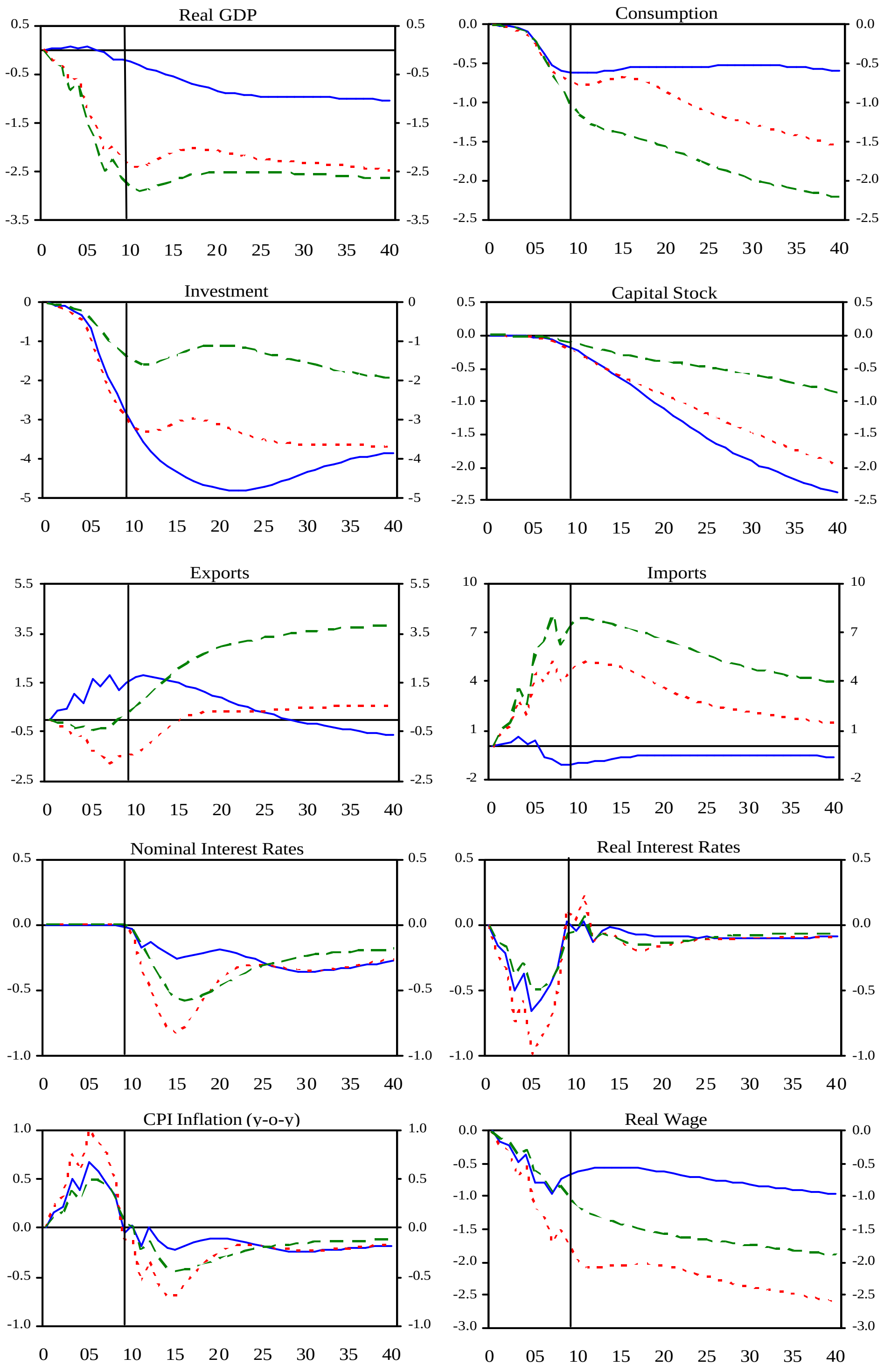
The impact of the shock on GDP varies across countries. In the United States, the euro area, and Japan the effect is negative and grows over time as the supply side of the economy adjusts to the permanently higher input cost. For the United Kingdom, the initial impact is slightly positive as the increase in the real value of exports more than offsets the negative effects on investment and consumption that are quite mild due to expectations that the persistent component of the shock is small. As both energy prices and expectations of its persistence continue to rise, the negative impact on both consumption and investment grows, more than offsetting the positive impact on the energy sector and GDP falls below baseline. In Canada, the positive impact on the real value of exports and a consumption boom driven by the significant increase in non-labor income from the energy sector dominate and GDP rises. As the non-energy sector adjusts to the higher input cost, the positive effect on GDP moderates slightly.

There are some interesting differences in the behavior of the capital stock and real wages across countries that reflect the energy intensities of production and the extent of domestic energy production. In the euro area and Japan, where there is essentially no domestic energy production, the capital stock declines the least. This reflects the fact that production of tradable goods must increase considerably to pay for the now much more expensive imported energy goods. In Canada, after the initial decline in the real wage owing to energy-price-induced pickup in the CPI, the real wage actual rises above baseline. The real wage also declines the least in the United Kingdom. In these countries, the impact on household income of the increased returns from the energy sector drive this result. Given the increase in non-labor income, the real wage must temporarily rise in Canada and remain fairly high in the United Kingdom to induce households to supply sufficient labor. This higher real wage leads to capital falling most in Canada and the United Kingdom.

