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Oil Price Movements and the Global Economy: A Model-Based Assessment

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This paper develops a five-region version—Canada, a group of oil-exporting countries, the United States, emerging Asia, and Japan plus the euro area—of the global economy model encompassing production and trade of crude oil. In the presence of real adjustment costs that reduce the short- and medium-term responses of oil supply and demand, our simulations can account for large endogenous variations of oil prices with large effects on the terms of trade of oil-exporting versus oil-importing countries, and result in significant wealth transfers between regions. This is especially true when we consider a sustained increase in productivity growth or a shift in production technology toward more oil-intensive goods in regions such as emerging Asia. In addition, we study the implications of higher taxes on gasoline, showing that such a policy could increase world productive capacity while being consistent with a reduction in oil consumption. [JEL E66, F32, F47]

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Over the last few years, the persistent surge in oil prices in both the spot and futures markets has represented a challenge to the forecasting abilities of private and public institutions worldwide. Even as the average monthly spot price of oil increased from $19 per barrel at end-2001 to $43 at end-2004, market participants expected prices to decline over time to "more reasonable levels." However, since 2005, there have been striking upward revisions of near- and longer-term price expectations from the futures markets, and the oil spot price in 2006 occasionally rose above $70 per barrel, and has stayed persistently above $50 per barrel.

This paper provides a preliminary assessment of these issues—and their relevance for the world macroeconomy—by developing an extended version of the global economy model (GEM) that explicitly encompasses consumption, production, and trade in oil. We address two key questions about the oil price run-up since 2003. First, what are the underlying causes of the oil price run-up? And given those causes, what are some potential policy measures that could reduce oil prices with the least amount of (negative) impact on global welfare? Using the GEM allows us to study developments in the world economy that have significant effects on oil prices, the international transmission mechanism through terms-of-trade fluctuations, and the related wealth transfers between oil-importing and oil-exporting regions. We explore mainly the demand side—namely robust global growth supported by the rapid (and continual) economic expansion in emerging Asia (particularly in China and India), which seems to have surprised market participants (IMF, 2006).

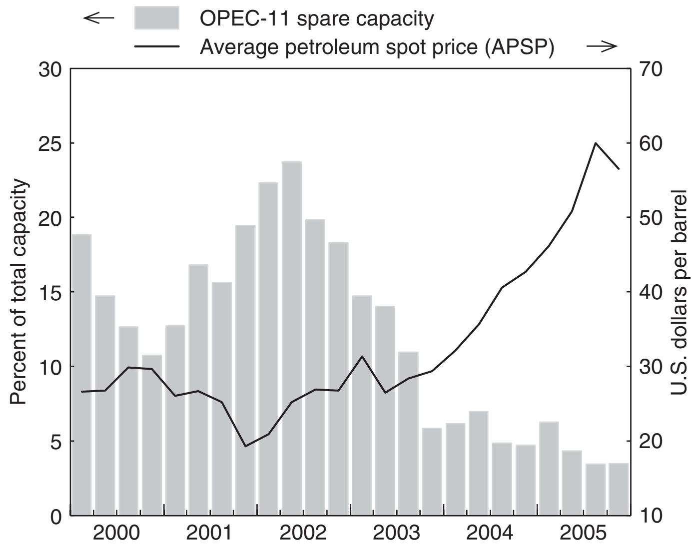
I. Oil and the World Economy: Some Stylized Facts

There has been a persistent upward trend in oil prices over the last few years. Part of this is associated with repeated unanticipated increases in oil demand as GDP growth has been higher than expected, particularly in emerging Asia (IMF, 2005).

Although we will argue that oil price increases are being driven mainly by the increase in oil demand, the magnitude of these increases is most likely resulting from oil supply factors (which figure prominently in our calibration of the oil sector). The most prominent of these is that OPEC spare capacity (including Iraq) has bottomed out. This fact is highlighted in Figure 1, which shows quarterly figures for OPEC spare capacity as a percent of total supply, and the average petroleum spot price (APSP).[1] Starting in mid-2003, there is a divergence between oil prices and spare capacity, which by June 2006, was estimated at around 1.3 million to 1.8 million barrels per day (Energy Information Administration, 2007). At the same time, lagging investment in infrastructure and refinery construction, as well as the aforementioned fact

[1]The APSP is the simple arithmetic average of the U.K. Brent, Dubai Fateh, and West Texas Intermediate spot oil prices.

