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The Incidence of Carbon Pricing: Norway, Russia and the Middle East

by
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Introduction

One of the factors complicating ongoing negotiations to mitigate greenhouse gas (GHG) emissions is the heterogeneity that exists amongst countries. It has long been recognised that there is asymmetry both with respect to the potential impacts of global warming on individual countries, as well as with the economic impacts on countries of abatement regimes (Schelling, 1991). On the economic side, a strong source of heterogeneity is found in the highly varied distribution of endowments of hydrocarbon resources. The world's deposits are not uniformly located across all countries: some countries have them in abundance, while other countries import virtually all of their domestic use.

For countries that have deposits, high demand creates rents that governments can control and can allocate to serve policy objectives. Rent allocation, however, is not always free of impacts on economic efficiency. In extreme cases, Wintrobe (2000) observes that natural resource wealth can create conflict among social groups who are vying for control of the rents.[1] In less extreme cases, the rent allocation may take the form of government policy that regulates pricing of domestic hydrocarbon products at relatively low levels. Both of these cases lead to economic inefficiencies.

Below we explore differences in how three economies with large hydrocarbon deposits will respond to policy that increases the price of carbon dioxide emissions. Those responses are shown to vary widely and are largely related to policies concerning domestic use of hydrocarbons. We note that, to the extent that the differences are not widely understood, information asymmetries exist and may create the conditions underlying the results of Mailath and Postlewait (1990). Those asymmetries will make it difficult to conclude negotiations to coordinate global policy to mitigate carbon dioxide emissions.

The three countries/regions that are studied are: Russia, Norway and the Middle East.[2, 3] For perspective, Table 1 illustrates the relative magnitudes of production shares and export earnings from oil and gas in these regions. The first row (share of oil and gas) is shown in comparison to all other economic sectors. This value can be understated since, unlike the next row, it is calculated at prices in the domestic economy – *i.e.* the oil and gas are not valued at international prices. It also does not include transport and other related services that deliver the products to users. Nonetheless, the high fraction of oil and gas production in economic output in these regions/countries makes them important, if not dominant, sectors. The second row illustrates the importance of oil and gas to the well-being of each region's citizens – clearly they make major contributions to incomes, so policies that distort the oil and gas sector can have important implications for the economy as a whole.

How the rents from export sales are allocated may alter the domestic market for oil and gas, and thus affect the magnitude of a country's response to climate change mitigation policies. A simple case is where use of domestic oil and gas is subsidised through prices that are mandated to be low by government policy. In that case, the export

Table 1. **Output share and export earnings from oil and gas, 2005**

	Russia	Norway	Middle East
Share of oil and gas in gross output	19%	10%	21%
Estimated export earnings per capita[1]	$1 030	$14 450	$1 900
Population (million)	144	4.6	187

1. For natural gas, Middle East includes only the value of exports to OECD countries.
Source: Authors' calculation from IEA (2007), OPEC (2006), Central Bank of Russia (2005), Statistic Norway (2007), GTAP database version 6.

price is the opportunity cost of the oil and gas, so economic inefficiencies exist. New policies related to climate change would increase prices to consumers of the subsidised goods and reduce the distorting impact. What happens on the producer side will depend on how the policy is implemented. If the tax is implemented without changing the producer price, then the efficiency gain will come only from reduced demand. If, however, the producer price is allowed to be market driven, then it may increase even with the tax – in which case the efficiency gains from the policy will be even larger.

IPCC (2007) documents the contribution of anthropogenic sources of greenhouse gases (GHG) to potential changes in climate. An important finding of the work was that the climate may be more sensitive than previously thought to increased concentrations of GHGs. A doubling of GHGs above pre-industrial levels may lead to a greater change in temperature than was previously thought, and could thus be more disruptive for natural processes and human societies. Indeed, studies such as those surveyed by IPCC (2007b) suggest that marginal costs for carbon dioxide emissions (often referred to as the *social cost of carbon*) are between $4 and $95 per tonne – with $25 serving as a central value. In other words, a carbon dioxide tax of $25 might be justified for abating emissions.[4]

Policies to impose those costs on emissions will lead to the cost of fossil fuels increasing significantly. In fact, the consumer price of fossil fuel-based products will increase, while the producer price will decrease. Thus the resource rents will decrease, even while the consumer price of oil and gas are increasing. Pricing carbon dioxide emissions globally is thus likely to impact on the income that Norway, Russia and the Middle East receive from exports. Equally important, however, is the impact on domestic use of oil and gas for consumption and production. Each region listed in Table 1 has its own domestic prices for oil products and natural gas that reflect policy objectives of its government (the differences in cost of production are small compared with the differences in final demand prices). Table 2 illustrates two prices for energy sources in those countries.

Table 2. **Domestic tax-inclusive energy prices ($), 2005**

	Russia[1]	Norway	Middle East
Natural gas (per million BTU)	1.20	~6	<1.20[2]
Unleaded gasoline (premium/litre)	0.54	1.67	<0.25

1. Russia's gas prices have been changing recently and in 2008 are expected to reach $2.40 (Troika Dialogue, 2007). These prices are still well below the level in other countries so while they impact on the magnitude of the results below, the qualitative explanation remains the same. Gasoline prices in Russia are also significantly below that of European countries, while being a little higher than in the US.
2. IEA (2007) reports gas feedstock prices in some individual countries as ($ per million BTU): Iran, 0.35; Saudi Arabia 0.75; Oman 0.80; United Arab Emirates 1.00. An exact average for the region was not available, but the essential point of the table is made by illustrating that it is low relative to the others – especially Norway.

Source: IEA (2006) and American Chemistry Council (2005).

As Table 2 shows, there is a good deal of heterogeneity in the domestic energy prices of each country/region. IEA (2006b) reports that the economic value of energy subsidies in Russia in 2005 were equivalent to $40 billion in the then-current exchange rate. Saudi Arabia and Iran together were reported as having subsidies of $57 billion. Those calculations were based on the difference between the domestic price of various energy sources, and a measure of the globally-traded price. They were thus not precise measures of actual government budget outlays, as they may include the effects of elements not considered to be subsidy-related; *e.g.* health and safety regulatory frameworks.

Of particular interest for this paper is the impact of a policy that would place a price on carbon dioxide emissions. Since fossil fuels have a high carbon content (though natural gas also has considerable hydrogen), a carbon dioxide tax would increase their costs to users. For illustration, a $100 tax per metric tonne of carbon dioxide emitted would amount to a $0.24 tax on a litre of gasoline (or almost $1 per US gallon), and a $5.31 tax per 1 million BTUs of natural gas.[5]

Of course, for any given tax, the price impact will depend on the demand elasticity of the product, as well as on the initial price. If we assume a given elasticity applies in all three regions, then the largest impact of a particular tax will be expected in the Middle East, followed by Russia, then Norway – this is because Norway has the highest prices, followed by Russia and the Middle East.[6] This paper shows that this simple intuition is incomplete. It does so by highlighting a variety of impacts that carbon pricing would cause. It then notes what these impacts imply for future diversification strategies.

We begin with some background on each region.

Fossil fuels, energy efficiency and diversification

The differences between these regions are significant in ways that are worth noting further. The use of fossil fuels per person and per unit of GDP is more intense in Russia than in the other two economies, as implied in Table 3 from CO_2 emissions. All three regions, however, are considerably higher than the world average in emissions per capita, but Norway is considerably lower in emissions per unit of GDP.

Table 3. **CO_2 emissions from energy, 2005**

	Norway	Russia	Middle East	World
Emissions (tonne) per capita	8.0	10.8	6.6	4.2
Emissions per GDP[1]	0.20	4.41	1.57	0.75

1. Kilogram per $ (in year 2000) of GDP.
Source: IEA (2007).

To see how those emissions are allocated, Table 4 breaks them into four categories. Final demand uses of energy are contained, in part, in the Transport and Other categories. The table makes clear the heterogeneity between the regions. Table 3 above shows that Russia has the highest emissions per capita of these countries, Table 4 now shows that a large share of those emissions come from energy transformation sectors. In particular, Russia uses a large share of its fossil fuels for the generation of heat and electricity in Heat Plants and Combined Heat and Power Plants (IEA, 2006d). These activities are directly supporting industrial and commercial activity so they are important as intermediate inputs into the economy.