One of the most striking features of these simulation responses is the very benign inflation outcome. This primarily reflects that fact that workers accept the decline in their real consumption wage. In GEM, the real wage is fundamentally pinned down by the interaction of households' preferences and firms' production technology. In the long run, the increase in the real factor cost, energy, leads to a reduction in the capital stock, a decline in the marginal product of labor and, consequently, a reduction in the real producer wage. Although, costly adjustment of nominal wages slows the decline in the real wage, the real wage declines quickly. Households accept the decline in the real consumption wage from both the rise in energy prices and the decline in the real producer wage. Consequently, the increase in firm's energy costs are offset by lower real wages and there are no second-round effects flowing through to non-energy intermediate goods prices and on to CPI inflation. As shown in Hunt, Isard and Laxton (2002), if workers do not attempt to resist this decline in their real wage, then energy price shocks will not result in persistent inflation even if policymakers accommodate the direct impact of the shock on the price level. Alternative specifications of the wage process, such as Calvo (1983) contracts, would generate more inflation persistence if headline CPI inflation was used by those able to renegotiate wages in a particular period and/or used as passive indexing for those unable to renegotiate as is done in Smets and Wouters (2003).

Figure 3. An Energy Price Increase Matching Recent History
(percent or percentage point deviation from baseline)

Solid - United Kingdom Dotted - United States Dashed - Euro area


Real GDP

Consumption

Investment

Capital Stock

Exports

Imports

Nominal Interest Rates

Real Interest Rates

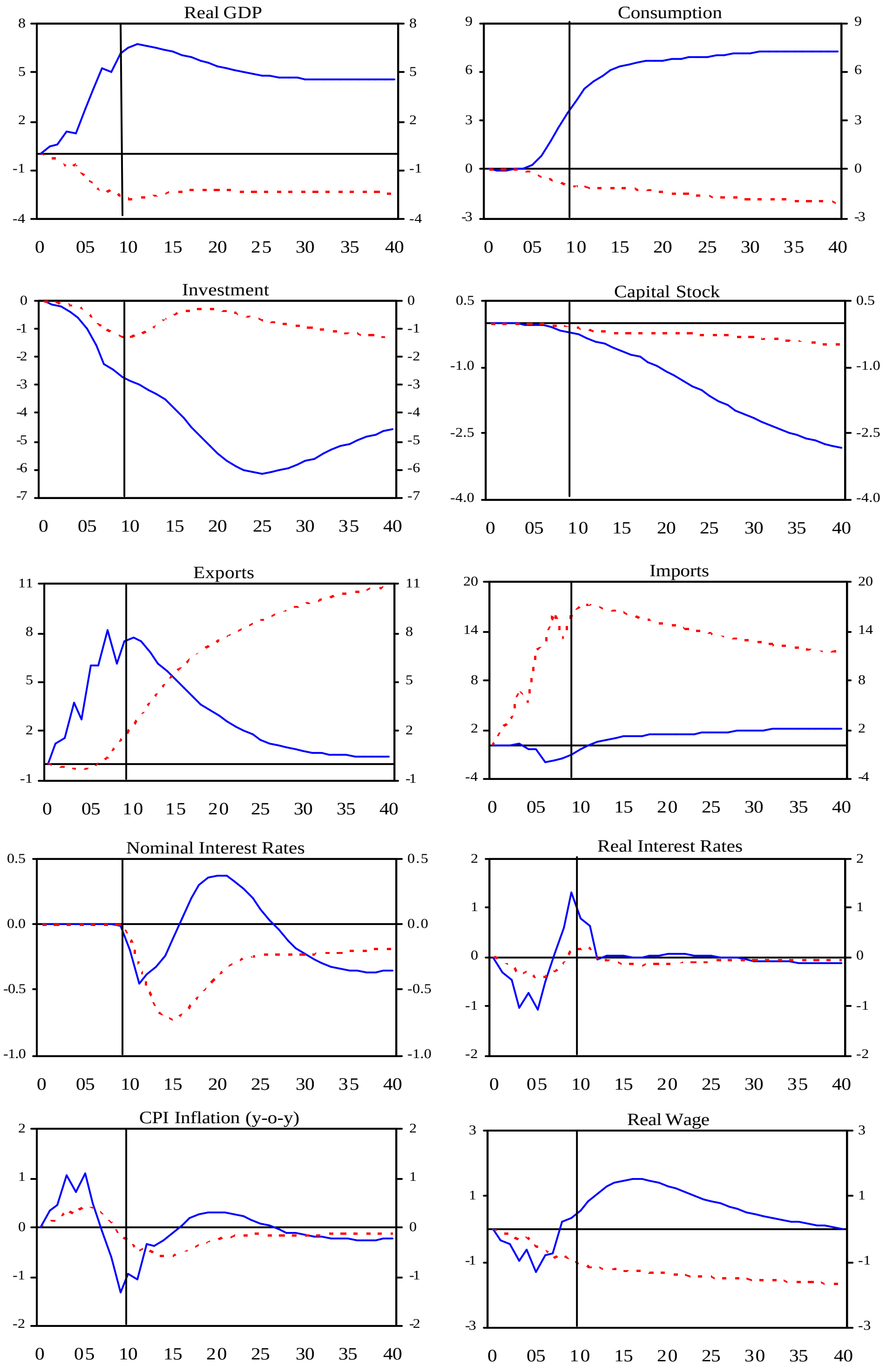
CPI Inflation (y-o-y)

Real Wage

Source: GEM Simulations.

Figure 4. An Energy Price Increase Matching Recent History
(percent or percentage point deviation from baseline)

Solid - Canada Dotted - Japan



Source: GEM Simulations.

