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# POLITICAL AND ECONOMIC INFLUENCES ON THE FUTURE WORLD MARKET FOR NATURAL GAS

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# Political and Economic Influences on the Future World Market for Natural Gas

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## About the Geopolitics of Natural Gas Study

Natural gas is rapidly gaining in geopolitical importance. Gas has grown from a marginal fuel consumed in regionally disconnected markets to a fuel that is transported across great distances for consumption in many different economic sectors. Increasingly, natural gas is the fuel of choice for consumers seeking its relatively low environmental impact, especially for electric power generation. As a result, world gas consumption is projected to more than double over the next three decades, rising from 23% to 28% of world total primary energy demand by 2030 and surpassing coal as the world's number two energy source and potentially overtaking oil's share in many large industrialized economies.

The growing importance of natural gas imports to modern economies will force new thinking about energy security. The Energy Forum of the James A. Baker III Institute for Public Policy and the Program on Energy and Sustainable Development at the Stanford University Institute for International Studies are completing a major effort to investigate the geopolitical consequences of a major shift to natural gas in world energy markets. The study utilizes historical case studies as well as advanced economic modeling to examine the interplay between economic and political factors in the development of natural gas resources; our aim is to shed light on the political challenges that may accompany a shift to a gas-fed world.

## Disclaimer

## About the Authors

**Peter R. Hartley** is chairman of Rice University's Department of Economics and is widely published on such theoretical and applied economic issues as money and banking; business cycles; utilities and airlines regulation; internal financial and energy, environmental, health, and labor economics. His current research at Rice involves development of Rice's World Gas Trade Model; study of financial intermediaries, liquidity and borrowing constraints, and applied microeconomics. He gained policy experience as a member of the a team of economists advocating and advising on reform of the Australian electricity supply industry and worked for the prime minister's department in the Australian federal government in the mid-'70s.

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# Political and Economic Influences on the Future World Market for Natural Gas

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## ABSTRACT

This working paper first develops a Reference Case that allows required rates of return on investments in energy infrastructure to vary geographically. Those rates of return reflect an assessment of the risks associated with energy business investments in various countries. By comparison, the Base Case, which was presented in the working paper, "The Baker Institute World Gas Trade Model," assumes the required rates of return on investments match those sought on similar projects in the United States. The working paper then contrasts selected scenarios with the Reference Case. The selected scenarios are meant to reflect a range of political actions and economic outcomes that could affect the world market for natural gas. The political scenarios selected for study were suggested by the kinds of events discussed in the historical case studies.

## INTRODUCTION

The Base Case assumed uniform rates of return across countries but allowed for different rates of return on different categories of investment. Specifically, we assumed that pipeline investments were least risky, followed by liquefied natural gas (LNG) regasification and liquefaction terminals and then by mining projects (or exploration and development). The risk associated with pipeline investment is low as regulation often keeps the costs associated with transporting gas via pipeline quite stable. By contrast, since LNG liquefaction and regasification terminals embody less mature technologies, their costs of construction are likely to be more variable. Some of the risks associated with LNG, however, may be ameliorated by "bankable" contracts for LNG sales that limit variability in returns. The resource mining projects are most risky because there is substantial geologic uncertainty (such as initial reserve assessment, ultimate recoverability, and so forth), as well as economic uncertainty resulting from variation in commodity prices.

Assuming rates of return on a given category of investment are uniform across countries ignores political factors that can greatly affect the risks of investing in different countries. These differing risks are a major reason that resources in some countries remain undeveloped. The relatively small amount of capital currently invested in such countries should make the return to capital relatively large and attract new investments, but the political risks more than offset the higher expected return.

The Reference Case examined in this working paper allows rates of return on a given category of investment to differ across countries. The different risk-adjusted discount rates in each country reflect various political factors, such as government stability, bureaucratic quality, corruption, internal conflict, and ethnic tensions. Although economic and geologic fundamentals may attract potential investors to certain locations, political factors such as these may reduce expected returns and discourage investments. All other features of the Baker Institute World Gas Trade Model (BIWGTM) remain unchanged from the Base Case. The reader therefore is referred to the working paper, "The Baker Institute World Gas Trade Model," for details on how demand and supply and infrastructure costs were calculated.

After developing the Reference Case, we analyze the effects of selected political actions apart from the factors that are reflected in discount rates. For example, particular political actions could prevent the development of certain projects. To illustrate this latter kind of risk, we consider a case where political barriers prevent the development of pipeline infrastructure from Russia to Northeast Asia. The formation of a gas cartel is also studied as a possible political scenario that could impact the development of the global market for natural gas.

Finally, we examine two scenarios that illustrate how different economic assumptions can affect forecast outcomes. In particular, our forecasts embody conjectures about the availability of alternative energy technologies and the evolution of economic growth in different countries. We consider two particular variations on these assumptions: one in which there is higher demand resulting from more rapid economic growth in China and another where more aggressive development of the backstop technology erodes long term demand for natural gas. Economic growth in China is of current interest since it has been cited as the major reason for recent surges in the world demand for raw materials and energy. We examine the effects of more rapid adoption of an alternative to natural gas because much of the recent growth in natural gas demand has been for power generation and further developments in coal gasification, solar, wind and other technologies could limit that source of demand growth.