Table 4. **Sectoral share of energy-related CO_2 emissions, 2005**

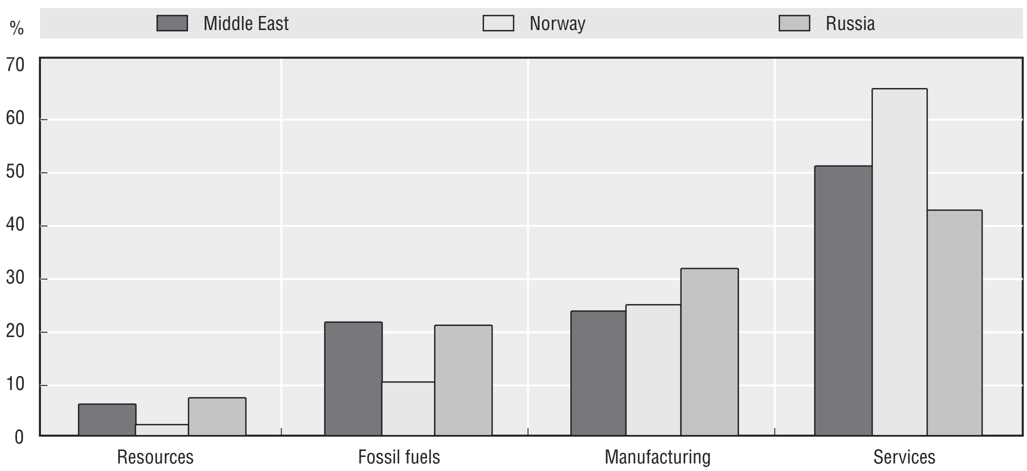
Per cent

	Energy transformation	Manufacturing	Transport	Other
Norway	26	20	34	10
Middle East	43	22	22	13
Russia	60	13	13	12

Source: IEA (2006).

Another perspective on differences between these regions is in economic diversification. Norway has a highly diversified economy that would be indistinguishable from other European economies without its oil assets. Figure 1 shows the sectoral share of four aggregates in gross output. It uses a System of National Accounts (SNA) definition of a sector so it is not directly comparable to Table 4, where an activity-based definition of a sector is used. Norway's service sector produces 65% of gross output compared with 43% in Russia (in 2001). The Middle East is the region with the lowest share of gross output in manufacturing: 23% compared with 31% for Russia.

Figure 1. **Sectoral share in gross output (2005)**



Source: GTAP Database version 6.

The results shown in Tables 3 and 4, as well as Figure 1, are directly linked to the prices shown in Table 2. Through taxation, Norway forces final consumers to be very fossil fuel efficient – they face European prices for energy and thus have European levels of emissions per unit of income. Russia, on the other hand regulates domestic prices for natural gas, and has only a little taxation of domestic transport fuels. Most countries in the Middle East keep domestic prices for fossil fuels low by not taxing the use of fossil fuels, and a few sell refined petroleum products domestically at prices below their international value. Unlike Russia, however, Middle Eastern countries do not have extensive domestic industries that are dependent on low-cost fossil fuels – though some are used in chemicals industries. Norway is thus one of Europe's carbon-efficient economies in spite of its large fossil fuel sector. Its carbon dioxide emissions per unit of GDP are less than half that of the United States, and low even by European standards. Norway can thus be seen as a country that produces large quantities of fossil fuels, but does not consume very much itself.

Russia's economic growth over the past few years has been fuelled primarily by energy exports, given the increase in Russian oil production and relatively high world oil prices (Russian Economic Report, 2006). Roughly 72% of crude oil production and 32% of natural gas production was exported in 2004 (IEA, 2006d). Russia's heavy dependence on oil and natural gas exports make it vulnerable to fluctuations in world prices. Typically, a $1 per barrel change in oil prices will result in a $1.4 billion change in Russian revenues in the same direction. Russia has recently been increasing its exports of refined petroleum products in an attempt to increase the value-added in energy-related exports.

The Middle East is the region most dependent on oil and gas resources. Some attempts have been made to diversify away from that economic base, but these have often also been based on the use of cheap energy sources – particularly in the Gulf states and Iran. Petrol-chemicals have been one area where attempts have been made at diversification; aluminium smelting has been another since the cost of electricity is a major component in the cost of producing aluminium. More recently, liquefied natural gas (LNG) plants/facilities, gas-fired electricity and desalination plants have been developed. Indeed, recent demand has been growing strongly enough that in the future the distinction between Russia and the Middle East may be largely eliminated.

In the past, the low levels of diversification and demand for natural gas caused it to be routinely flared off. The United Arab Emirates with its manufacturing and services sectors (financial/banking especially) is perhaps the most successful example of diversification. Nonetheless, for the oil-rich countries as a whole, diversification to the extent it has happened, has generally meant developing industries around their oil and gas wealth to expand employment and blunt the impact of demand fluctuations for crude oil. Most of the Middle East's oil production is exported – 81% of crude oil production. A much smaller proportion of its natural gas is exported – 15% (IEA, 2006d).

Impact of changing fossil energy costs

Given the different contexts that the three economies face, one can expect considerable heterogeneity across them in response to changes in the prices of fossil fuels. It is clear, and uninteresting, that each would stand to lose from a fall in the producer price of crude oil and natural gas. Russia's moves to process crude oil domestically and export refined petroleum products has little, if any, impact on its losses from such price decreases because refining margins are generally not much impacted by input prices since competitive markets leave little room for retail price control.

More interesting would be a change in the price of fossil fuels that is induced by policy to deal with climate change. Using a Pigouvian tax,[7] there would be a rise in the consumer price while the producer price declined. Intuitively, one would expect that all three regions would incur adverse consequences from such a policy, but that the Middle East might be more adversely impacted given its heavy reliance on fossil fuels as a source of national income. As we now see, some additional factors make the outcome of a carbon dioxide tax more interesting.

A global carbon dioxide tax

A global carbon dioxide tax is admittedly simplistic. It would require all countries to implement one, so the negotiations around such a tax would be difficult to conclude. It would also have to be accompanied by additional policies that would help achieve burden

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sharing since a tax would be unfairly burdensome for developing regions (Chichilnisky and Heal, 1994).[8] It is nonetheless useful for illustrating the impacts of a comprehensive climate change policy. It also has some characteristics that are attractive from fiscal policy and other perspectives (Cuervo and Ghandi, 1998; and Shah and Larsen, 1992; Cooper, 2005). Indeed, a number of countries implemented an energy or carbon tax in the early 1990s (see Shrum, 2007, for a brief survey), and in the US the Clinton Administration proposed a BTU tax in 1993 that never reached implementation. Finland began applying a carbon dioxide tax in 1990 that was equal to € 18.05 per tonne in August of 2007. Sweden also began applying a tax in 1991 whose value in August 2007 was equal to € 150 per tonne. Sweden's tax however, exempts electricity and only requires industries to pay 50% – an explicit attempt to avoid disadvantaging its industries in domestic and international markets. Great Britain began applying an energy levy in 2001 that is intended to reduce its use (with reduction of carbon dioxide emissions as an important ancillary objective). Other countries, such as Norway, apply energy taxes that are related to carbon content, but whose coverage is limited and thus have only a small impact on emissions.

Given the mounting scientific evidence of the need for climate change mitigation policies (IPCC, 2007), understanding their differential impacts, and especially the sources of those impacts, may facilitate negotiation and implementation of climate change polices. To study the detailed impacts of a carbon dioxide tax, a useful tool is a numerical model that uses actual data to calculate responses. The kind of partial-equilibrium based discussion above already suggests that we would expect the differences between the three regions to be significant in response to a carbon dioxide tax. To move beyond that intuitive discussion and examine how important the differences between regions are would require a more complete framework. A general equilibrium model would illustrate the differences in considerable detail and permit a more in-depth analysis. A numerical general equilibrium model also has the advantage of being based on estimates of behavioural parameters (such as various demand and substitution elasticities), while simultaneously accounting for other sources of heterogeneity across these regions.

The ENV-Linkages model

ENV-Linkages is a recursive dynamic neo-classical general equilibrium model that has been developed for policy analysis within the OECD. It is a global economic model built primarily on a database of national economies. The model represents the world economy in 34 countries/regions, each with 26 economic sectors. Each of the 34 regions is underpinned by an economic input-output table (usually sourced from national statistical agencies). Those tables identify all the inputs that go into an industry, and identify all the industries that buy specific products. Since the main interest for this work is in three specific regions, we will not focus much on the other 31 regions. Nonetheless, having that regional detail implies that inter-linkages through trade are well represented. More detail concerning the model is provided in the annex.