4.0 Alternative Responses of the Monetary Authority and Labor Suppliers

In the simulation experiment, the monetary authority's awareness of the supply-side implications and wage bargainers' acceptance of the required decline in their real consumption wage lead to very benign inflation outcomes, even when policy looks through the first round effects. To illustrate how the energy price increase could lead to more persistent inflationary pressures, alternative responses are considered. First, if policymakers model the evolution of the supply-side of the economy as a determinist or highly persistent process, they may only gradually incorporate the supply-side implications into the policy setting process. As illustrated in Orphanides (2000), during the 1970s the real-time estimates of potential output used by the Federal Reserve appeared to considerably overestimate what is now viewed to have been the level of potential output following the first oil price shock in 1973-74. Hunt (2006) illustrates how responding to an overestimate of potential output incorporated into a standard Taylor (1993) rule could have contributed to the secondary burst of persistent inflation that followed initial spike in CPI inflation in the United Sates in 1974-75.

To illustrate this point, the simulation experiment is re-run for the United Kingdom putting a coefficient of unity on the policymaker's estimate of the output gap in equation 4 (dotted line in Figure 5). The policymaker's estimate of potential output only gradually incorporates the negative implications for aggregate supply of the permanent increase in a real factor cost.[5] With monetary policy now aiming to simultaneously stabilize inflation and support aggregate demand at too high a level, a secondary burst of persistent inflation follows the initial spike in CPI inflation generated by the direct effect of higher energy prices. The magnitude and duration of this secondary acceleration in inflation will depend on the speed with which the policymaker learns about the true level of potential output. Faster learning than assumed here would reduce the secondary acceleration. It is interesting to note that nominal interest rates actually rise faster in this scenario than in the base case (solid line in Figure 5) reflecting the important role that expectations can play. Here agents in the model economy understand the policymakers' error and expectations fuel the acceleration in inflation. Policymakers fall behind the curve resulting in real interest rates that are below those in the baseline.

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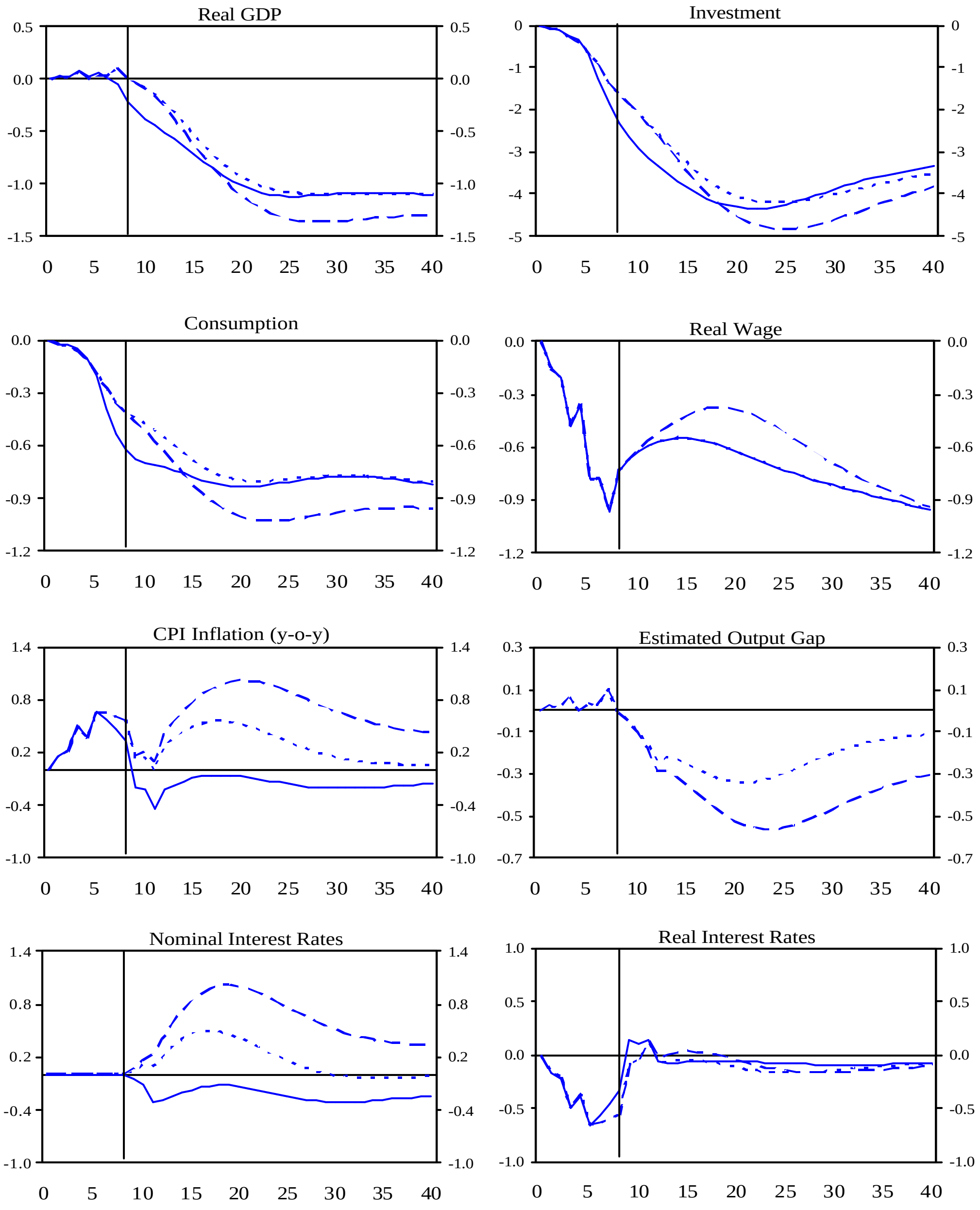
[5] Initially the policymaker's estimate of potential output is generated putting a weight of 0.95 on the pre-shock level of output and a weight of 0.05 on the post-shock long-run level of output that is achieved once all adjustment has occurred. As the policymaker moves through time the weight on the old level of output gradually declines to zero and the weight on the new long-run level of output gradually increases to unity.