Figure 1. OPEC-11 Spare Capacity and World Oil Prices



that it takes, on average, 11 years before an oil discovery is ready for production, have further compounded supply-side rigidities. Along with heightened geopolitical risks, oil supply has become markedly binding, making it excessively vulnerable to even minor disruptions.

II. New Features and the Calibration of the Model

For the complete description of the GEM, the reader is referred to Pesenti (2008). Here it suffices to discuss the regional composition, the addition of the oil and gasoline sectors, and the overall calibration of the model.[2]

The world economy consists of five country blocs (“regions”), divided into two groups. The oil-exporting regions consist of Canada and the group of oil-exporting countries (GOEC) that includes OPEC, Mexico, Norway, and Russia. The oil-importing regions consist of the United States, emerging Asia, and the bloc of remaining countries that includes Japan and the European Union.

There are extensive modifications to the model to allow the production of refined oil (“oil” for short) as a traded upstream intermediate good, and gasoline (car fuel and retail heating fuel) as a nontraded downstream intermediate good.

[2]A more complete description of the oil and gasoline sectors can be found in Lalonde and Muir (2007).

As with traded and nontraded goods, gasoline is produced with domestic labor inputs, domestic capital, and oil. Oil can be imported or produced domestically. Gasoline forms part of the final consumption good, and, therefore, enters the consumer price index (CPI) directly. This allows the monetary authority to pursue an inflation targeting regime, based on CPI excluding energy (CPIX). Oil is the only traded upstream intermediate good. It is produced with capital, labor, and crude oil reserves.

As with other intermediate goods, both gasoline and oil producers have market power that can change over time. Oil prices are not subject to nominal rigidities, unlike intermediate goods prices or wages. However, there are real adjustment costs on the use of capital and labor in the supply of both oil and gasoline that result in very limited short-term responses of their production to changes in demand. These are introduced in an attempt to capture the effects of severe capacity constraints in the energy sector, as well as the multiyear delay between oil discoveries and their commercial availability. On the demand side, these real adjustment costs capture the fact that it takes years to change the fuel efficiency of the stock of motor vehicles or to replace the stock of technology that is used for heating and cooling. As a result, these real adjustment costs imply that both the demand and supply for crude oil will be extremely inelastic in the short run, requiring large movements in crude oil prices to clear the energy market.

There are several caveats about the model structure of the oil sector. First, oil is assumed not to be a storable commodity whose price is linked to the rate of return on other assets, thereby implying that its price is determined entirely on its use value. Second, since the model does not include oil inventories (which would offset the real adjustment costs in the case of temporary oil demand shocks, for example), oil and gasoline prices may respond too strongly to temporary shocks. Overall, this implies that the model is not meant to explain very short-run variations in oil prices due to market disruption: rather, it has been designed to explain the interaction of oil prices and the world economy over the medium term.

The calibration of the entire model builds upon work already presented in Faruqee and others (2007), but with extensive modifications for Canada, the United States, and the euro area based on Murchison and Rennison (2006); Gosselin and Lalonde (2005); and Coenen, McAdam, and Straub (2008), respectively, and more generally on Juillard and others (2006), found in Table 1.

To calibrate the oil and gasoline sectors, we attempt to capture the broad features of the world market (see the bottom of Tables 1 and 2). In the case of oil production, some oil-exporting countries of the GOEC have the least capital-intensive technology (capital share of oil production is 12.9 percent), but Canada has a relatively capital-intensive technology (capital share of oil production of 29.7 percent), meant to capture realistic features of the oil extraction process (such as the Athabasca tar sands). The elasticity of substitution among factors used in oil production is 0.6, but it is 0.7 in gasoline production. The lower degree of elasticity in oil production reflects

Table 1. Steady-State National Accounts—Expenditure Side
(In percent)