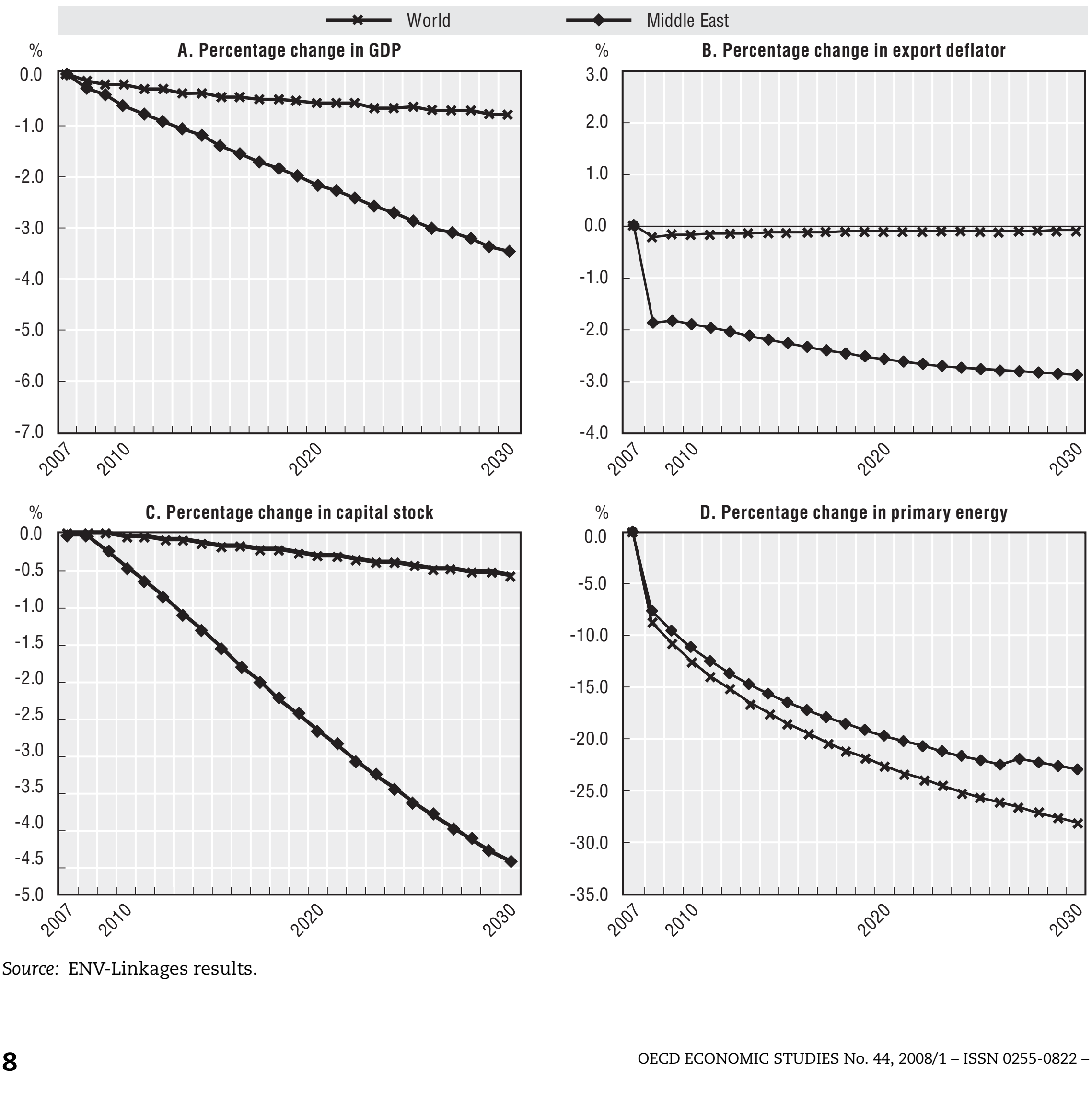
Quantitative results

The experiment undertaken for this analysis is an illustrative $25 tax per tonne of carbon dioxide emitted that is increasing relative to the real value of all produced goods by 0.5% per year.[9] The amount of the tax is chosen arbitrarily, but the results reported below would scale up or down with changes in the tax rate. This is imposed on inputs of fossil fuels in all economic sectors, including final demand by government and consumers. The database that the model uses (GTAP version 6) incorporates IEA data and supplementary information to reflect the user price of fossil fuels (Burniaux and Truong, 2002). The heterogeneity in prices illustrated above is captured in the model's reference case. The impact of the tax will differ by energy types given their carbon dioxide emissions – it distinguishes between emissions (per unit of input) of each sector's energy use. The tax is global so all countries are directly impacted. What is key in the results reported below is the impact that the tax has on domestic use. Since the tax adds a fixed cost to a litre of gasoline or a million BTU of natural gas, the percentage increase in price is dependent on the pre-tax cost of gasoline or natural gas. Regions that have low pre-tax prices will thus see a larger impact of climate change mitigation policy.

Middle East

The response in the Middle East region to the carbon dioxide tax is of a reduction in exports due to reduced demand, and thus a fall in export prices (Figure 2B). The loss of export markets translates directly into a loss of GDP which is approaching 4% by 2030, compared with a global GDP loss of 1% (Figure 2A).

Figure 2. **Middle East**



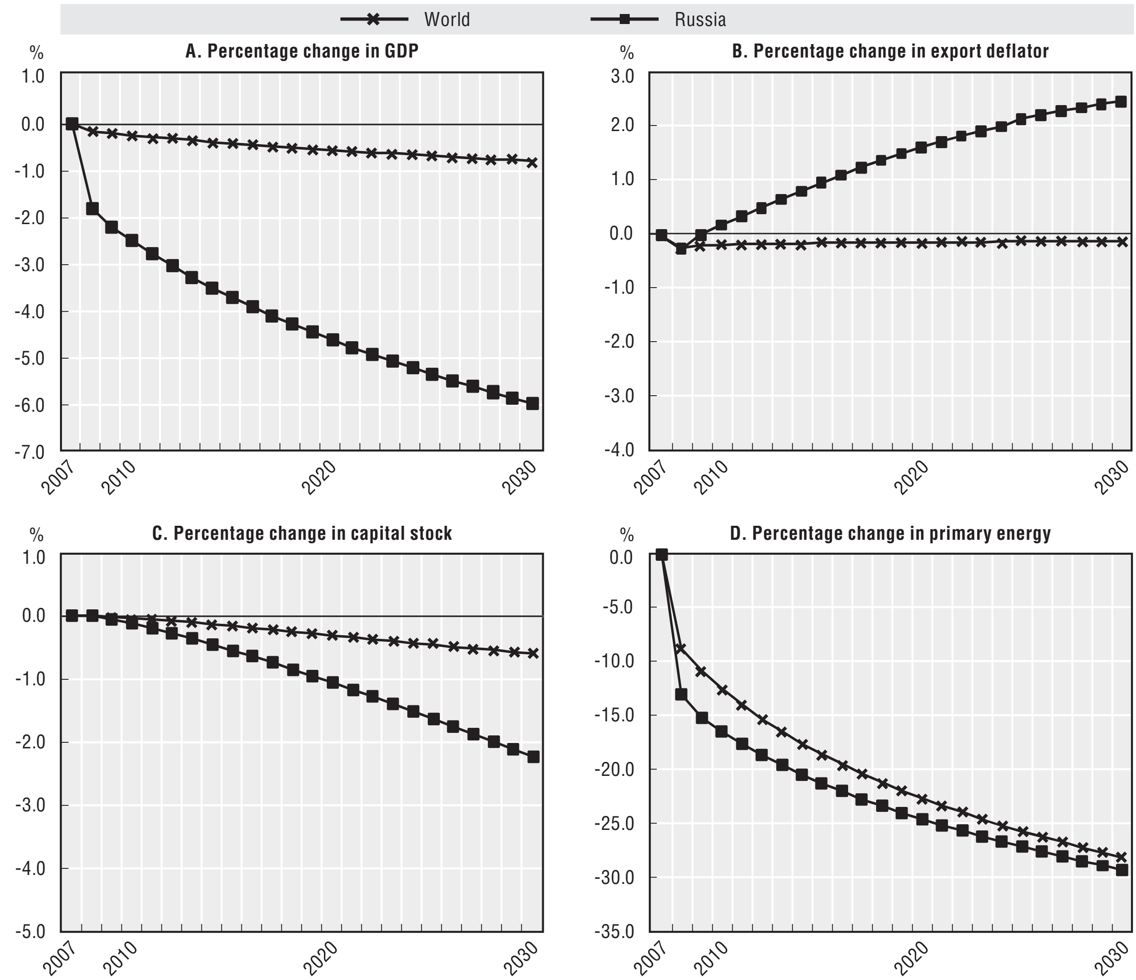
Source: ENV-Linkages results.

The reduction in production is associated with a reduction of capital (Figure 2C) as investment slows in the fossil fuel sector. Since most of the fossil fuels produced are exported, the reduction in primary energy (Figure 2D) largely matches the international reduction in energy used.

Russia

By contrast, Russia suffers a larger GDP loss than the Middle East, even though the change in its capital stock is smaller – the GDP loss is almost twice as big.

Figure 3. **Russia**



Source: ENV-Linkages results.

Figure 3B illustrates that Russia's export deflator is rising even though energy prices for its export market have fallen. Underlying this is the fact that Russia uses more energy (heat and electricity) for domestic industry than does the Middle East. This increase in the price of exports shows that relative to the rest of the world, the price of all exports from Russia increase – thus causing some loss of markets. The price of exports is increasing relative to the rest of the world because domestic energy prices are lower than in the rest of the world. If Russia's energy prices were equal to those in the rest of the world, the relative price of exports would have to fall given the decline in fossil fuel export prices.