## CALCULATING RISK-ADJUSTED RETURNS

In this exercise, we used two sources of information to calculate risk-adjusted returns for gas investments. The first is a composite measure of political risk borne by a private investor in each host country constructed using data from the *International Country Risk Guide (ICRG)*, published monthly by the PRS Group, Inc. The second is a data series on the "risk premium on lending" obtained from the World Bank. These two data sources were used to derive a risk premium for gas investments relative to the United States. This differential risk premium was then added to the real rates of return required on each type of gas investment in the U.S. to derive corresponding real rates of return for all other countries.

We constructed a "gas investment risk index" using a subset of the political risk variables tabulated in the ICRG. The index measures the risks for privately financed projects. Indeed, the ICRG data set is designed to help guide private investors. However, the large-scale, cross-border projects we are modeling involve strategic and foreign relations between countries in addition to domestic tax, regulatory and subsidy policies or loan guarantees. Thus, government stability and sovereign risk are likely to be the critical measures of risk.

The criteria extracted from the ICRG dataset over the period January 1984 through November 2002 were as follows:[1]

1. **Government Stability: "**A measure of the government's ability to carry out its declared program(s) and its ability to stay in office. This will depend on the type of governance, the cohesion of the government and the governing party or parties, the closeness of the next election, the government's command of the legislature, popular approval of government policies, and soon." **Scored 0-10, with lower scores for higher risks.**

2. **Investment Profile: "**This is a measure of the government's attitude to inward investment as determined by the assessment of four sub-components: the risk to operations (scored from zero [very high risk] to four [very low risk]); taxation (scored from zero to three), repatriation (scored from zero to three), and labor costs (scored from zero to two)." **Scored 0-20, with lower scores for higher risks.**

3. **Internal Conflict:** "This is an assessment of political violence in the country and its actual or potential impact on governance. The highest rating is given to those countries where there is no armed opposition to the government, and the government does not engage in arbitrary violence, direct or indirect, against its own people. The lowest rating is given to a country embroiled in an ongoing civil war." Intermediate ratings take into account kidnapping and terrorist threats. **Scored 0-10, with lower scores for higher risks.**

4. **Corruption:** Incorporates "the most common form of corruption" such as bribes and protection payments, but is more focused on "actual or potential corruption in the form of excessive patronage, nepotism…and suspiciously close ties between politics and business". **Scored 0-10, with lower scores for indicating higher levels of corruption.**

5. **Law and Order:** "Law and Order are assessed separately, with each subcomponent comprising [zero to seven] points. The Law subcomponent is an assessment of the strength and impartiality of the legal system, while the Order subcomponent is an assessment of popular observance of the law." **Scored 0-20, with lower scores indicating a less established legal system.**

6. **Ethnic Tensions:** "This component measures the degree of tension within a country attributable to racial, nationality, or language divisions." This may be particularly important where an infrastructure investment may span a particular ethnic enclave, creating potential for shut-down due to uprisings or hold-up. **Scored 0-10, with lower scores for higher risks.**

7. **Bureaucratic Quality:** "The institutional strength and quality of the bureaucracy is another shock absorber that tends to minimize the revisions of policy when governments change. Therefore, high points are given to countries where the bureaucracy has the strength and expertise to govern without drastic changes in policy or interruptions in government services." **Scored 0-20, lower scores indicating a less efficient bureaucracy with greater political interference.**

The averages of the above variables for the period January 1984 through November 2002 were then summed and divided by 10 to give a total score from 0 to 10, with lower

[1] Criteria definitions listed below are obtained from Howell, L. D. (2001). Components were selected from the ICRG tables based on an expert assessment of their relative importance for an investor in gas infrastructure. Relative weights of the different components have been retained from the ICRG index.

numbers corresponding to higher risk. The resulting index number for each country is referred to as the "gas investment risk index" (GIRI).

We used data on the risk premium on lending from the World Bank *World Development Indicators* to convert the GIRI score to a required rate of return. While the risk premium on lending reported by the World Bank is not specific to natural gas investments, it does reflect relative risks associated with investments across countries. Regressing the average risk premium from 1999-2003 on the GIRI scores yields a rule by which GIRI scores can be mapped to interest rates. This allows the factors underlying the GIRI scores, which are specifically targeted to measuring political risks in the natural gas industry, to be converted to a usable data measure. In addition, while the World Bank data is available for only 65 countries, the GIRI scores are available for 140 countries. The regression therefore allows the World Bank data to be extended to the additional countries. The results of the regression are as follow (standard errors in parentheses):[2]

$$\underset{}{\rho} = \underset{(3.015)}{15.001} - \underset{(0.442)}{1.359}\ GIRI \qquad (1).$$

From the regression analysis, we see that a lower GIRI score, which by construction corresponds to higher risk, is associated with a higher country risk premium, and the relationship is statistically significant. For example, GIRI scores range from 0 to 10, indicating that the country risk premium, $\rho$, will range from 15.0 to 1.4. This provides a fairly wide range of required returns on investment across countries. The risk premium in each country, which is given in the appendix in Table 1, is the predicted value from the regression (1) for that country's GIRI index. To obtain a country's return on equity for a given investment category, we then add the calculated risk premium for that country *relative to the U.S.* to the required return on equity in the U.S. for that type of investment. The leverage for each type of investment is still assumed to be uniform across countries. Hence, the risk adjustment affects the required return on pipelines least, followed by LNG infrastructure, and finally mining operations.