Figure 5. Alternative Responses of Monetary Authority and Labor Suppliers
(percent or percentage point deviation from baseline)

Solid - base case.
Dotted - output gap in reaction function.
Dashed - output gap in policy rule and temporary increase in labor suppliers' market power.



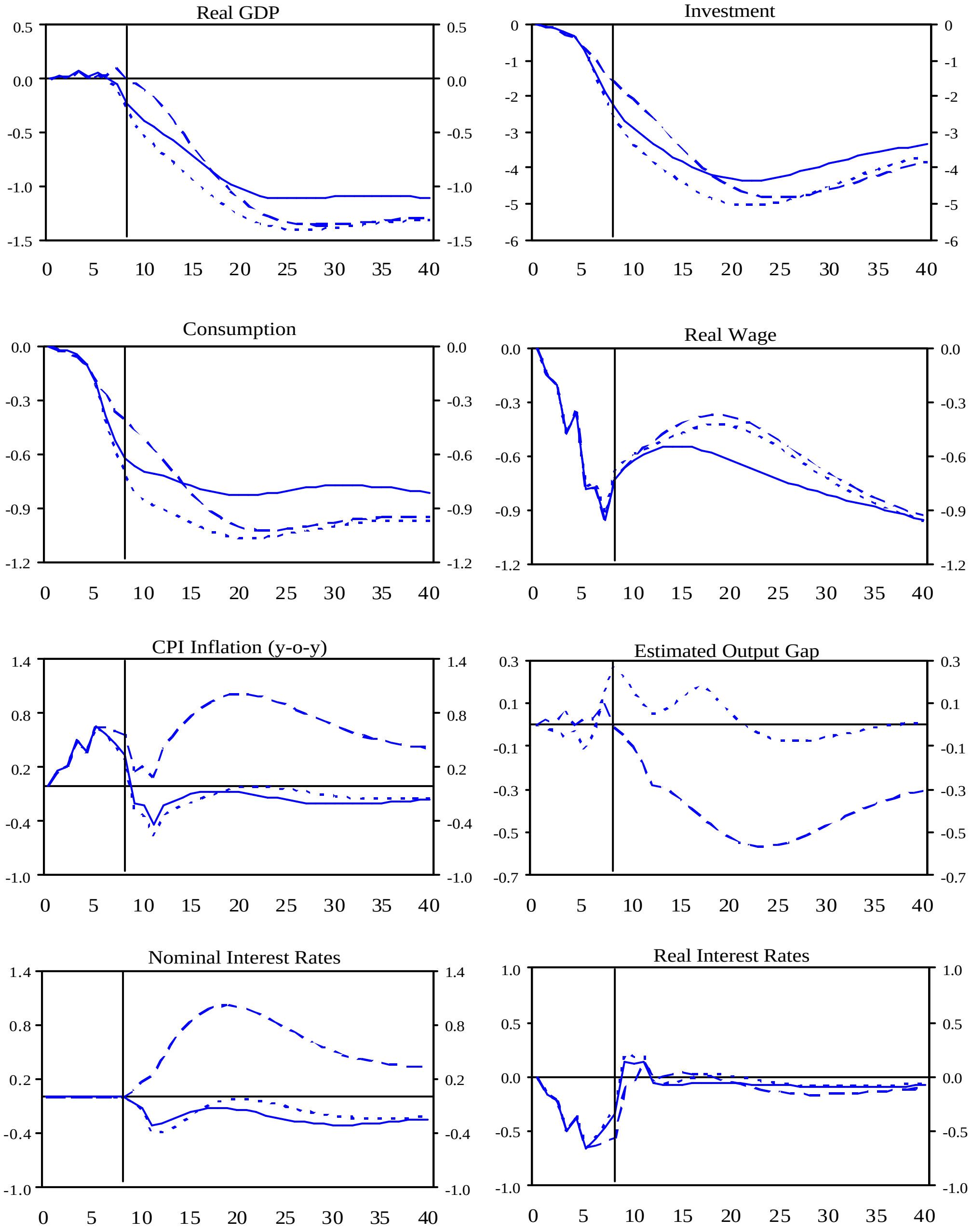
Source: GEM Simulations.

In addition to the inflationary consequences of misperceptions about the level of potential output, the inflation outcome could deteriorate further if workers resist the required decline in their real consumption wage. To illustrate this point, a temporary increase in wage bargainers' market power is added to the simulation (dashed line in Figure 5). This has the effect of adding some resistance to the decline in the real consumer wage. To capture the fact that this resistance would take time to materialize as workers gradually realize that the rise in energy prices is permanent, the increase in market power is phased in during the third and fourth years of the simulation. In part, this increased market power could arise because of the easier monetary conditions. In this scenario, the secondary burst of inflation roughly doubles in magnitude even though the relative increase in real wages is small. This reflects the fact that with the same view of the potential output process, the policymaker's error about the output gap increases. This arises because, given the relatively higher real wages, firms adjust the labor input faster, moving more quickly to the long-run equilibrium level of capacity output.