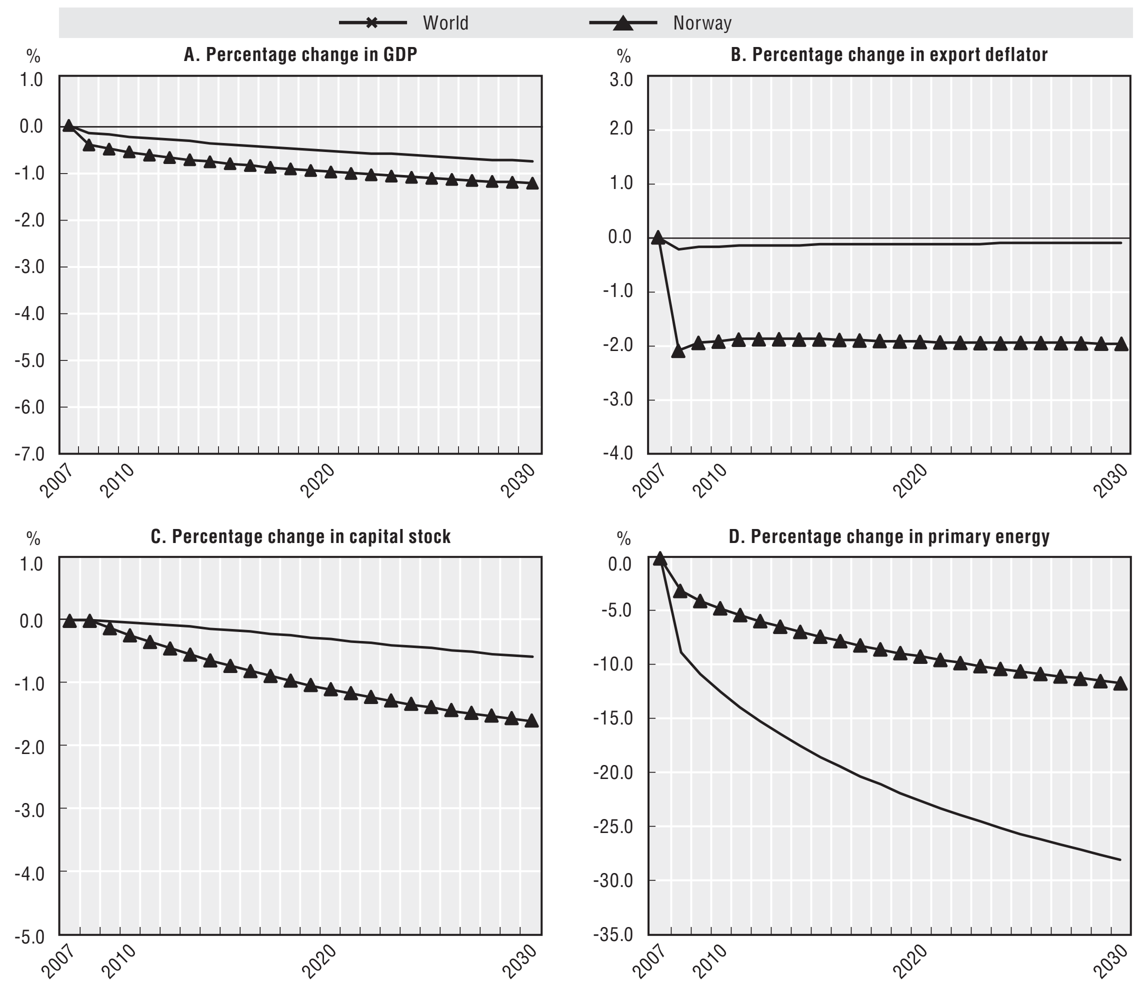
Finally, as Figure 3D illustrates, there is a decline in energy use in Russia that is larger than elsewhere. Again, this is caused by the larger percentage increase in energy prices in the domestic market.

This result offers an interesting lesson to Middle Eastern countries that are attempting to diversify away from heavy reliance on fossil fuel exports. In the past, countries in that region have discussed expanding chemical industries and aluminium manufacturing that would provide value-added to their energy sources and act to dampen energy demand cycles that heavily impact on the region's economic activity. Because activity in these industries would be correlated to fossil energy prices, the region would actually increase the domestic impact of climate change policy – it would make itself more like Russia. True economic diversification would require establishing industries that were largely unaffected by energy prices, and thus would not be impacted strongly by a carbon dioxide tax.

Norway

Norway's experience with the carbon dioxide tax (Figure 4) shows a well-known phenomenon that is put into reverse: *Dutch Disease*.[10] The loss in GDP is small – almost

Figure 4. **Norway**

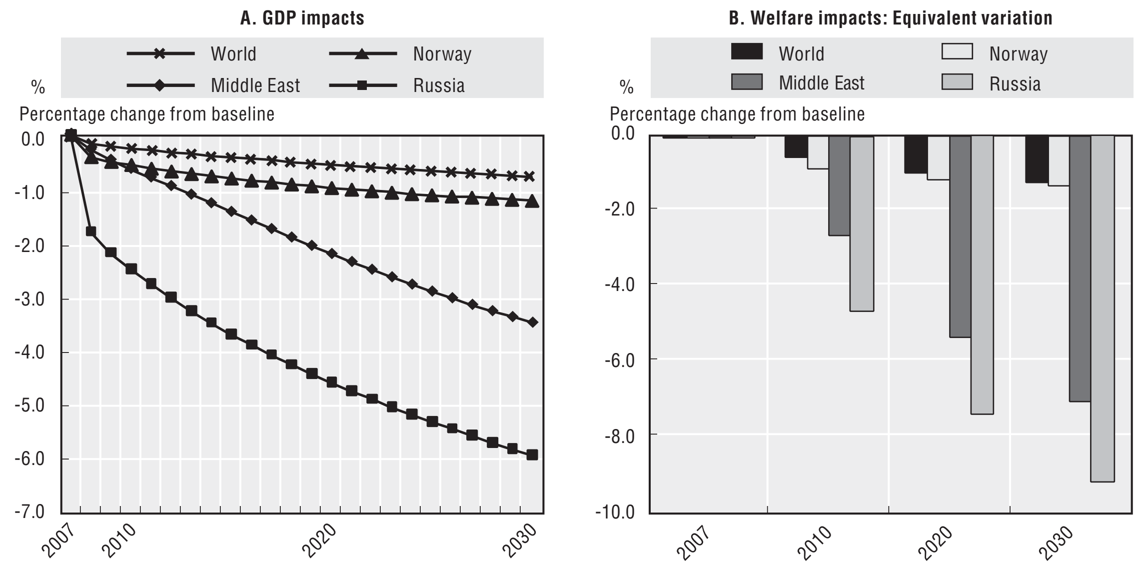


Source: ENV-Linkages results.

identical to that of the rest of the world – because the price of all exports *falls* with the loss of petroleum markets. In other words, losing markets in one area creates the opportunity to gain markets in other areas. This is reinforced by the fact that Norway's domestic energy price is already similar to that of other European countries, and higher than non-European countries – meaning that the percentage increase in domestic energy prices is smaller than the world average.

Comparison of GDP between the three regions is illustrative of relative impacts. Global GDP impact is presented in Figure 5A for reference. Any comparison of GDP to other regions and countries needs to be done carefully since a major export product will be decreasing in value. There is a potential deterioration in the terms of trade for the three regions. Indeed, when we examine the terms of trade we see the Middle East's terms of trade down by 2.5% and Norway's down by a comparable 1.9% in 2030. Perhaps not surprisingly given the observations made above, the terms of trade in Russia improved by about 3% in 2030. This should have been predictable looking panel B in each of the previous three figures. The export deflator is down in Norway and the Middle East, but since Russia uses a lot of energy in producing its exports, its export deflator increases. For each region, import prices are only mildly changed so the terms of trade move with export prices.

Figure 5. **Comparative GDP and welfare impacts**



Source: ENV-Linkages results.

Figure 5B gives the equivalent variation[11], which shows little difference between Norway and the world as a whole, but very large losses for the Middle East and Russia – in spite of Russia's improvement in its terms of trade. The difference between the regions is very strong and the magnitude of the impact on the Middle East and Russia stands in sharp contrast to Norway.

Recent trends in the Middle East, however, suggest that it may be becoming more like Russia. The export market demand for natural gas is extremely strong – Qatar is expanding its exports from projections of nearly 31 million tonnes of LNG in 2007 to an anticipated 77 million tonnes by 2011-12. In addition there is very strong domestic demand growth in nearly all of the Gulf States – such that it can't currently be met from existing supplies. As a result Oman is having problems finding sufficient feedstock for a new LNG plant at Qalhat. Kuwait, Bahrain, and the United Arab Emirates all have tight natural gas markets, as does Saudi Arabia. This is quite a change from earlier periods and represents a deepening of demand markets. Even oil has seen demand surge – a combination of cheap transport fuel prices and increased incomes from increasing exports. All this suggests that to some extent, the region is making itself more vulnerable to the kind of impacts illustrated above for Russia.