Ratio of GDP	Canada	Oil-Exporting Countries	United States	Emerging Asia	Remaining Countries
Private consumption	56.5	64.3	65.8	50.1	58.8
Private investment	17.4	16.8	16.4	34.5	18.3
Government expenditures	26.0	19.1	17.2	15.8	23.2
Trade balance	0.1	−0.2	0.5	−0.4	−0.2
Exports	37.1	23.8	14.2	26.1	8.8
Oil for producing gasoline	1.2	2.0	0.1	0.2	0.2
Other oil	4.6	7.8	0.2	0.7	0.6
Imports	37.0	24.0	13.7	26.5	9.0
Oil for producing gasoline	0.4	0.3	0.3	0.6	0.2
Other oil	1.8	1.4	1.4	2.3	1.0
Total oil demand	3.9	3.9	3.5	5.0	2.7
Gasoline demand	3.0	2.3	3.3	2.5	3.1
Net foreign assets	−7.5	21.4	−50.0	35.0	23.0
Percent share of world GDP	2.4	9.3	30.1	10.6	47.6

some of the long-term costs in switching production technology, whereas the higher degree in gasoline production reflects the fact that there are several methods of varying efficiency (and hence capital and labor intensity) to manufacture gasoline from oil. To significantly lower short-term oil price elasticities of demand toward near-Leontieff levels, we impose strong short-run real adjustment costs on capital and labor, using the Rotemberg (1982) formulation, of around 300, with additional adjustment costs associated with changes in the use of oil in the production of intermediate tradables, nontradables, and gasoline, and in the use of gasoline as a component of the final consumption bundle (also set to 300).

To allow for a world price for oil and a single global market, there are very high elasticities of substitution between domestic and imported oil (at 10), although for imported oil there is less preference as to the region of origin (at 3). Moreover, we have assumed almost no price markup in the oil sector for any region, with the exception of the group of exporting countries, which has a markup approaching 500 percent. It is estimated that the cost of oil production for OPEC countries is somewhere around \$2 to \$5 per barrel, while for a country like Canada it is closer to \$25

Table 2. Steady-State National Accounts—Production Side
(In percent)

Ratio of GDP	Canada	Oil-Exporting Countries	United States	Emerging Asia	Remaining Countries
Tradables	43.9	36.2	48.2	65.1	45.8
Nontradables	49.5	53.4	50.0	34.3	50.0
Gasoline	2.3	2.0	2.9	2.2	2.4
Oil production	7.5	11.9	3.1	2.3	2.1
Factor incomes (percent share of oil production)					
Capital	29.7	12.9	20.7	24.0	26.5
Labor	10.8	8.1	8.3	16.2	9.9
Land	59.5	79.0	71.0	59.8	63.6

Note: Columns will not sum to 100, as gasoline and oil production overlap as a share of GDP.

(Energy Information Administration, 2007). Therefore for any given oil price in the world market, the group of the oil-exporting countries has the largest markup to sustain the price of oil and guarantee production in the other regions, where production costs are much higher. For gasoline, the markup is around 16 percent for all regions. This excludes government taxes on gasoline, which we set for illustrative purposes at 30 percent in Canada and the remaining countries bloc, and 15 percent elsewhere.

Bilateral world trade flows are calibrated to reflect the 2003 levels of imports in the five regions, whereas the aggregate export-to-GDP ratios are those necessary to support the net foreign asset-to-GDP ratios we have chosen (Table 1).[3] The United States is a large net debtor (50 percent of GDP), Canada is a small net debtor (7.5 percent of GDP), and the other three regions are all net creditors of varying degrees (with emerging Asia being the largest net creditor at 35 percent of GDP). The higher trade is, as a percent of GDP, the more likely an economy will be affected strongly by foreign shocks. Canada is very open (exports plus imports to GDP are 74.1 percent), as is emerging Asia (52.6 percent) and the GOEC (48.0 percent), while the United States (27.9 percent), and the European Union and Japan (17.8 percent) are much more insulated from foreign disturbances. However, this is not necessarily the case in the oil market (Energy Information Administration, 2007). Here, not only does the degree of openness matter, but the direction of trade as well. The net exporters are Canada at 3.7 percent

[3]The import data are based on a combination of the IMF's Direction of Trade Statistics and the UN's COMTRADE database of commodity-based trade flows.

of GDP and the GOEC at 8.1 percent of GDP, while the other regions are net importers at 1.4 percent of GDP for the United States, 1.9 percent of GDP for emerging Asia, and 0.4 percent of GDP for the remaining countries. Additionally, the group of oil-exporting countries has the largest amount of its GDP coming from oil production (12 percent).