The important interaction between labor suppliers' response to the shock and the monetary authority's estimate of potential output is highlighted by considering an additional scenario. In this scenario it is assumed that the monetary authority understands the structure of the economy and can compute the flexible-price solution for output. This is the outcome for GDP that would be achieved if there were no nominal rigidities in the economy. This flexible-price level of GDP is then used by the monetary authority as its estimate of potential output. This estimate is in turn used to compute the output gap appearing in the reaction function. Further, this scenario also includes the temporary increase in wage bargainers' market power (dotted line in Figure 6). When the monetary authority fully understands the supply side of the economy, there is no secondary burst of persistent inflation even if there is a temporary increase in workers' market power that slows the adjustment in real wages.

Figure 6. Responding to the Flexible-Price Output Gap
(percent or percentage point deviation from baseline)

Solid - base case.
Dashed - output gap in policy rule and temporary increase in labor suppliers' market power.
Dotted - flexible-price output gap in policy rule and temporary increase in labor suppliers' market power.



Source: GEM Simulations.

5.0 The Implications of the Source of the Energy Market Imbalance

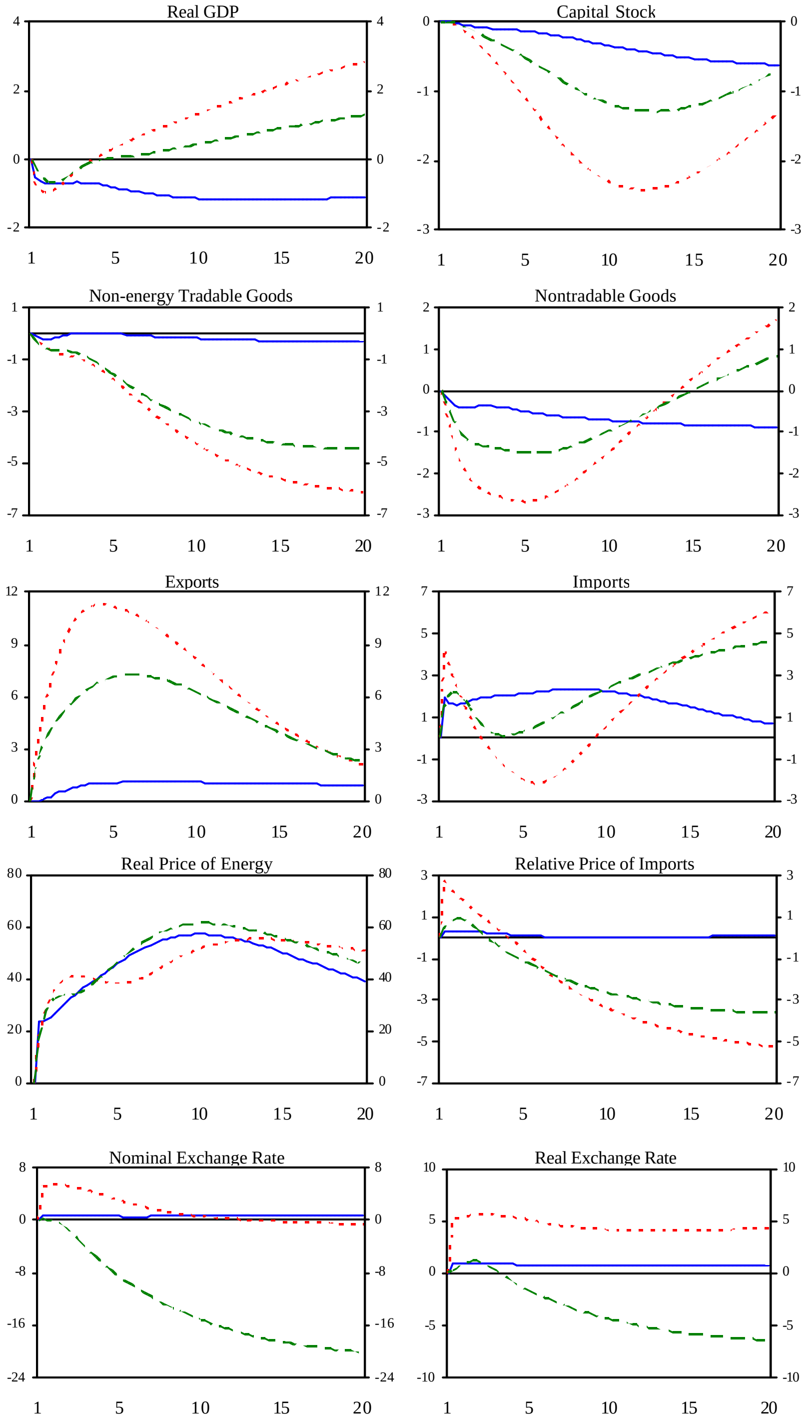
As noted earlier, the energy price shock considered to this point is generated by altering factors on the supply side (markup and *Land*). This would be an appropriate characterization of the shock if demand was growing as expected, but the supply of energy was not. However, if demand for energy is growing faster than expected because of other factors on the supply side of the economy that are generating faster than expected real economic growth, then the simulations will be ignoring an important dimension. Specifically, it is often claimed that faster than expected growth in emerging Asia is driving energy prices higher. This rapid growth in Asia is thought to be contributing to declining prices for many manufactured goods imported by industrial countries. Ignoring this effect will overstate the negative impact of higher energy prices on industrial country GDP because of the positive terms-of-trade effect of falling prices of non-energy imports.