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[2] The number of observations was 65, the $R^2 = 0.131$ and the $t$-test for the significance of the slope coefficient has a $p$-value of 0.003.

**THE REFERENCE CASE SOLUTION (ADJUSTING FOR RISK)**

By way of comparison to the Base Case, in the near term (through roughly the middle of next decade) the risk-adjusted rates make little discernible difference to supply, both across countries and over time. As time progresses, however, adjusting for risk renders global supply slightly lower in the Reference Case relative to the Base Case, while the composition of supply by country also changes. Figure 1 graphs the supply projections in the Reference Case by regional grouping.

Adjusting for risk noticeably reduces production in Iran and, to a lesser extent, in Russia.[3] Russia, however, continues to play a pivotal role in the global natural gas market. It supplies large amounts of gas to consuming markets in both the Atlantic and Pacific basins by both pipeline and LNG. As in the Base Case (where returns are uniform), East Siberian gas begins flowing into Northern China at the beginning of next decade and eventually into the Korean peninsula. Furthermore, in the 2030s, northeast Asian demand again grows sufficiently to draw supply from as far as West Siberia. In contrast to the Base Case, however, the Reference Case indicates the construction of a pipeline linking West Siberia to East Siberia much earlier, allowing East Siberian supplies to flow *west* from 2012 to the mid-2020s. This development may reflect in part a response to reduced supply of pipeline gas from Iran into Europe. Another contributing factor is the increased supply of LNG from Australia, particularly during the decade from 2020-2030. Much of this Australian gas is shipped to Northeast Asia as higher returns in Russia generally raise price in those markets.

Higher required rates of return on investment increase natural gas prices and reduce demand across all demand regions and countries (see Figure 1). Producers withhold supplies until prices are driven up to support the higher returns on investment.

[3] Although Table 1 indicates that the risk premium in Iran is smaller than in Russia, Iran has less infrastructure already in place and hence the higher required return has a larger effect on overall capacity.

The most evident change in natural gas trade after accounting for risk is the reduction in exports from Iran (see Figure 1). There are other discernible impacts as well. For example, Russia sees its exports grow more slowly, whereas Australia, a relatively low-risk supplier, exports more natural gas earlier in the model time horizon. In addition, Canadian exports to the United States are more robust for a longer period. This occurs because LNG imports into the United States (Pacific plus Atlantic) are noticeably lower in the Reference Case relative to the Base Case. Higher risks adversely affect LNG facilities more than pipelines because the latter investments are financed by higher proportions of debt. When equity returns are uniform, substantial LNG supplies come from high-risk regions such as Iran, Nigeria, Angola, and Venezuela. Higher risk delays investment in these regions, which in turn reduces LNG supply. Thus, the United States must turn to other sources, most notably pipeline imports from Canada, to sate demand.

In contrast to the United States, LNG imports into China are slightly higher in the Reference Case. Raising the required returns on investing in pipelines from Russia to China makes LNG more attractive at the margin. This is particularly so when a relatively low-risk supplier, such as Australia, can supply LNG to China at a relatively low cost. In fact, Australia gains a larger overall market share of LNG exports at the expense of Iran, Nigeria, and Angola (all relatively high risk areas) in particular (see Figure 1). In an intertemporal equilibrium, projects in the latter countries are delayed until prices rise sufficiently to allow investments to earn the higher required rates of return.

Since higher rates of return delay investments and reduce available supply, prices are generally higher in the Reference Case relative to the Base Case, rising above \$7/mmbtu in both Tokyo and at the Henry Hub before 2040 (see Figure 2). Another discernible difference is that the dispersion in prices across locations is somewhat lower in the Reference Case. In particular, prices in Beijing and Delhi are closer to prices in the other cities. In the Base Case, each of these regions receives supplies from relatively high-risk areas – Beijing by pipe from Russia, and Delhi by pipe from Iran. A higher risk premium on those infrastructure developments in the Reference Case, delays those supplies coming to market. The higher prices in China and India attract more LNG imports, more closely connecting their prices to those of other countries competing for LNG. Prices at Zeebrugge and the Henry Hub are also somewhat closer in most years in the Reference Case. Since Europe receives much of its gas supplies from Russia and North Africa in the Base Case, higher risk in these regions will delay investments and raise prices. This, in turn, will increase competition in the Atlantic basin for LNG supplies, and more closely link prices in North America and Europe as LNG suppliers arbitrage between the two markets.

There is also an indication that the cycles in prices are somewhat shorter in the Reference Case relative to the Base Case. With higher required rates of return, investments will generally be smaller and more frequent. [4] This in turn will lead to the more frequent price fluctuations.

### POLITICAL SCENARIOS

We examine two politically motivated deviations from the Reference Case. The first involves disputes that prevent the construction of critical international pipelines. Obviously, countries that would otherwise benefit from such pipelines are affected by their absence. In general, both the exporting and the importing country are worse off although the welfare losses need not be shared equally as they depend on alternative sources of supply for the importing country and alternative export markets for the exporting country. In addition, while the effect of eliminating large international pipelines will influence those nations directly involved, there are secondary effects on countries that are *not* directly involved in the projects.

The second political scenario involves a restriction on supply that arises from an alliance among several major suppliers. The Reference Case shows that natural gas supply is likely to become concentrated in a relatively small number of countries, including many of the current members of the oil cartel, the Organization of Petroleum Exporting Countries (OPEC). Furthermore, many of these countries are likely to place

[4] This conclusion follows, for example, from the theoretical model discussed in Hartley and Kyle (1989).

gas production in the hands of their respective national oil companies. It therefore may be no more difficult for these countries to cartelize the developing international gas market than it was for them to cartelize the oil market.