"Subsidies" in Russia and the Middle East

The prices of oil and gas illustrated in Table 2 were important factors in the results illustrated above (price elasticities were assumed to be similar in each region). Given their importance, a few additional observations are warranted concerning Russia and the Middle East.

When Russia began its transition to a market economy in the early 1990s it had an infrastructure for exporting oil and gas that was significantly developed. Oil and gas were, however, sectors that were troubled by difficulties from communist-era management (IEA, 2002). Economic restructuring during the early 1990s led to dislocation on a large scale – OECD estimates of the economic contraction from 1992 to 1998 are on the scale of 38% of GDP. As part of an effort to offset the impact on consumers, the government lowered (already low) electricity and natural gas prices in the late 1990s. This likely gave a short-term boost to industry. Oil products were not considered part of basic energy needs, and were thus not subjected to similar controls. By the early 2000s – with world oil prices recovering, the rouble devalued, and reforms coming out of the financial crisis taking effect – Russia's industrial sector and particularly its oil industry were in sharp recovery. Its natural gas sector, however, was still under domestic price controls.

Those controls did not extend to exports. In general, the price of natural gas exports was set by international market forces – though for some export markets, notably former Soviet Union countries, prices were lower. This created an incentive for maintaining and developing a capacity to transport natural gas to external markets while neglecting domestic markets. Indeed, natural gas exports increased by 5% (measured in energy terms) between 1992 and 1998 even while domestic production decreased by 11% – though it is likely that the sharp economic decline contributed to the domestic decrease. An export transport monopoly was (and is) held by its largest natural gas producer Gazprom. Since even larger increases in capacity for exports were not built during this period, it may well have been the case that Russia (Gazprom) was behaving strategically as a price-setter.[12] The Bluestream Pipeline from Russia to Turkey has been viewed as an attempt by Gazprom to protect its status as a price setter in the European market by limiting the ability of Caspian-area competitors to access Europe (Tsereteli, 2005). Given the results above, an interesting question arises concerning the appropriate prices that should have been set domestically.

Given Russia's very large reserves, it is not clear what its domestic price should have been: domestic long term marginal cost, or the export price. If Russia feared that technological developments in the future might make its gas reserves worth much less than today, then its current domestic price should not necessarily be equal to its export price. This would be the case if there was a possibility that a future energy technology might have marginal cost lower than the marginal cost of its natural gas while it still had substantial reserves. Indeed, with reserves that could sustain some 80-odd years worth of

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consumption at current rates, future technological change creates substantial uncertainty for the value of those reserves. In those circumstances, Russia's best strategy would be to export as much as possible at whatever price those markets will bear, but to keep the domestic price near long term marginal cost (*i.e.* the cost that included incentives to maintain as well as expand infrastructure, and to continue with further exploration of new sources of natural gas).

The price in European markets may not have been appropriate for Russia domestically in the past, but there is some evidence that the actual domestic price was too low. IEA (2006c) reports that the average price for all domestic users was $31 per thousand cubic metres in 1998 (which was roughly 90% of the export price – in fact that domestic price was often not paid by domestic users since many bartered trades or refused to pay). That domestic price was on a downward trend that reached a low of $11 in 1999/2000 (roughly 10% of the export price in those years). The price from 1999 to 2002 was even below the apparent marginal cost of $22 per thousand cubic metres.[13] After 2002, the price rose above marginal cost and has been increasing since (with a higher proportion of customers actually paying for natural gas). Tarr and Thomson (2004) also argue that an optimal strategy for Russia would be a dual pricing structure that had Russia (Gazprom) behaving strategically in international markets while pricing at long run marginal cost in domestic markets. They estimated Russia's long run marginal cost to be around $40 per thousand cubic meters. Recent increases in production costs associated with increases in labour and capital costs, as well as depletion of its low-cost reserves would put its long run marginal cost closer to $60 per thousand cubic meters – still well below the export price, and prices in most industrialised countries.[14] Ahrend and Tompson (2004) come to similar conclusions and argue that reform of Russia's gas markets should lead only to the domestic price being set at long term marginal cost – which they acknowledge is well below the export price. These observations suggest that recent price increases for natural gas could remove completely any implicit subsidy given to domestic consumers and still leave Russia vulnerable to the kinds of results noted above. This is because domestic prices would remain below that of its industrial competitors.

With Russian ratification of the Kyoto Protocol, however, a new factor has now been added to the determination of the domestic price for natural gas. It should be above current marginal (and long term marginal) cost irrespective of the size of its reserves (even if Russia had virtually limitless supplies of natural gas). This is because a GHG abatement regime would force Russian energy costs to increase, thereby narrowing the difference between Russia's domestic price and the prices of industrial competitors and trading partners. Given the results illustrated above, there is a strong case for slowly moving domestic prices closer to that of its trading partners; that is, doing it on its own timetable would be preferable to having to move more abruptly in a subsequent internationally-negotiated GHG abatement regime.

In the Middle East region, many countries subsidize their domestic consumption. GTZ (2007) reports retail gasoline prices in Iran, Saudi Arabia and Kuwait at $0.09, 0.16, and 0.22, respectively. In Iran subsidies were estimated to be worth 16% of GDP in 2000 (Tarki, 2004) and rising rapidly with increasing oil prices. Iran only refines about half its domestic demand. Since the other half is imported from abroad, subsidies automatically rise with increasing oil prices. Moreover, the subsidies encourage illegal re-exports of cheap gasoline: implying that the Iranian treasury finances re-export activity and subsidizes its neighbours' gasoline consumption. Von Moltke *et al.* (2003) report that annual growth in energy use (encouraged by subsidies) was 5.4% between 1990 and 2000 – enough to increase energy use by 72%. More recently, between 2001 and 2006, oil consumption grew in Iran and Saudi Arabia at over 5% annually and at more than 7% in Kuwait. These rates of growth are sufficient to call into question the region's capacity to increase exports in response to high export prices. They also lead directly to the region's sensitivity to climate change abatement policy by making consumers dependent on cheap energy.

Information asymmetries and climate change negotiations

The results reported here may lead to the disquieting conclusion that the Middle East and particularly Russia have little incentive to join a climate change mitigation regime. Indeed, given these results one would ask why Russia ratified the Kyoto Protocol at all. Buchner and Dall'Olio (2002) show that the circumstances for Russia's ratification were somewhat unique in that other issues (side-agreements) induced Russia into signing. Even so, Russia and the Middle East have strong incentives to participate in order to avoid some of the particularly adverse consequences of climate change – such as melting of the polar ice caps (Schellnhuber, 2006). Unrestricted indefinite emissions of greenhouse gases raise the possibility of such outcomes. The question is thus not "if" these regions should join, but rather "under what circumstances".

A substantial literature on information asymmetries suggests that if the types of heterogeneities highlighted here were not accounted for, negotiations to reach an accord for the post-2012 period would be difficult. Kennan and Wilson (1993) highlight that information asymmetries cause long (and sometimes painful) negotiations to occur just to get participants to reveal their preferences so that mutually acceptable solutions can be explored. In negotiations between firms and labour unions, strikes and lockouts are means of revealing information concerning bargaining positions (Fisher, 2001).

The provision of GHG mitigation is a public good that requires collective action through negotiation, but the set of feasible outcomes becomes restricted under asymmetric information. Indeed, Mailath and Postlewaite (1990) show that as the number of agents becomes large, the probability of finding an acceptable solution under information asymmetries approaches zero. This happens even when there is a clear net benefit to be had from collective action.

Our argument here is that when that result is combined with unknown degrees of heterogeneity – *i.e.* that individual country circumstances are not well understood by everyone participating in the negotiations – then the range of possible outcomes that could be agreed upon may become vanishingly small. This is arguably the case with a problem such as climate change, where the free-rider incentive is evident and thus suspicion of strategic behaviour may greet each claim of special circumstance. It may be the case that global negotiations cannot reach agreement with a large number of countries participating until there is broader understanding of what the impacts of a changing climate and mitigation policy will be on individual countries.

This line of analysis is different from the currently dominant approach to looking at climate change policy as a game-theoretic problem (*e.g.* Finus, 2002 a,b). In the current literature, as long as a welfare-improving negotiated outcome exists, there is an assumption that it will be found. The problem in that work is seen as ensuring that the institutional arrangements that facilitate, monitor, and enforce outcomes will be put in place. Failure to get an agreement is seen as a failure to put in place the right institutions

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(*e.g.* international governance). Mailath and Postlewaite (1990), however, show that the problem may be much deeper in the presence of information asymmetries; *i.e.* you may never get a solution without removing the asymmetries.

Rigorous quantitative analysis is thus necessary for each major country/region participating in the negotiation to remove, as much as possible, information asymmetries and subject claims of exceptions to rigorous scrutiny. The work that has been reported here is a step in that direction.