To consider how important this positive terms-of-trade effect might be, we compare three alternative energy price shocks of similar magnitude on the version of the model calibrated to represent the euro area and the rest of the world. The first shocks is generated the same way as those previously considered, changing energy sector supply-side factors. The second is generated by increasing labor supply in the rest of the world. The third is generated by temporarily increasing tradable sector productivity growth in the rest of the world. The magnitudes of the shocks are chosen to generate an increase in the price of energy that rises over ten years by a little over 50 percent with roughly half of that increase being permanent in the long run. The shocks are calibrated to get as similar as possible dynamic paths for the price of energy, but they are not identical.

The results for some variables related to the output effect are present in Figure 7. The solid line traces out the path when energy sector supply-side factors alone are generating the higher prices. The dashed line traces out the impact when an increase in labor supply in the rest of the world is the source and dotted line races out the paths when the driver is an increase in productivity the non-energy tradable sector in the rest of the world. The first point to note is that in the very short run, the impact of the shocks on output is broadly similar. Initially GDP declines (as do investment and consumption, but not shown) in all shocks. However, the decline in GDP is temporary when non-energy sector supply factors in the rest of the world are driving the shockand GDP rises above bases line after just over 3 years. One of the key factor driving this result is export demand in the rest of the world. Quickly rising output and incomes fuels demand for euro area exports. In addition, the falling prices of imports from the rest of the world increase the relative value of euro area exports. Unlike under the pure energy sector shock, production in the euro area switches away from tradables and toward nontradables. In the pure energy price shock, the production of tradables must remain relatively high to pay for the now higher cost imported energy. Whether the non-energy sector shock arise from labor supply or tradable productivity growth matters for the euro area's real exchange rate. Under the labor supply shock the real exchange rate appreciates, which helps to generate the declining relative price of rest-of-world tradables sufficient to increase demand given greater supply capacity. Under the tradable sector productivity shock, the real exchange rate appreciates, the Balasa-Samuleson effect.

Figure 7. Alternative Drivers of Higher Energy Prices
(percent or percentage point deviation from baseline)

Solid - Energy Sector Supply
Dotted - ROW Non-energy tradable Sector Productivity
Dashed - ROW Labor Supply



Source: GEM Simulations.

The variables graphed in Figure 8 illustrate a very interesting point about CPI inflation in the euro area. Under the two non-energy sector shocks, CPI inflation exhibits considerable persistence. This reflects the impact of growing demand in the rest of the world and the positive terms of trade component on the real wage in the euro area. Under the energy sector shock, the real wage in the euro area declines permanently. As outlined in previous sections, this reflects the fact that the permanent increase in a factor cost leads to a reduction in the utilization of all inputs, a lower marginal product of labor and, consequently, a lower equilibrium real wage. Provided labor suppliers accept this reduction quickly, there is no persistence in the inflationary impact of higher energy prices. However, with rising demand for euro area exports and the wealth effect of the terms-of-trade improvement, the long run capital stock rises in the euro area as does the real wage. The recover in the real wage coupled with greater demand pressures leads to persistence in inflation. In fact, interest rates must rise and remain above baseline for an extended period under the non-energy sector shock to contain the inflationary consequences.

There as several reasons why these simulation results should be interpreted qualitatively rather than quantitatively. First, the magnitude of the positive long-run impact on industrial country GDP if non-energy supply factors in emerging Asia are driving higher energy prices will depend on trade linkages. The stronger are the trade linkages between the individual industrial countries and emerging Asia, the larger will be the positive effects. Second, the short-run inflationary consequences will depend on the behavior of the exchange rate, with China managing its exchange rate the impact is likely to be much different than in these simulations that assume a free floating exchange rate. Third, rising wealth in emerging Asia is probably also have an impact on the energy intensity of demand. This will have an impact identical to the pure energy sector shock, that is, driving up energy prices with no positive offsetting affects on industrial country GDP. Finally, these shocks are done under certainty while there is still considerable uncertainty about what is in fact driving higher energy prices and how persistent they are likely to be. Expectations will play an important role in shaping the macroeconomic outcomes and future work should explore the implications of this carefully.