*Scenario 1: No pipelines from Russia to Northeast Asia*

Eastern Siberia has substantial gas reserves and undiscovered potential. South Korea and Japan have substantial demand, with virtually no indigenous reserves. Moreover, while China has some domestic gas resource, projected demand will soon outstrip domestic supply and lead to a substantial appetite for gas imports. In terms of the economic and geologic fundamentals, the relationship between Russia and Northeast Asia resembles the relationships between regions in North America such as Alberta and Chicago, or South Texas and Miami, that currently are linked by long haul pipelines covering distances not too dissimilar from Kovytka to South Korea. It therefore is not surprising that early in the model time horizon in the Reference Case, reserves in East Siberia can satisfy Northeast Asian demand at a price that is competitive with imported LNG. Toward the end of the time horizon, the cost of adding to East Siberian reserves exceeds the cost of shipping gas from West Siberia, which results in gas flowing from West Siberia into the then developed Northeast Asian pipeline grid. Thus, in the Reference Case, pipeline gas from Russia supplies a substantial fraction of Northeast Asian demand over the model horizon.

Political relations between Canada and the United States and between states within the United States are much closer and more stable than relations between Russia, China, North Korea and South Korea. Accordingly, political tensions could easily stymie development of a pipeline connecting East Siberian gas resources to China. Moreover, any pipeline from Russia to South Korea would most likely have to pass through North Korea. Such a pipeline could only be built with the acquiescence of North Korea, making it an unlikely event for some time.

The first scenario disallows any pipelines connecting Russia to China or Russia to South Korea. We also rule out the pipeline from Uzbekistan to China because it provides an alternative route, albeit indirect, for gas sales from the Volga-Urals region in Russia to China. The scenario assumes, however, that a pipeline can still be built from Sakhalin Island to Japan.

In the absence of a pipeline connecting East Siberia to China and Korea, Russian producers will seek alternative outlets for their gas. Two options include constructing a pipeline to Nahodka to export gas as LNG or constructing a pipeline from East Siberia to Europe via West Siberia.

Although a pipeline to Nahodka is possible, the model predicts this will not happen. LNG supplies from Southeast Asia and Australia and pipeline supplies from West China have lower costs. Instead, East Siberian gas is transported to the west.

Pipeline gas exports to Japan from Sakhalin Island also increase relative to the Reference Case. Eliminating the pipelines from Nahodka to Korea and Nahodka to Northeast China renders the pipeline from Sakhalin to Nahodka uneconomic, freeing up additional Sakhalin gas for export to Japan. This, in turn, affects Pacific Basin LNG trade and other markets.

While Russia is the major supplier disadvantaged by not allowing the Russia-China and Russia-Korea pipelines, other countries affected include Saudi Arabia, Nigeria and Iraq (see Figure 3). Increased Russian pipeline exports to Europe displace some exports from these countries.

Despite increased exports to Europe, Russian production declines relative to the Reference Case. The cost of long haul transportation disadvantages East Siberian resources relative to other options. Thus, while East Siberian resources are exploited, they are not exploited to the same extent as in the Reference Case.

Since China has proved reserves and geologic potential, the elimination of cheap pipeline imports from Russia results in an expansion of Chinese domestic production.

The opportunities to replace imports with domestic supply are, however, somewhat limited. Domestic supply responds positively early in the time horizon and even more strongly from around 2016-2030, but by the mid-2030s, geological factors limit Chinese domestic supply.

Prominent among the countries where domestic production responds positively to the Northeast Asian pipeline foreclosures are Australia, the United States, and Indonesia in the short to medium term, and Iran, Qatar and Azerbaijan in the longer term. Several of these countries are well placed to supply more LNG to Korea and China. As Northeast Asia turns to LNG, increased competition for LNG drives up prices everywhere. At the margin, this favors more costly domestic production. In some countries, the supply response is better characterized as a shift in the intertemporal pattern of production rather than a change in aggregate supply. Although higher prices accelerate production in the short run, rising costs of domestic resources eventually abate the trend. Examples include Norway, Bahrain, Venezuela, Brazil and Turkmenistan.[5]

Relative to the Reference Case, China and South Korea substantially increase their LNG import capacity (see Figure 3). One consequence is a large expansion of LNG exports in the Russian Pacific relative to the Reference Case (see Figure 3). The increase occurs later than LNG expansions in Australia and Southeast Asia, which partially fill the void left by a reduction in Russian pipeline gas supply to Northeast Asia. As prices rise, Sakhalin LNG becomes increasingly profitable, and LNG exports from Sakhalin Island grow substantially in the later time periods. The absence of a pipeline from Sakhalin to China and South Korea, via Nahodka, also helps to facilitate the increase in LNG supply

[5] In another scenario that we do not report in detail, we ruled out the Pakistan-India pipeline in addition to the pipelines from Russia to China and South Korea. The Pakistan-India pipeline also carries substantial gas in the Reference Case solution and is another project that would be vulnerable to political disruption. The general pattern of supply response is similar in the two cases, although responses from each country tend to be larger when the Pakistan-India pipeline also is ruled out. Particularly noteworthy is that United States production is considerably higher beyond 2028. As we note below, India also becomes a large importer of LNG in this scenario, and the higher LNG prices encourage more U.S. domestic production and fewer LNG imports.

from Sakhalin. At first glance, the increased export of LNG in the Russian Pacific might appear inconsistent with the notion underlying the original experiment. If China, Japan and South Korea decline to import gas via pipeline from Russia, why would they import Russian gas as LNG instead? The answer lies in the real option that LNG imports provide. A pipeline will connect countries as supplier and customer much more firmly than LNG. Importing countries relying on LNG have an option to turn to alternative suppliers. This option does not exist with pipelines.