III. Why Oil Prices Have Increased: Some Illustrative Experiments

This section starts by presenting some simulation results that show that, in the presence of real adjustment costs, an upward shift in productivity growth can result in the combination of high oil prices and robust global growth. As an extension of the productivity shock, we illustrate how the model can be used to assess major risks to the future demand for crude oil that are the result of uncertainty about future levels of oil intensity and real incomes in emerging Asia. Taken in combination, these experiments can provide the explanation for the increase in oil prices over the past several years.[4]

Higher Productivity Growth in Oil-Importing Regions

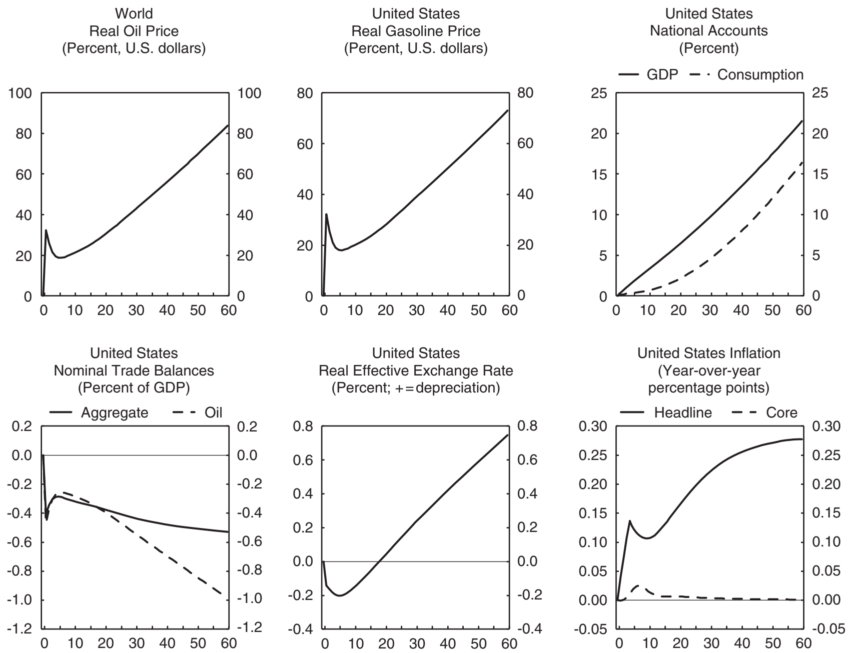
To investigate the effects of rising global demand for oil, we consider a positive shock in the oil-importing regions (the United States, emerging Asia, and the remaining countries bloc), which raises productivity growth in both the tradables and nontradables sectors by 1 percentage point for 20 years (Figures 2 and 3). The oil-importing regions obviously benefit from higher levels of productivity in their own region, but the increase in oil prices over time also results in a favorable terms-of-trade shock for regions that are net exporters of oil (Canada and the GOEC), and a negative terms-of-trade shock for the regions that are net importers of oil.

The price of oil trends upward in tandem with the increase in the demand for oil, reflecting the assumption of diminishing returns in the production of oil, because of a fixed factor (land). For example, for the group of oil-exporting countries, oil prices jump up on impact, decline over the first year, before rising steadily over time. Oil prices are substantially higher over the medium term, reflecting the sluggish response of the supply of crude oil, reaching a level that is about 80 percent higher after 15 years. Oil production increases by only 1.6 percent in the group of oil-producing countries. It is important to emphasize, in this simulation, that we are assuming that there are no new discoveries of oil, and that production can only be increased by adding more capital and labor, based on existing reserves.

The rise in oil prices results in an improvement in the oil trade balance for Canada and the GOEC, and a deterioration in the regions that import oil. The rise in the price of oil results in an upward trend in the relative price of

[4]The results here abstract from any increases in the price of oil not related to the fundamentals of the market, such as the perceived political risks attached to regions such as the Middle East or the sub-Saharan African countries. Quantification of such uncertainty has no role in a structural model such as the GEM.

Figure 2. Higher Productivity Growth in the Oil-Importing Regions—Part I
(*Deviation from control*)