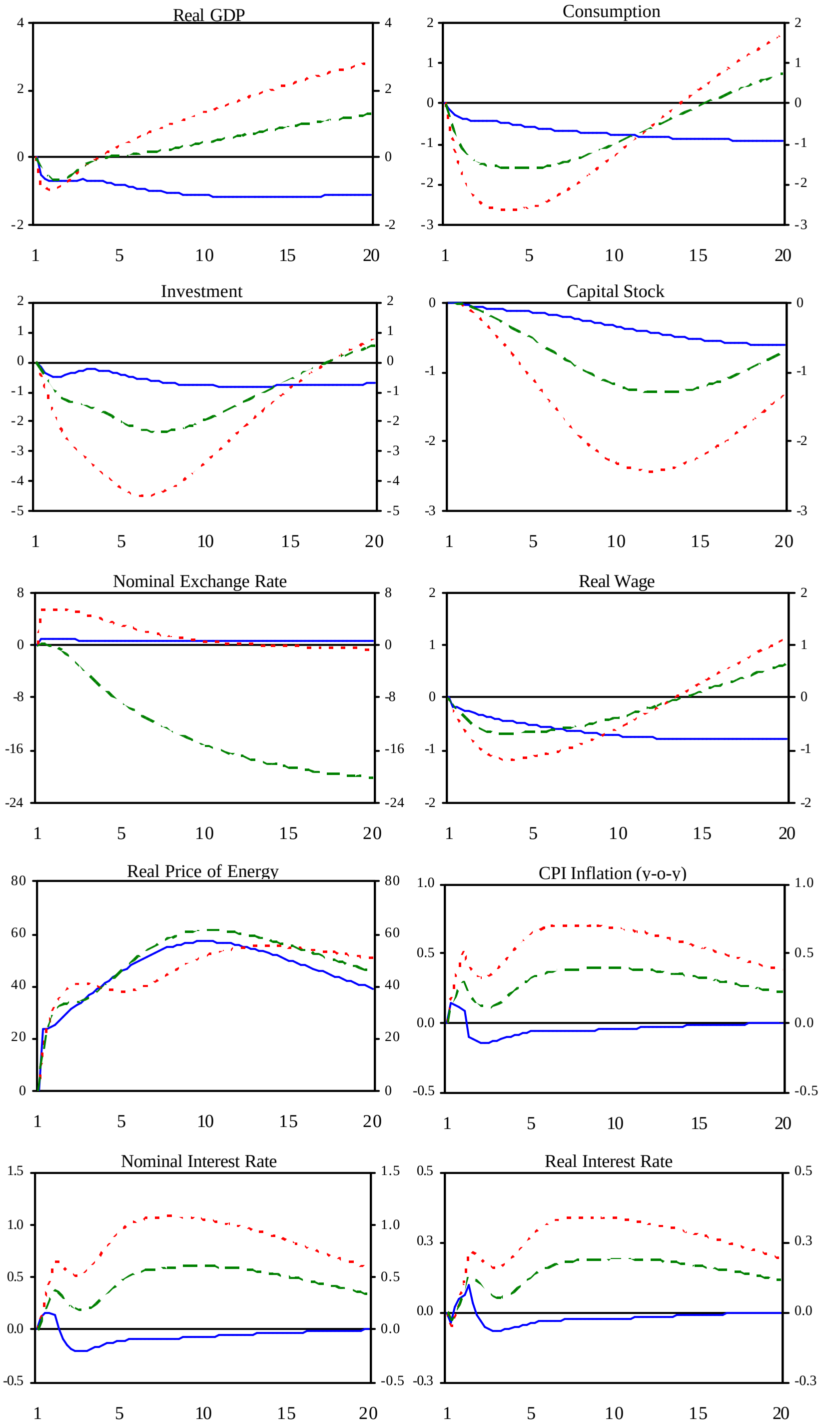


Figure 8. Alternative Drivers of Higher Energy Prices
(percent or percentage point deviation from baseline)

Solid - Energy Sector Supply
Dotted - ROW Non-energy tradable Sector Productivity
Dashed - ROW Labor Supply

Source: GEM Simulations.

6.0 Conclusions

The impact of higher energy prices on the level of GDP in most of the major industrial economies will depend on the underlying factors driving energy prices. If increases in non-energy sector supply factors in emerging Asia are an important component, then there will be some offsetting effects to the negative impact of a permanent increase in a factor cost. In Canada, however, even under the pure energy sector shock, the impact on GDP is positive because of Canada's large net export position in energy.

Headline inflation spikes up in proportion to the energy intensity of households final consumption bundle in each country, and persistent inflation effects can arise. Under the pure energy sector shock, if the resulting reduction in aggregate supply is not fully internalized into the monetary policy setting process, persistent above-target inflation can emerge following the initial direct effects on headline CPI inflation. A temporary increase in labor suppliers' market power, when monetary policy is being guided by a slowly evolving estimate of aggregate supply, can greatly amplify the second round acceleration in inflation. When higher energy prices are being driven by non-energy supply factors in the rest of the world, then persistent inflation effects arise because of additional demand pressures and a long-run increase in real wages.

Although the simulation results from the rise in energy prices seen since end 2003 suggest that for most industrial countries the negative implications for GDP are significant, there are reasons for optimism in the medium term. If increases in other supply factors in the non-energy sector in emerging Asia are driving energy prices higher, then industrial countries will reap some benefits from falling non-energy import prices and rising demand for exports. In the long run, GDP could rise depending on the extent of individual industrial countries' trade linkages with emerging Asia. However, one interesting aspect in the simulations is that monetary authorities will need to be even more vigilant about the inflationary consequences if non-energy supply factors in the rest of the world are an important factor driving energy prices.

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Appendix I: Technical Presentation of Energy in GEM

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.[6] The final good is produced with the following CES technology:

$$A_t = \left\{ (1-g)^{\frac{1}{e}} N_{N,t}^{1-\frac{1}{e}} + g^{\frac{1}{e}} \left[(1-g_{OA})^{\frac{1}{e_{OA}}} \left(n^{\frac{1}{e_{QM}}} Q_t^{1-\frac{1}{e_{QM}}} + (1-n)^{\frac{1}{e_{QM}}} \left[M_t \left(1-\Gamma_{M,t}\right)\right]^{1-\frac{1}{e_{QM}}} \right)^{\left(\frac{e_{QM}}{e_{QM}-1}\right)\left(1-\frac{1}{e_{OA}}\right)} \right. \right.$$

$$\left. \left. + g_{OA}^{\frac{1}{e_{OA}}} \left(n_O^{\frac{1}{e_{QMOA}}} Q_{OA,t}^{1-\frac{1}{e_{QMOA}}} + (1-n_O)^{\frac{1}{e_{QMOA}}} M_{OA,t}^{1-\frac{1}{e_{QMOA}}} \right)^{\left(\frac{e_{QMOA}}{e_{QMOA}-1}\right)\left(1-\frac{1}{e_{OA}}\right)} \right]^{\left(\frac{e_{OA}}{e_{OA}-1}\right)\left(1-\frac{1}{e}\right)} \right\}^{\left(\frac{e}{e-1}\right)} \tag{1}$$