Higher LNG prices also encourage the flow of pipeline gas from Malaysia to mainland Southeast Asia in addition to increased export of LNG from Papua New Guinea, Brunei, Indonesia, Australia and Middle Eastern countries such as Iran, Saudi Arabia, Qatar and Oman (see Figure 3).[6] As noted above, overall Saudi production falls as increased competition from Russian pipeline gas in Europe decreases the demand for Saudi exports via pipe through Syria and Turkey, but some of the displaced resource reappears as increased LNG.

Restricted pipeline construction in Northeast Asia also affects the Americas. Increased competition for Pacific basin LNG supplies reduces LNG imports into the U.S. Pacific coast. However, LNG imports into the U.S. Atlantic coast and Canada increase. This is facilitated by increased exports of LNG from Russia to the Atlantic Basin as the absence of export outlets to the East pushes gas volumes to the West.

An increase in Venezuelan LNG exports, which are supported by higher prices for LNG relative to the Reference Case, contributes to the rise in U.S. Atlantic Basin LNG imports. As Asian markets attract LNG supplies, some Middle Eastern production that flows to the Atlantic in the Reference Case flows to the Pacific instead. South American, West African, and even Russian LNG expand to fill the void in the Atlantic. We also see

[6] In the scenario where the Pakistan-India pipeline also is ruled out, India becomes a larger importer of LNG than China from 2026–2038. India can still import gas via pipeline from the east, however, and in consequence Thailand also imports more LNG when the Pakistan-India pipeline also is ruled out. On the other hand, the U.K., Belgium, Italy and France import less LNG than when only northeast Asian pipelines are constrained.

that Mexican LNG imports from the Atlantic basin decline. This is facilitated by increased production in northern South America, which allows more aggressive development of pipeline import infrastructure into Mexico through Central America.[7]

Global demand changes by less than 1 tcf in most years relative to the Reference Case, indicating that the marginal supplies from Russia are capturing market share without having a significant impact on price (see Figure 3). Nevertheless, China and South Korea do not find perfect substitutes for the lost Russian imports, and demand in those countries declines. We do see, however, a modest increase in demand in Russia, Ukraine, Belarus, Azerbaijan, Uzbekistan, Germany and other European countries that import gas from Russia. This occurs because East Siberian gas raises volumes flowing through Western Russia and lowers prices in Russia relative to the Reference Case.

Figure 4 indicates the price changes relative to the Reference Case for all of the scenarios being considered. We see that reduced pipeline imports of natural gas to China from Eastern Russia raise gas prices in Beijing as China must rely on LNG to meet demand.[8] Tokyo also sees slightly higher prices on average while in Zeebrugge average prices over the whole period decline slightly (in real terms). Another point worth noting is that expanded LNG trade more closely links prices in a greater number of markets to arbitrage points lying offshore, thereby causing more rapid convergence of prices.[9]

[7] In the scenario where the Pakistan-India pipeline also is ruled out, demand in India also declines relative to the Reference Case, while demand in Pakiston increases. Demand changes in the U.K. and Germany also become more consistently positive. Also, while the U.S. shows somewhat larger declines in consumption from 2014–2026, demand in the U.S. actually expands relative to the reference case from 2032–2040.

[8] The large swings in prices result from shifts in the timing of large infrastructure investments.

[9] If the Pakistan-India pipeline also is ruled out, prices in New Delhi and Beijing increase by a similar amount from 2024. The difference in price changes in the remaining cities also become much less volatile from 2024 as the even greater role of LNG trade in the world gas market helps to link prices across regions.

*Scenario 2: OPEC becomes a gas exporting cartel*

The OPEC countries have developed a mechanism for coordinating production controls in the oil market. An important part of the control mechanism is that production has been placed under the discretion of national oil companies. If natural gas production in these countries is concentrated in the hands of the same (or similar) national companies, then gas field development may also be slowed in order to increase gas prices.

We model a gas cartel by requiring OPEC members to earn a higher rate of return on their investments in pipelines and liquefaction facilities. This is an indirect way of modeling a quantitative restriction on future natural gas exports. The higher required rate of return will delay investment in gas export infrastructure and limit export capacity.[10] An alternative approach would involve raising the return on all gas-related investments in OPEC member countries. This would, however, increase domestic gas prices within the OPEC countries, which is not consistent with the manner in which these countries have exploited their monopoly power in the oil market. Rather, domestic oil prices have been kept below world prices, with the quotas on exports acting like an export tax equivalent.