Conclusion

The contrast between the three regions that we considered is striking in how strong the different responses are, even though all three regions are heavy fossil-fuel exporters. While all three are (economically) adversely impacted by the global carbon dioxide tax, Norway is the least impacted. This comes about largely because the government has made it a national policy not to make Norway dependent on its fossil-fuel reserves for its economic well-being, with energy prices in Norway being well above the global average. Since a tax on carbon dioxide emissions raises the price of a fossil fuel by a fixed amount in all countries, those with already high prices will see a smaller percentage increase, and thus are less impacted.

The lessons for the Middle East that come from this work are twofold. On the one hand, it makes the obvious point that the region stands to be adversely impacted by global GHG-abatement policies. On the other hand, it also suggests that diversification strategies that rely on inputs of cheap fossil fuels will only deepen the consequences of such policies. True diversification requires developing sectors that are at best anti-cyclical to fossil-fuel industries, or at least neutral with respect to cycles in those industries.

Russia has already acknowledged the need to reform its domestic energy prices. An international carbon dioxide tax would increase the price of Russian oil and gas to consumers (foreign and domestic), while lowering the price that suppliers receive. It is thus in Russia's interest to follow through, and even accelerate, its domestic energy reforms so that domestic consumers of energy are impacted by GHG abatement policy no more adversely than Europe's consumers, or its other industrial competitors.

A message from this work is evident for other countries as well. Vulnerability to climate change abatement policies is partially a function of current and past policies regarding energy and sources of carbon dioxide emissions. If dealing with climate change is going to be a policy objective, then it will be best to start moving sooner to energy prices that are closer to that of other major economies.

A final message from this work is that lack of widespread understanding of impacts of climate change mitigation policy creates information asymmetries that will make reaching global agreement difficult. Rigorous quantitative analysis is thus necessary for each major country/region participating in the negotiation – to remove, as much as possible, information asymmetries and subject claims of exceptional circumstances to rigorous scrutiny. The work that has been reported here is a step in that direction.

Notes

1. Sachs and Warner (1995) noted a correlation between high natural resource abundance and slow economic growth.
2. The Middle Eastern region here is defined as Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen and Occupied Palestinian Territories. The limitations of source data precluded further disaggregation. Norway is also combined with Iceland and Liechtenstein.
3. Pricing carbon dioxide emissions would also impact on coal, but only a little coal is consumed in Norway and the Middle East. Russia, on the other hand, has 11% of its gross (pre-export) energy production coming from coal (IEA, 2006). In the results reported below, coal emissions are priced, but coal does not substantially explain the differences between regions.
4. Although a tax of $25 is studied below, it is not intended to be justified on the basis of cost-benefit. The economic costs of carbon dioxide emissions are not well enough understood to use the $25 estimate for cost-benefit analysis.
5. Using US Energy Information Administration data on emission factors (*http://www.eia.doe.gov* /oiaf/1605/coefficients.html). The same tax would add $269 to the cost of a tonne of bituminous coal.
6. Since the tax would be expected to be permanent, long-term price elasticities would apply. A survey of transport elasticities by Hanly, *et al.* (2005) show a fairly robust long-term response, with the average price elasticity around 0.64 for transport fuels.
7. A tax that exactly internalises non-markets transaction, or externalities (Pigou, 1920).
8. An international tradable permit scheme can facilitate burden sharing through the allocation of permits, but has some drawbacks in requiring periodic re-negotiation of the permit allocation – which will transfer very large sums of money between countries.
9. The model does not account for the impact of productivity growth on consumer prices for individual goods (only prices of aggregate goods are represented). Therefore, these prices would be increasing more rapidly over time in real consumer prices. That is, in an aggregate sector, productivity increases imply that output of that sector represents more individual units of goods and services. A consumer price index of the model's goods and services should account for that change and keep the units constant over time. One can infer from this that the growth in the tax rate would be higher relative to consumer prices.
10. See McKibbin and Wilcoxen (1998) for an analysis of Dutch Disease induced by the creation of tradable permits for carbon dioxide emissions.
11. Defined here as the change in real income relative to baseline income. See Fane and Ahammad (2004) for a discussion of measures of equivalent variation in a modelling context.
12. With recent increases in export capacity to Europe by Norway and the Middle East, Russia may be losing any ability it may have had to influence European natural gas prices.
13. The price of $22 is inferred from a contracted price that Gazprom negotiated with Lukoil in 2003 (IEA, 2006c).
14. Personal communication with Isabel Murray of the International Energy Agency.

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Annex: The ENV-Linkages Model

The ENV-Linkages model is a recursive dynamic neo-classical general equilibrium model that has been developed for policy analysis within the OECD. It is a global economic model built primarily on a database of national economies. The model represents the world economy in 34 countries/regions, each with 26 economic sectors. Each of the 34 regions is underpinned by an economic input-output table (usually sourced from national statistical agencies). Those tables identify all the inputs that go into an industry, and identify all the industries that buy specific products. Since the main interest for this work is in three specific regions, we will not focus on the other 31 regions. Nonetheless, having that regional detail implies that inter-linkages through trade are well represented.

Income generated by economic activity ultimately reflects demand for goods and services by final consumers. ENV-Linkages represents consumers as being largely similar at a very aggregated level of consumption. As such, the model postulates a representative consumer who allocates disposable income according to preferences: among consumer goods and saving. In this version of the model, consumers purchase goods and services as produced by firms (a *transition matrix* to map produced goods into specific consumer goods is not implemented). The consumption/saving decision is static instead of forward-looking: saving is treated as a "good" and its amount is determined simultaneously with the demands for the other goods, the price of saving being set arbitrarily equal to the average price of consumer goods. This means that consumers are saving a constant proportion of their income and not adjusting savings to reflect future events that may impact on income.

Formally, a representative consumer maximises well-being (utility) subject to resource constraints:

$$Max\ \ U = \sum_i \mu_i \ln(C_i - \theta_i) + \mu_s \ln(\frac{S}{P_s}) \qquad subject\ to \quad \sum_k P_k C_k + S = Y, \quad and \quad \sum_k \mu_k + \mu_s = 1$$

where U represents utility, C is a vector of consumer goods, P_k represents consumer prices, S represents the value of saving, P_s the relevant price of saving, and Y is total income (completely allocated between consumption and savings). The parameter, θ, is the floor level of consumption – its main function is in making the utility function non-homothetic (see Dowrick, *et al*. 2003). Both the floor level of consumption and the share parameters, μ, are calibrated to a given set of *initial* consumption shares and income elasticities. Since consumers are not represented with forward-looking behaviour, some care needs to be exercised in studying policies that consumers may reasonably be expected to anticipate – either the policy itself or its consequences. Analysis of tax changes, or any other event, that are announced today but not enacted until the future would not be appropriate with this modelling framework.

For each country, the consumer's objective function thus gives rise to household private consumption and savings (letting *k* represent individual goods),

$$C_k = Pop\theta_k + \frac{\mu_k}{P_k^c} Y^*, \qquad where \quad Y^* = Y^c - Pop\sum_k P_k^c \theta_k \qquad \text{(consumption)}$$

$$S = Y^c - \sum_k P_k^c C_k \qquad \text{(savings)}$$

where *Pop* represents population, Y^c represents household disposable income and Y^* is a *supernumerary* income (*i.e.* income above the subsistence level).

Production

Firms in all sectors in ENV-Linkages minimise the cost of producing the goods and services that are demanded by consumers and other producers (domestic and foreign). Production is represented by constant returns to scale technology, though diminishing costs can be achieved through fixed costs.

Figure 6 illustrates the nesting of the model's principle sectors (the agriculture sectors have a slightly different nesting, but that is not important for this analysis).

In this model, each node is represented by a constant elasticity of substitution (CES) production function. This gives marginal costs and represents the different substitution (and complementarity) relations across the various inputs in each sector. There are material inputs – including energy – that are used by all sectors in the economy, and, as well, there are the value-added factor inputs, capital and labour. In some sectors the material inputs include natural resources, *e.g.* trees in forestry, land in agriculture, *etc.* The material inputs generate the input/output tables of each economy represented in the model.