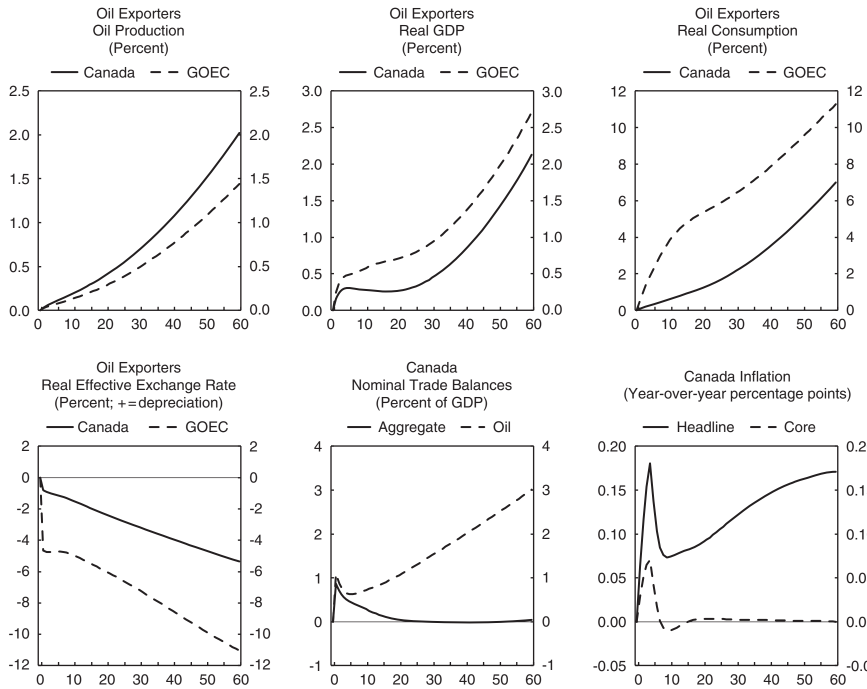
gasoline. Although monetary policy is successful at keeping core inflation close to the assumed target, headline inflation is systematically higher than in the baseline.[5]

The dynamics for consumption, investment, and GDP are relatively straightforward. In those regions that experience higher productivity growth, investment trends upward until the capital stock in these economies adjusts to its new higher level. In the medium term, high investment rates in these regions crowd out investment in the oil-exporting countries, as their rates of return on non-oil investment projects are significantly lower. However, these effects are eventually offset by higher rates of return in the oil sectors in these economies, and aggregate investment rises above baseline. Consumption rises by more than GDP in the oil-exporting regions, and by less than GDP in the oil-importing regions, which simply reflects the wealth effect attributable to terms-of-trade improvement that the latter experiences.

There are two major forces that require the real effective exchange rates for the oil-importing regions to depreciate in the long run. The first is a result

[5]While we do not have a neutral policy rate in the reaction function, the latter is specified in such a way that allows the real interest rate to depart from its long-run equilibrium value when there are shocks that change the marginal product of capital over long periods of time. This, of course, is a necessary condition to keep core inflation close to the target.

Figure 3. Higher Productivity Growth in the Oil-Importing Regions—Part II
(*Deviation from control*)



of the improvement in the terms of trade in the oil-exporting regions, and the second reflects the assumption that higher growth in the oil-importing regions stems from higher levels of productivity in both the tradables and nontradables sector. In this case, equal-sized productivity shocks in both the nontradables and tradables sectors lead to a depreciation of the exchange rate in the long run, while the standard Balassa-Samuelson effect—which predicts a real exchange rate appreciation in the long run—relies on productivity growth in the tradables sector exceeding that of the nontradables sector.

Perhaps surprisingly, for the United States, the real exchange rate appreciates in the short run. This reflects the fact that this region must absorb most of the depreciation in emerging Asia and the remaining countries bloc, both blocs being characterized by strong trade linkages with the United States. The appreciation also explains the short-run fall in U.S. net foreign liabilities measured as a ratio of nominal GDP, even as the trade balance worsens. In the very long run, the desired stock of U.S. net foreign liabilities is actually higher than in the baseline, a fact that contributes to generate pressure toward a long-run depreciation. The latter is needed to generate a trade surplus that finances the higher interest burden on the larger stock of net foreign liabilities.