Table 2 shows, for OPEC member countries in the Reference Case, the weighted average cost of capital on investments in gas export infrastructure. By comparison, the corresponding values for the U.S. are 8.4% for pipelines and 10.1% for liquefaction capacity. In the "Gas-OPEC" scenario, the required returns on export infrastructure in the member nations are set to 15%. The effect of cartelization on the OPEC countries thus is more significant for the United Arab Emirates, Qatar, Kuwait and Saudi Arabia than for the countries with higher initial required returns, such as Nigeria and Iraq. In addition,

[10] An export tax would be a more accurate way of modeling the effect of a cartel, but the modeling software does not allow for the imposition of export taxes or import tariffs. The export tax would drive a wedge between *current* export prices and domestic prices as well as future ones. The higher rate of return will operate to exports much more gradually. It also will restrict exports more from OPEC member countries that had less export infrastructure in place in 2002.

since the initial required returns are higher for LNG investments, cartelization has a bigger effect on pipeline than on LNG exports from these countries.

**Table 2: Weighted average cost of capital for OPEC countries in the Reference Case**

| OPEC member | Pipeline investments | Liquefaction investments |
|---|---|---|
| Algeria | 8.94% | 11.71% |
| Indonesia | 9.00% | 11.90% |
| Iran | 8.80% | 11.29% |
| Iraq | 9.16% | 12.38% |
| Kuwait | 8.60% | 10.69% |
| Libya | 8.80% | 11.31% |
| Nigeria | 9.20% | 12.50% |
| Qatar | 8.56% | 10.59% |
| Saudi Arabia | 8.60% | 10.71% |
| United Arab Emirates | 8.56% | 10.58% |
| Venezuela | 9.00% | 11.90% |

According to the model results, cartelization results in lower production for OPEC as a group, relative to the Reference Case (see Figure 5). Production is substantially lower in those countries where the change in the required return on investment is highest (Saudi Arabia, Qatar and the United Arab Emirates), while production is not substantially different in those countries that have high political risk (Nigeria, Iraq and Indonesia).

OPEC members Libya and Algeria display a different pattern of supply response. While Libya reduces production through 2020, production actually expands somewhat from 2020–2040. Algeria shows small production increases through 2012 and again from 2036–2040, with somewhat larger annual decreases in production in the interim. In the Reference Case, Saudi Arabia and Iraq become large exporters via pipeline in the latter decades of the model time horizon. In the Gas-OPEC Case, however, this does not occur. The lack of pipeline exports from the Middle East to Europe opens up more opportunities for Libya and Algeria to earn greater returns on exports without greatly restricting supply.

Production in Venezuela is relatively unaffected by cartelization. Reduced LNG exports from the Middle East to the Atlantic Basin raises the price, allowing Venezuela to earn rents on its liquefaction capacity without having to significantly restrict its own supply.

Perhaps the most surprising outcome is that Iran expands output substantially in the Gas-OPEC Case relative to the Reference Case. As with other OPEC members, the required rate of return is higher in the Gas-OPEC Case, but Iran can earn such returns while *expanding* its production. This can occur because Iranian supplies are a close substitute for supplies from other Persian Gulf members. Thus, supply from Iran relative to Qatar and Saudi Arabia is very sensitive to the *differential* in required returns between Iran and those countries.

Figures 6 and 7 illustrate the argument. Figure 6 focuses on total production of Iran, Qatar and Saudi Arabia, under the Base Case, the Reference Case, and the Gas-OPEC Case, while Figure 7 focuses on LNG output. In both the Gas-OPEC and Base Cases, returns on investment are equal in all three countries, albeit higher in the Gas-OPEC Case. Although production rises faster in the Base Case than in the Gas-OPEC Case, the patterns of production across the three countries are similar. In effect, the competitive landscape in the Persian Gulf is levelized in the Base and Gas-OPEC Cases. In the Reference Case, however, the riskier political environment in Iran necessitates a higher rate of return on investment in Iran than in either Saudi Arabia or Qatar. When the required returns are the same, Iran is a larger supplier than Qatar throughout the model period. When Qatar has a lower required rate of return on investments in export infrastructure it is generally a larger producer.

We also see that Iran is a much larger supplier of LNG, particularly after 2030, when the required returns on liquefaction (or export pipeline investments) in the three countries are equal. Comparing the second and third charts in Figure 7, increased Iranian production in the case where there are uniform equity returns as opposed to varying risk-adjusted returns, comes partly at the expense of Qatari and Saudi LNG exports, but mainly at the expense of exports from elsewhere in the world.[11] By contrast, increased Iranian LNG production in the Gas-OPEC scenario relative to the Reference Case comes largely at the expense of Saudi LNG exports.

In summary, in the Gas-OPEC scenario Saudi Arabia has the largest decrease in supply, ending direct LNG exports.[12] One of the largest increases comes from Iran, where LNG production increases substantially beyond 2030. Algeria also increases LNG supply, but most other LNG exporting OPEC member countries, including the United Arab Emirates, Nigeria, Indonesia and Venezuela, reduce LNG output. This result is in line with the current politics inside OPEC where Algeria and Iran are pushing for the strengthening of cartelization for natural gas exports while Qatar is on the record opposing such an effort.

There are some other interesting features of the supply changes graphed in Figure 5. Apart from Iran, other countries to show large increases in production when OPEC countries cartelize include Russia, Turkmenistan, Azerbaijan, Australia, the United States and Greenland. In Canada, production decreases through the mid-2020s relative to the Reference Case, but increases substantially beyond the mid-2020s. In the United States and Canada combined, supply generally increases with the exception of a few years. Figure 5 also reveals that an aggregate of other countries increases supply on net in response to the reduced OPEC country exports. The total supply response from non-OPEC countries together with Iran is substantial, although the supply offset comes at a higher price. Throughout the period 2002–2040, the total annual world supply in the

[11] Since total world demand is also slightly higher in this case, some of the increased Iranian exports will serve additional demand.