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 $e > 0$. The elasticity of substitution between the tradable intermediate good and the tradable energy good is $e_{OA} > 0$. The elasticity of substitution between the domestic and foreign tradable intermediate good is $e_{QM} > 0$ and $e_{QMOA} > 0$ is the elasticity of substitution between the domestic and foreign energy good. The parameters g and $g_{OA} \in (0,1)$ 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 $\Gamma_{M,t}$.

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[6] 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,
$A_t = (1/s)\int_o^s A_t(x)d_x$

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

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

$$M_t^D = g\left(1-g_{OA}\right)\left(1-v\right)\left(\frac{P_{M,t}}{P_t}\right)^{-e_{QM}}\left(\frac{P_{X,t}}{P_t}\right)^{e_{QM}-e_{OA}}\left(\frac{P_{T,t}}{P_t}\right)^{e_{OA}-e} A_t$$

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

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

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

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

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

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

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

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

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). Also, $\overline{P}$ denotes the wholesale or producer price, h_{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),[7] 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.

Demand for Energy in Intermediate Goods Production

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

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

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

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

where Z denotes the level of productivity, ℓ the labor input, K the capital input, O the energy input, x the constant elasticity of input substitution, g and a 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:

$$Q^D_{ON,t} = v_{ON}\left(\frac{P_{QQ,t}}{P_{ON,t}}\right)^{-e_{ON}} O_{N,t}, \tag{12}$$

$$Q^D_{OT,t} = v_{OT}\left(\frac{P_{QO,t}}{P_{OT,t}}\right)^{-e_{OT}} O_{T,t}, \tag{13}$$

$$M^D_{ON,t} = \left(1-v_{ON}\right)\left(\frac{P_{MO,t}}{P_{ON,t}}\right)^{-e_{ON}} O_{N,t}, \tag{14}$$

$$M^D_{OT,t} = \left(1-v_{OT}\right)\left(\frac{P_{MO,t}}{P_{OT,t}}\right)^{-e_{OT}} O_{T,t}, \tag{15}$$

$$O_{N,t} = g_N\left(\frac{P_{ON,t}/P_t}{Z_{N,t}MC_{N,t}/P_t}\right)^{-x_N}\frac{N_t}{Z_{N,t}} \tag{16}$$

$$*\frac{\left[1-\Gamma_{OT,t}-f_{OT}\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}-1\right)\left(\frac{O_{T,t}}{T_t}/\frac{O_{T,t-1}}{T_{t-1}}\right)\right]^{x_T}}{1-\Gamma_{OT,t}}\text{, and}$$

$$O_{T,t} = g_T \left(\frac{P_{OT,t}/P_t}{Z_{T,t} MC_{T,t}/P_t} \right)^{-x} \frac{T_t}{Z_{T,t}}$$

$$* \frac{\left[1 - \Gamma_{OT,t} - f_{OT} \left(\frac{O_{T,t}}{T_t} / \frac{O_{T,t-1}}{T_{t-1}} - 1 \right) \left(\frac{O_{T,t}}{T_t} / \frac{O_{T,t-1}}{T_{t-1}} \right) \right]^{x_T}}{1 - \Gamma_{OT,t}}, \qquad (17)$$

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 e_{ON} and e_{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:

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

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

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

$$\frac{P_{MO,t}}{P_t} = \left(\frac{\bar{P}_{MO,t}}{P_t} + h_O \frac{P_{N,t}}{P_t} \right) (1 + tax_O), \qquad (21)$$

where tax_O is the rate at which the government taxes energy used as an intermediate input, and h_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 x_N and x_T.

Energy Production

The CES production technology for energy is given by:

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

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, $g_O and a_O$ are the parameters that determine the shares of land and capital respectively, and $x_{O.}$ 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:

$$\frac{MC_{QO}}{P_t} = \frac{\left[j_O(W_t/P_t)^{1-x_O} + a_O(R_t/P_t)^{1-x_O} + g_O(P_{L,t}/P_t)^{1-x_O}\right]^{\frac{1}{1-x_O}}}{Z_{O,t}}, \tag{23}$$

where $j_O = (1-a_O-g_O), W_t/P_t$ 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:

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

$$\frac{\bar{P}_{MOA,t}}{P_t} = \left(\frac{1}{q_O^* - 1}\right) h_{OA} \frac{P_{N,t}}{P_t} + \left(\frac{q_O^*}{q_O^* - 1}\right) \frac{MC_{QO}^*}{P_t} \left(\frac{e_t P_t^*}{P_t}\right), \tag{25}$$

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

$$\frac{\bar{P}_{MO,t}}{P_t} = \left(\frac{1}{q_O^* - 1}\right) h_O \frac{P_{N,t}}{P_t} + \left(\frac{q_O^*}{q_O^* - 1}\right) \frac{MC_{QO}^*}{P_t} \left(\frac{e_t P_t^*}{P_t}\right), \tag{27}$$

where e_t is the nominal exchange rate and q_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.

Nontradable Good Resource Constraint

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

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

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. There is also a symmetric set of equations added or modified as outlined above for the foreign sector.