Increase in the Demand for Oil in Emerging Asia

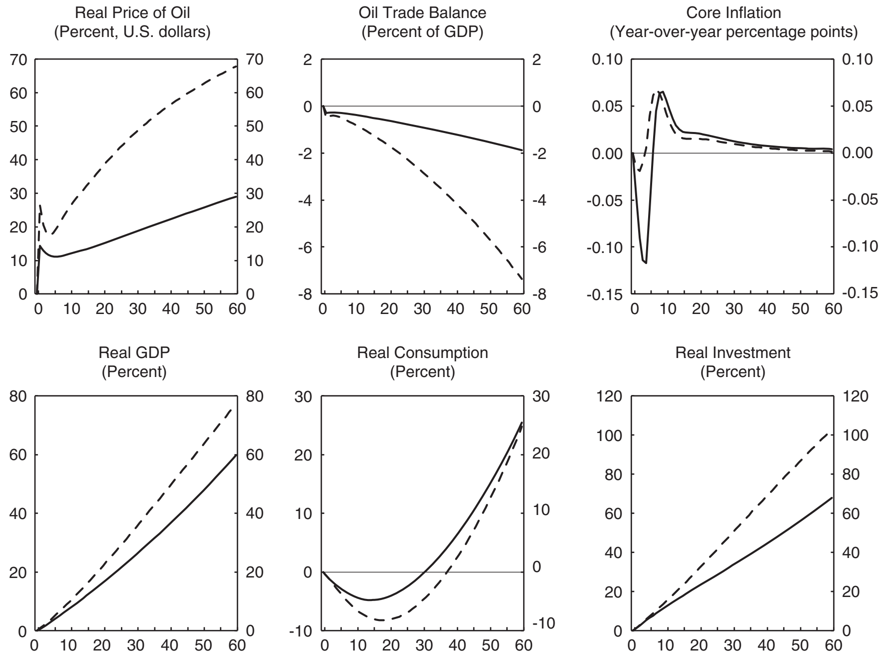
Long-term projections of the demand for oil depend critically on assumptions about the future of emerging Asia—its substantial population, the convergence of its real per capita income to the level of OECD countries, the use of motor vehicles, and the shift of production to goods requiring a more technologically advanced (and presumably energy-dependent) capital stock. Studies that have focused on the implications of this uncertainty have usually taken energy prices as given and assumed that the supply of oil will be sufficient to smoothly accommodate variations in its demand (IMF, 2005). Here, we introduce an endogenous response of energy prices. We assume that two factors drive the permanent shock to the future demand for oil in emerging Asia: a taste shift that raises consumers' demand for gasoline, and a technology shift that increases the amount of oil needed to produce tradable and nontradable goods. The shock is phased in, so that the real level of oil consumption rises by roughly 2.5 percent of GDP after 15 years. We introduce these factors in tandem with higher productivity growth in emerging Asia (of the magnitude found in the previous section).

In Figure 4, crude oil prices worldwide rise by an additional 10 percent on impact, decline during the first year and then trend upward over time reaching a peak that is more than twice as large as only the productivity shock. It should be understood that if we considered this intensity-in-use shock in isolation, the increase in oil prices would not be as large. The effects of the intensity-in-use shock are amplified by the increase in productivity, and vice versa—the outcome from the two shocks occurring simultaneously is closer to being multiplicative, rather than additive. The intensity-in-use shock also magnifies the shift of the terms of trade against emerging Asia. This extends more generally to a shift in the terms of trade in favor of the oil-exporting regions and against the oil-importing regions. As a result, consumption increases in the regions that are net exporters of oil and eventually declines in the regions that are net importers.

Again, the profile for oil prices reflects very low short-run elasticities of supply and demand for crude oil, which means that oil prices have to bear the entire burden of adjustment in the short run. The effects on oil trade balances are much larger in the short run for the GOEC and Canada relative to the baseline (equal to 8.1 and 3.6 percent of GDP, respectively). The negative effects on the oil trade balance in emerging Asia build up over time and reach about 5 percentage points of GDP after about 15 years above that of the pure productivity shock.

In sum, by considering extra shocks related to the usage of oil in emerging Asia, we can greatly amplify the effects on oil prices. The magnitude of the effect is greater than that of the shock by itself, because of the interplay between the shift in production and consumption preferences with the increase in productivity in emerging Asia.

Figure 4. Higher Growth and Oil Intensity in Emerging Asia
(*Deviation from control*)