[12] Some of the increased Saudi Arabian pipeline exports in the Gas-OPEC Case are exports to Qatar, which are zero in the Reference Case. Thus, Saudi Arabia effectively exports LNG *indirectly* via Qatar in the Gas-OPEC Case, but the amount so traded is much less than direct Saudi LNG exports in the Reference Case. In the Gas-OPEC scenario, we assumed that pipeline connections between OPEC members do not have the higher rate of return, so the “export tax” is paid only as the gas is traded from an OPEC member country to a country that is not a member of OPEC. It should also be noted that the tense political relations between Saudi Arabia and Qatar might not permit such transit (see chapter on the case study on Qatargas).

Gas-OPEC scenario is rarely more than 0.5% below world supply in the Reference Case and the *cumulative* loss in world supply by 2040 is only 4.6%. Moreover, the largest differences across cases occur later in the time horizon. Since the scenario is implemented by constraining investment in exporting infrastructure, it is not surprising that the more substantial effects are delayed.

In early years, high rent Russian supplies are the largest single replacement for lost OPEC output.[13] Most of the increased Russian supply is exported as LNG from Russian Atlantic ports beginning in the 2020s (see Figure 5). Along with increased LNG supply from places such as Equatorial Guinea, Angola and Greenland, this helps compensate for reduced LNG exports from OPEC countries to the Atlantic Basin. Other countries that expand LNG supply to partially compensate for lost OPEC output include Australia, Papua New Guinea and Oman. An aggregate of smaller exporters also increases supply, particularly through the 2020s. Over time, the cost of non-OPEC supplies inceases more rapidly than in the Reference Case. Eventually, resource depletion opens the door for increased production in some OPEC countries, notably Iran. The late 2030's is also a period of increased Saudi Arabian pipeline exports.[14] Russian exports via pipeline decline relative to the Reference Case as we approach 2040, which can be explained by the demand response to higher prices in countries that import Russian gas via pipeline.

The United States suffers the largest decline in demand in response to higher prices (see Figure 5). Other countries that also experience a significant negative impact include China, India and Pakistan in Asia, the U.K. and Italy in Europe and, in later years, Egypt and Algeria in North Africa. Some countries in the Middle East, including Saudi Arabia, Iran and Turkey, and parts of the former Soviet Union including Ukraine,

[13] Raising the required rate of return in OPEC member nations increases the price required before development will occur in those nations, favoring production of the "next best" resource. Since the Russian supply curve is relatively flat, substantial Russian production can occur before the next incremental supply from Russia is more costly than supplies from OPEC member nations.

[14] Since the declineinSaudi Arabian LNG exports beyond 2030 exceeds the decline in overall Saudi supply, pipeline exports have to increase during this period.

Uzbekistan, Azerbaijan and Russia, enjoy an increase in demand in the Gas-OPEC Case. However, the changes in demand are small compared with the country-by-country changes in supply. This reflects the fact that reductions in a single country's output can be met by alternative sources of supply at relatively low additional cost.

We also see that restrictions on gas exports from OPEC countries have a greater effect on LNG imports than on overall gas demand (see Figure 5). Through 2020, aggregate LNG imports actually rise, especially to Italy. Part of the explanation is that the Gas-OPEC case discourages direct pipeline exports from Libya to Italy, creating an opportunity for LNG. Ironically, Libya's OPEC obligations means it exports more gas to Tunisia in the Gas-OPEC Case, leaving Tunisia in turn to export more to Italy. However, the increased exports through Tunisia are at increased cost due to "pancaking" of transportation rates, thus allowing LNG to compete in greater volumes into the Italian, and ultimately European, market.

The U.S. Atlantic coast experiences the largest reduction in LNG imports under the Gas-OPEC scenario. LNG imports into the U.S. Pacific coast also decline after the mid-2020s. Canada and Mexico also reduce LNG imports. Other significant reductions in LNG imports occur in Western Europe, specifically the U.K., Ireland, Belgium, Spain and France.

Returning to Figure 4, we see that cartelization in the gas market has an appreciable impact on price. From 2002–2010, the main effect is to alter the timing of critical large infrastructure projects. Prices are generally lower than the Reference Case, with some variation caused by the timing of large infrastructure projects. Beyond 2010, however, prices generally are higher in the Gas-OPEC Case by around $0.10 per mcf up to 2020 and closer to $0.20 per mcf beyond that.

## ECONOMIC SCENARIOS

We examined two changes to the economic assumptions underlying the Reference Case. Since the political scenarios we examined lead to supply shocks, the economic scenarios focus on demand shocks.

*Scenario 3: Higher Chinese growth*

In our first alternative economic scenario, we increase demand growth in China by allowing for more rapid economic progress. Specifically, we assume that the recent experience in China carries more weight in determining future economic growth.[15] Average annual GDP growth in China from 2002-2040 is 3.4% in the Reference Case, compared with 5.1% in the high growth case.[16]

Figure 8 shows the major changes in demand across the globe resulting from the higher Chinese economic growth. Not surprisingly, higher Chinese demand for natural gas is the dominant feature of the figure. In fact, demand in almost all other countries is reduced, largely because increased demand for LNG from China raises the price of LNG globally, thereby reducing the call on gas elsewhere across the globe. The largest demand reductions occur in the marginal suppliers to China (Russia, Uzbekistan, Kazakhstan and Iran) and the closest competitors for imports to China (Japan and South Korea, and the United States). Higher prices in China are transmitted more directly to these countries. Demand also falls in Egypt and Algeria because increased Russian exports to the east raise the demand for North African gas in Europe, thus raising prices in both North Africa and Europe.