The top-level production nest has final output that is produced as a combination of aggregate intermediate demand and value added. For each good or service, output is produced by different production streams which are differentiated by capital vintage (old and new). Capital that is implemented contemporaneously is new – thus investment impacts on current-period capital; but then becomes old capital (added to the existing stock) in the subsequent period. Each production stream has an identical production structure, but with different technological parameters and substitution elasticities. Letting $X_{i,v}$ represent gross output of sector *i* using capital of vintage *v*, the equations representing production are derived from first order conditions of the firm's profit maximization objective:

$$INT_i = \sum_v \alpha_{i,v}^{INT} A_{i,v}^{\sigma_{i,v}^G - 1} \left(\frac{VC_{i,v}}{P_i^{INT}}\right)^{\sigma_{i,v}^G} X_{i,v} \qquad \text{(intermediate demand)}$$

$$VA_{i,v} = \alpha_{i,v}^{VA} A_{i,v}^{\sigma_{i,v}^G - 1} \left(\frac{VC_{i,v}}{P_i^{VA}}\right)^{\sigma_{i,v}^G} X_{i,v} \qquad \text{(value added)}$$

$$VC_{i,v} = \frac{1}{A_i} \left[\alpha_{i,v}^{INT} P_i^{INT^{1-\sigma_{i,v}^G}} + \alpha_{i,v}^{VA} P_i^{VA^{1-\sigma_{i,v}^G}}\right]^{(1/(1-\sigma_{i,v}^G))} \qquad \text{(variable costs)}$$

where *INT* is intermediate demand (P^{INT} its price), *VA* represents value-added (P^{VA} its price), *VC* is unit variable cost (average costs include the cost of capital), *A* is the technical change term. In these equations, the subscript ν denotes the vintage of the capital stock used in production (ν equals *old* or *new*). In order to determine the industry-wide cost that includes both capital vintages, there is an averaging (weighted) of variable costs across the two vintages. The model allows the production technology to be something other than constant returns to scale through the inclusion of fixed capital or labour costs, whose costs

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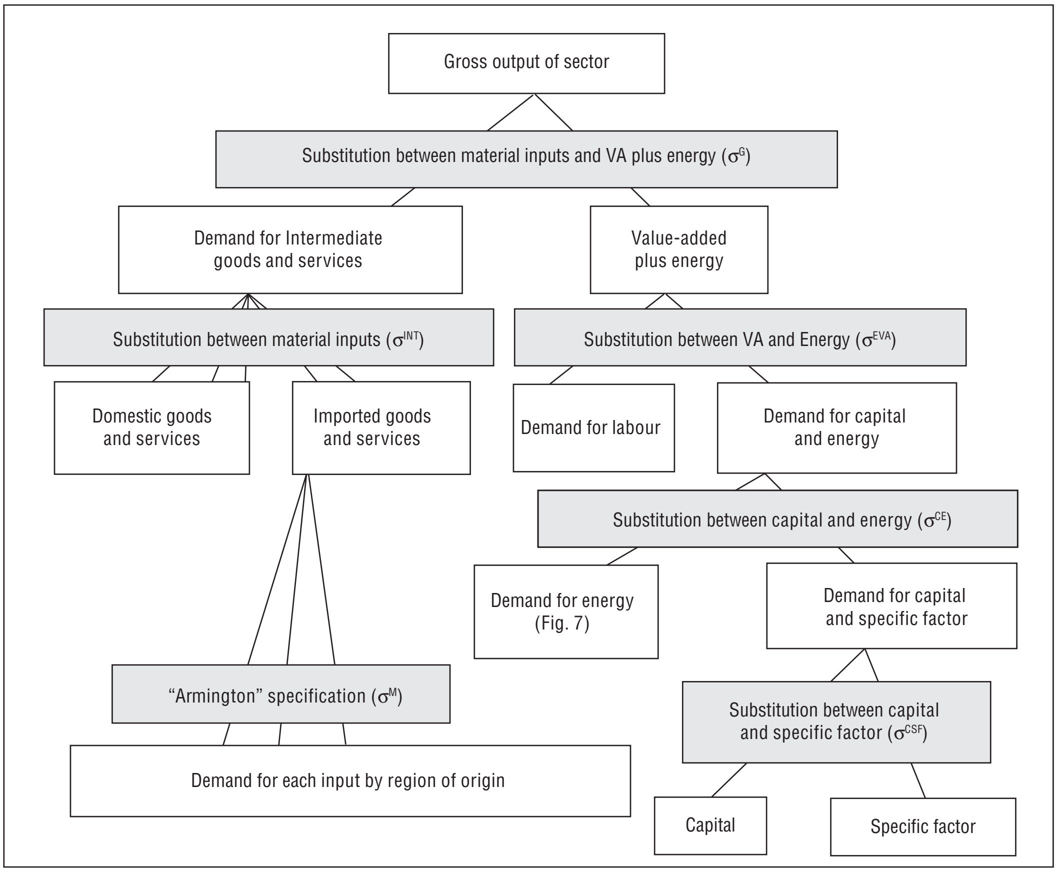
Figure 6. **Structure of production in ENV-Linkages**



are then added to variable cost *VC* to determine the unit output price. A markup is also possible in determining output prices – which allows the representation of non-competitive markets.

The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be only partially mobile across sectors, reflecting differences in the marketability of capital goods across sectors. The specification of partial mobility, however, does not impact on the usefulness of capital. There is homogeneity in the use of old and new capital.

Variable costs (*VC*) focus on intermediate inputs and value-added because, in each period, the supply of primary factors (*i.e.* capital, labour, and land) is usually predetermined (except, as noted above, for the influence of contemporaneous investment on capital). Energy is also in value-added, giving it an added degree of variability. On the right hand side of the tree in Figure 6 value-added is shown as being composed of a labour input along with a composite capital/energy bundle.

$$L_i = \sum_v \alpha^L_{i,v} \left(\frac{P^{VA}_{i,v}}{W_i}\right)^{\sigma^{EVA}_{i,v}} VA_{i,v} \lambda^{\sigma^{EVA}_{i,v}-1} \qquad \text{(labour demand)}$$

$$KE_{i,v} = \alpha^{KE}_{i,v} \left(\frac{P^{VA}_{i,v}}{P^{KE}_{i,v}}\right)^{\sigma^{EVA}_{i,v}} VA_{i,v} \qquad \text{(capital-energy demand)}$$

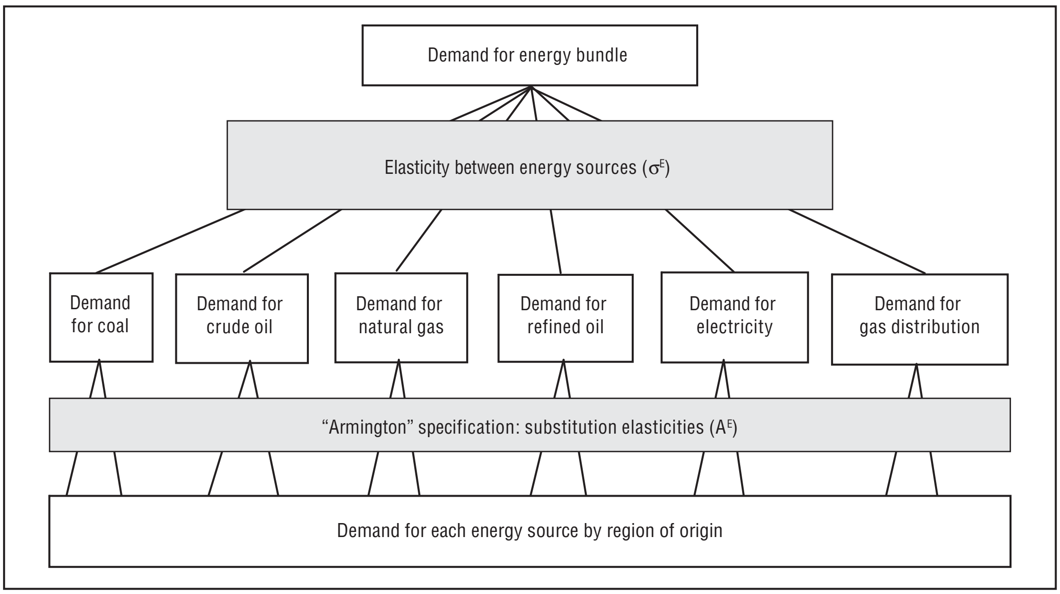
where *L* represents labour (*W* its price), and *KE* is the capital-energy bundle (P^{KE} its price), *VC* is unit variable cost (average costs include the cost of capital). The price of the value-added bundle is:

$$P_{i,v}^{VA} = \frac{1}{A_{i,v}}[\alpha_{i,v}^{KE} P_{i,v}^{KE\,1-\sigma_{i,v}^{EVA}} + \alpha_{i,v}^{L}\left(\frac{W_i}{\lambda_i}\right)^{VA^n\,1-\sigma_{i,v}^{EVA}}]^{(1/(1-\sigma_{i,v}^{EVA}))} \qquad \text{(price of value-added)}$$

Value-added (*VA*) is a sub-component of the top level node that produces sectoral output X_i. Similar sub-components also exist in formulating the capital and energy bundle. In fact, as shown in Figure 6 (bottom right node), the capital represented here is bundled with a sector-specific resource when one exists and energy is itself a bundle of different energy inputs.