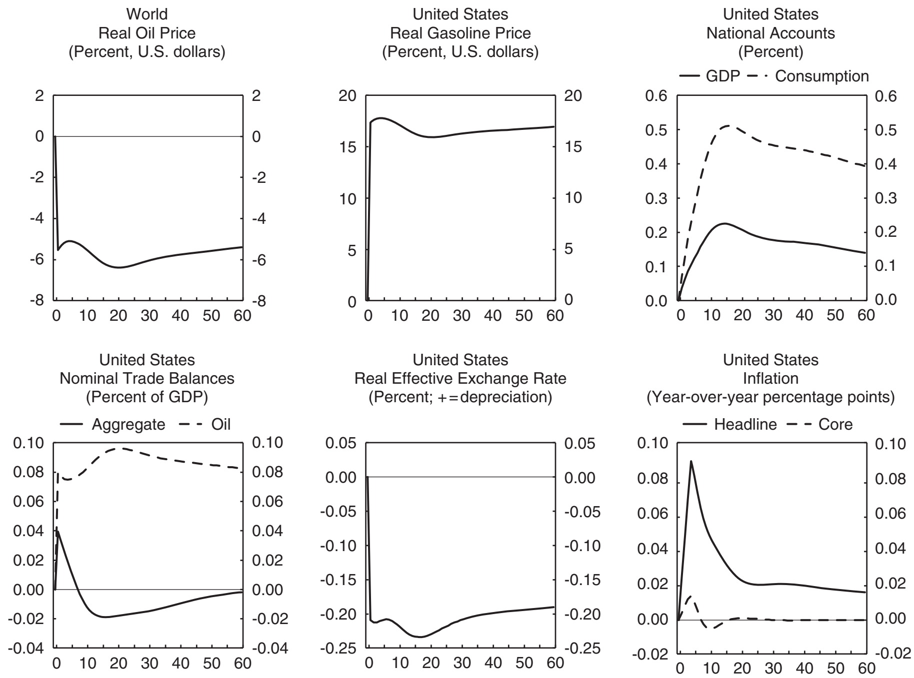
Note: Solid line = productivity only; dashed line = combined shocks.

IV. A Global Increase in Gasoline Tax Rates

Given the long-run nature (that is, usually a minimum of 15 years) of the scenarios offered above, it is appropriate to provide some normative suggestions as to how policymakers (particularly the regions' governments) can help reduce dependence on oil and reduce the negative impacts that still-increasing and high oil prices will have on future world output growth. We focus on one concrete policy measure, not regulatory measures or legal restrictions on fuel usage in the automobile sector or industry, as these can be hard to quantify in a model-consistent fashion. We demonstrate a global hike in tax rates of 25 percentage points on gasoline, in tandem with an offsetting reduction in taxes on labor income to achieve a notable reduction in oil prices and use of oil, but hold government tax revenues neutral. As a result, productive capacity increases, with positive effects on aggregate employment and investment. The results are reported in Figures 5 and 6.

The tax hike on gasoline eventually results in a substitution away from consumption of energy, but this is a very long and slow process given the low short-run elasticities of demand for oil. Oil prices decline by almost 5 percent. This decline in prices results in a reduction in the oil trade balance in the GOEC, that is about twice the effect for Canada, reflecting differences in their initial oil trade balances. The reduction in labor tax rates raises the

Figure 5. A Global Increase in Gasoline Tax Rates by 25 Percentage Points—Part I
(*Deviation from control*)



aggregate real wage, and results in higher investment and GDP in the oil-importing countries, but this effect is also quite significant in Canada, where the expansion in employment in the non-oil sector outweighs the decline in employment in the oil sector.

Consumption in the oil-importing (oil-exporting) regions increases (decreases) because lower oil prices represent a positive terms-of-trade shock and a wealth transfer from oil-exporting regions to oil-importing regions. In Canada, this negative terms-of-trade shock results in a decline in consumption in the short run, but, over time, the expansion in productive capacity and real income results in higher levels of consumption. Real exchange rates depreciate in the oil-exporting regions and appreciate in the oil-consuming regions.

The long-run welfare implications, expressed in terms of the consumption equivalent, are fairly small, as shown in Table 3.[6] The steady-state implications of the global gasoline tax among the regions are at most –0.4 percent of consumption. Not surprisingly, the biggest loser is the group of oil-exporting countries. Canada loses the consumption equivalent of 0.29

[6]Welfare is measured in terms of consumption equivalents, defined as the amount of consumption required to achieve a certain level of utility, holding labor supply (leisure) at its pre-shock steady-state level.

Figure 6. A Global Increase in Gasoline Tax Rates by 25 Percentage Points—Part II (*Deviation from control*)

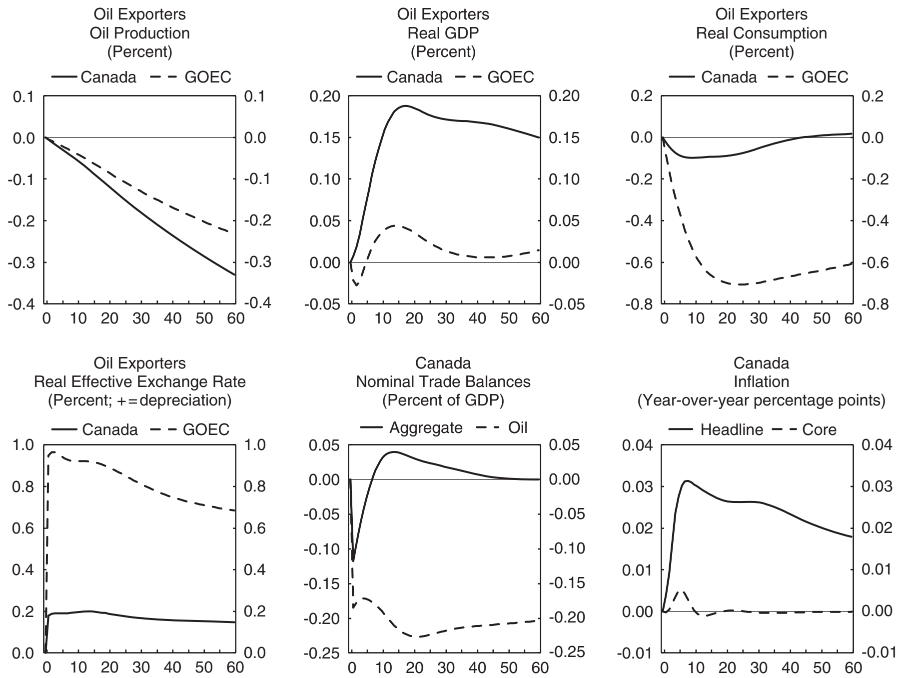


Table 3. Steady-State Welfare Implications of a Global Increase in Gasoline Tax Rates of 25 Percentage Points

Welfare (consumption equivalent)	Canada	Oil-Exporting Countries	United States	Emerging Asia	Remaining Countries
All consumers	−0.29	−0.40	−0.02	−0.04	−0.09
Forward looking consumers	−0.30	−0.42	−0.03	−0.07	−0.10
Liquidity-constrained consumers	1.02	0.66	0.56	1.01	0.70

percent in the long run—less than the other oil exporters because of its more diversified economy. In contrast, oil importers experience minimal welfare losses (less than 0.1 percent of consumption equivalent), as they do not face the direct wealth effect that the oil exporters experience from lower oil revenues. In general, liquidity-constrained consumers benefit, as their tax burden falls significantly relative to forward-looking consumers, who bear more of the burden of the gasoline tax (and are owners of the oil wealth which decreases). Therefore welfare declines in all regions, as the majority of consumers are forward looking.

V. Conclusions

In this paper, we developed a five-region model of the global economy and carried out scenario analyses to study the implications of different shocks driving oil prices worldwide. The model introduces significant real adjustment costs in the energy sector, making both the demand and supply for crude oil extremely inelastic in the short run, thus requiring large movements in crude oil prices to clear the energy market.

To answer the first question about the underlying causes of the oil price run-up since 2001, the model properties offer a story based on stronger productivity growth in oil-importing regions, coupled with shifts in oil intensity in production (emerging Asia). Oil price shocks stemming from higher growth in the oil-importing regions are accompanied by wealth transfers through terms-of-trade movements, leading consumption to grow slower than output in the oil-importing regions. In the medium term, high investment rates in the high-growth regions crowd out investment in the oil-exporting regions. Moreover, the positive effects of higher oil prices on consumption need not translate into reduced current account surpluses in the oil-exporting regions, to the extent that they are accompanied by an upward shift in the desired net foreign asset positions. The conclusions about the role of increased productivity in the oil-importing regions can be reinforced by considering emerging Asia in particular, with its increased intensive use of oil in the production of tradable goods.

Our second question, about whether policy can be used to ameliorate many of the negative impacts of increasing and higher oil prices, is answered by exploring the implications of a global tax hike on gasoline. Such a measure reduces oil prices by almost 5 percent, and results in a positive terms-of-trade shock for the oil-importing regions, as well as a wealth transfer from oil-exporting regions to oil-importing regions. This leads to an increase in consumption in the oil-importing regions and decreases everywhere else. Furthermore, the reduction in labor tax rates raises the aggregate real wage and results in higher investment and GDP. On net, the world suffers a small welfare loss, but this masks regional variations, where the effects are negligible in the oil-importing regions but notable in the oil-exporting regions.

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