The energy bundle is of particular interest for the analysis of climate change issues. Energy, as reported in Figure 7, is a composite of fossil fuels and electricity. Given the dual streams of production (from old and new capital), there is a high degree of substitutability between energy sources when capital is new (elasticity of 2), but after one year it becomes a sunk cost and falls to a low level of substitutability (elasticity of 25). Moreover, in the sectors that produce fossil fuels (such as natural gas), there is no substitutability between energy inputs (so the model does not allow coal liquefaction beyond its share in the base year).[1] The low level of substitutability of energy when old capital is present is consistent with empirical findings by Arnberg and Bjorner (2007) that look at plant level changes in energy intensity. However, since this model includes the possibility of changes in industry composition, our overall responsiveness to energy price changes will be higher than they found at plant levels.

Figure 7. **Structure of energy demand in ENV-Linkages**



Once a sector's optimal combination of inputs is determined from relative prices, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions.

A fixed mark-up exists in the model to allow examination of alternative specifications of competitive behaviour – though it was not used for the analysis here.

Total output (supply) of any good or service consists of an Armington combination of domestic production and imports. This must equal total demand, consisting of demand from domestic firms, domestic consumers and exports.

Technical change

ENV-Linkages features technical change that is exogenously specified. In the baseline of the model (to 2030), labour productivity has been assumed to globally follow a trajectory that leads to convergence in growth rates to 1¾ per cent per year (see OECD, 2008 for more information). In the simulations, however, there is no explicit mechanism that would connect that to changes of aggregated labour productivity in response to a carbon dioxide tax. Indeed, the model does not link policy instruments of any kind to labour productivity – though a link can be introduced (by changing the exogenous rate of productivity growth along with the introduction of a policy instrument). At a practical level, the technical change parameters of the CES production function are exogenously set. This limitation in the model's representation of technological change means that some may view the results as somewhat pessimistic.

Nonetheless, a CES representation of production features some technological change as firms and industries respond to price changes. Indeed, when the price signal is strong enough a CES production technology predicts that new technology will be forthcoming that does not currently exist. Since the elasticities in the model are taken from an empirical literature that covers periods of technological change in response to price changes, there is a degree of consistency with empirical evidence. In fact, any attempt to introduce an explicit representation of endogenous technological change would have to adjust the substitution elasticity so as not to over-represent the impact of new technologies.

For the simulations reported above, if policy were implemented in a manner that accelerated technical change, it would reduce the impact on each region of the carbon dioxide tax. It should not, however, change the main result of this paper; *i.e.* the heterogeneity of the regional responses. In order to change the main issue addressed in the paper, technological change in response to the policy would have to be unique to each region.

Investment

This version of the model does not include an investment schedule that relates investment to interest rates.[2] Investment is equal to domestic saving in each period; *i.e.* investment is equal to the sum of government savings, consumer savings and net capital flows from abroad induced by trade imbalances. The differences in sectoral rates of return determine the allocation of investment. Sectors with higher investment, therefore, are more able to adapt to changes than are sectors with low levels of investment. Indeed, declining sectors whose old capital is less productive begin to sell capital to other firms (which they can use after incurring some cost for modifications).

Foreign trade

World trade in ENV-Linkages is based on a set of regional bilateral flows. The basic assumption is that imports originating in different regions are imperfect substitutes;

i.e. different countries may produce similar goods, but they are never identical (though some goods, such as crude oil, are very similar). Therefore in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. This specification of imports – commonly referred to as the Armington specification – formally implies that each region faces a reduction in demand for its exports if domestic prices increase. The Armington specification is implemented using two CES nests. At the top nest, domestic agents choose the optimal combination of the domestic good and an aggregate import good consistent with the agent's preference function. At the second nest, agents optimally allocate demand for the aggregate import good across the range of trading partners *r*.

$$M_i = \beta_i^m \left(\frac{P_i^A}{P_i^M}\right)^{\sigma_i^m} X_i^A \quad \text{(import demand: 1st level CES nest)}$$

$$P_i^M = [\sum_r \beta_{i,r}^W {P_{i,r}^M}^{1-\sigma_{i,r}^w}]^{(1/(1-\sigma_i^w))} \quad \text{(price of imports)}$$

where M is import of a particular good or service (P^M its price) and X^A represents Armington-based aggregate demand, which gives the demand for imports (P^A is its price).

The bilateral supply of exports is specified in parallel using a nesting of constant-elasticity-of-transformation (CET) functions. This specification complicates the determination of aggregate output since it is no longer a simple addition of domestic demand plus exports. At the top nest (where CET is used), domestic suppliers optimally allocate aggregate supply across the domestic market and the aggregate export market. At the second nest, aggregate export supply is optimally allocated across each trading region as a function of relative prices (analogous to the import specification above).

$$X_i = [\alpha_i^{-1/\sigma_i^X} {X_i^D}^{(\sigma_i^X+1)/\sigma_i^X} + \alpha_i^{-1/\sigma_i^X} {E_i^D}^{(\sigma_i^X+1)/\sigma_i^X}]^{(1/(1-\sigma_v^X))} \quad \text{(gross ouput: 1st level CES nest)}$$

where X is gross output, X^D is domestic demand, and E^D is the demand coming from abroad.

Trade measures are fully bilateral and can include both export and import taxes/ subsidies. Trade and transport margins can also be included; in which case world prices would reflect the difference between FOB and CIF pricing.

Prices

ENV-Linkages is fully homogeneous in prices, *i.e.* only relative prices matter and the model only solves for relative prices. The price of a single good, or of a basket of goods, is arbitrarily chosen as the numéraire of the price system. In this version of the model, an index of OECD manufacturing exports has been chosen to anchor prices, and is set to one in both the base year and all subsequent years. From the point of view of the model specification this has an impact on the evaluation of international investment flows. They are evaluated with respect to the price of the numéraire good. Therefore, one way to interpret the foreign investment flows is as the quantity of foreign saving which will buy the average bundle of OECD manufacturing exports.

The domestic producer price in the model is defined as the variable cost (*VC*) plus a mark-up and taxes. The consumer price is a composite of individual industry Armington prices, which are based on domestic output prices and import prices.

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Government and long-term closure

Government collects income taxes, indirect taxes on intermediate and final consumption (*e.g.* carbon taxes), production taxes, tariffs, and export taxes/subsidies. Aggregate government expenditures are linked to real GDP, so government programmes grow with the rest of the economy. Since predicting corrective government policy is not an easy task, the real government deficit is exogenous. Closure of the model to ensure reasonable long-term properties therefore implies that some fiscal instrument is endogenous – in order to anchor the given government deficit. The fiscal closure rule in ENV-Linkages is that the marginal income tax rate adjusts to offset changes that may arise in government expenditures, or as a result of other taxes. For example, a reduction or elimination of tariff rates is compensated by an increase in household direct taxation, *ceteris paribus*. If change in the long-term deficit is desired as a result of the tariff change, the deficit can be changed exogenously by the amount of the decreased revenues – so there is no offsetting change in income taxes.

Each region runs a current-account surplus (or deficit), which is fixed (in terms of the model numéraire basket of goods). Closure on the international side of each economy is achieved by having a counterpart of these imbalances result in a net outflow (or inflow) of capital, which is subtracted from (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (which is equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). Given the rules for government and international closure, this final particular closure rule implies that investment is driven by saving.

Dynamic features and calibration

The ENV-Linkages model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations concerning prices and quantities. Dynamics in the model originate from three sources: *i)* accumulation of productive capital; *ii)* the putty/semi-putty specification of technology; and *iii)* productivity changes.

Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the *new* than with the *old* capital vintages – technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (*e.g.* tariff removal), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

Dynamic calibration

The model is calibrated on exogenous growth rates of population, sector-specific and aggregate labour productivity growth. The residual autonomous energy efficiency improvement in energy use (known as the AEEI factor) is dynamically calibrated in order to reproduce *IEA World Economic Outlook* (2006) prospects concerning energy demand. There are various alternatives for calibrating the key growth parameters in the baseline scenario. The model uses labour productivity growth to project forward a changing composition of economic output, and uses and aggregate labour productivity growth to achieve some convergence in long-term productivity *growth*. In aggregate, the regions converge at a rate given by Sala-i-Martin (1996) to 1.75. Since convergence is very slow (2% closing of the productivity gap per year), none of the regions have converged within the horizon used for the analysis below (to 2030).

The GTAP database version 6 (Dimaranan, 2006) provides much of the data necessary for simulation. For use with the model, the database is aggregated globally to 26 sectors and 34 regions.

Notes

1. On-going work to estimate these parameters using Bayesian techniques (Robinson, Cataneo, and El-Said, 2001) may change these elasticities in future versions of the model.
2. A *maquette* version of ENV-Linkages has been developed that links investment to rates of return and is being used for studying intertemporally optimal dynamic paths.

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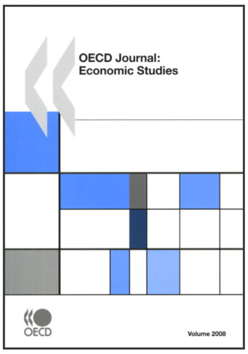

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