[15] In technical terms, we chose a country-specific coefficient for China in the growth equation (estimated in the previous chapter) to reflect China's recent growth experience more than its sample average one.

[16] The comparative GDP growth rates by decade are 4.7% from 2002-2010, 3.3% from 2010-2020, 3.0% from 2020-2030, and 2.4% from 2030-2040 in the Reference case and 6.9% from 2002-2010, 5.5% from 2010-2020, 4.4% from 2020-2030, and 3.2% from 2030-2040 in the high growth case.

We also see in Figure 8 that the increases in demand in China begin to slow in the later time periods despite the higher rate of economic growth. This results from the direct effect on demand of price increases and greater use of the backstop technology. Since the demand shock originates in China, it is perhaps not surprising that the greatest change in the use of the backstop technology also occurs in China. Other countries that experience a significant increase in the use of the backstop include Russia, the United States, Uzbekistan, Kazakhstan, Azerbaijan and Egypt.

The reductions in demand from other countries are insufficient to accommodate the increased Chinese demand absent an increase in global production. The most significant increases in supply tend to come from those countries that can supply LNG to the global market (see Figure 8). Moreover, the countries that increase production tend to be distributed across the globe, indicating the intricate relationships that may evolve between supply and demand in a global market. For example, while it is not surprising that increased demand in China prompts increased production in Russia, Australia and Indonesia, with the latter two increasing exports of LNG, it is more surprising to see strong supply responses from Venezuela and Norway. The diversion of Russian and Middle Eastern resources toward China allows both Venezuela and Norway to capture market share in the Atlantic Basin markets.

Increased demand for LNG drives up prices to varying degrees everywhere, thereby encouraging additional production.[17] In addition to Russia, Australia, Indonesia, Venezuela and Norway, we also see production increases in Papua New Guinea, Greenland, Qatar and Algeria, all of whom, in the Reference Case, are major LNG exporters. There are also notable increases in production in the United States, Mexico and, not surprisingly, China.

[17] Although some countries reduce supply in some years, each of these countries increases supply in other years. Hence, the reductions are best thought of as intertemporal shifts in the pattern of production rather than overall declines. The relatively large "remaining" category of supply increases in these years also implies that many countries exploit their reserves more heavily in the early years, although the supply change in any one country in any one year is not large.

Figure 8 indicates that the net supply changes in most periods substantially exceed the changes in LNG supply over the same period. This can only happen if increased pipeline flows satisfy either domestic consumption or pipeline exports. Conversely, when the net change in LNG supply is larger, as in the late 2030s, higher prices afloat reduce demand domestically and encourage export to, in particular, China. A similar argument applies to each country considered individually. For example, the relatively large changes in Iranian LNG exports in the 2030s are not matched by a similar increase in overall Iranian production. The additional LNG comes largely from a reduction in pipeline exports from Iran.

Much of the increased LNG supply is ultimately destined for China, where we see a large increase in LNG imports relative to the Reference Case (see Figure 8). Chinese LNG imports slow beyond 2030 partly due to increased use of the backstop technology but also because increased imports of pipeline gas from Russia reduce the need for incremental LNG.

Higher demand for Pacific Basin LNG resulting from increased Chinese imports negatively impacts some other large Pacific Basin LNG importers. In particular, imports to the U.S. Pacific decline. It is interesting, however, that imports in the U.S. Atlantic rise. This occurs as the "arbitrage point" in the United States gas pipeline network shifts further west allowing some Atlantic Basin LNG to indirectly satisfy (through displacement of supplies from Alaska, Alberta and the San Juan and Permian Basins) demand in the western United States. Increased imports in the U.S. Atlantic, in turn, negatively affect other Atlantic Basin LNG importers, such as Italy, the U.K., Belgium, Canada and Mexico.

At first glance, it is somewhat surprising to see South Korean imports of LNG rise, which occurs despite lower demand in South Korea. The explanation is that pipeline flows from Russia do not penetrate the Korean peninsula as heavily as in the Reference Case. Given the greater demand in China, resources would have to be extracted more rapidly in East Siberia in order to achieve the same level of pipeline flows to South Korea. However, the model solution indicates that it is less costly for South Korea to increase imports of LNG.

As seen in Figure 4, higher Chinese growth drives up gas prices around the world, particularly beyond 2010. In addition, while the largest impact is on prices in Beijing, followed by Tokyo, the increasing integration of the world gas market through greater LNG trade leads to similar price increases in all locations beyond the mid 2030s.

*Scenario 4: More aggressive development of alternative technology*

The final scenario examines the effects of a negative change in the demand for natural gas. Specifically, we assume that alternative technology becomes available just as in the other cases, but at a lower price of $4/mmbtu. Such an outcome might occur, for example, if a breakthrough in solar technology, coal gasification, nuclear power, or some other technology for generating electricity reduces the demand for natural gas as an input into electricity generation.

The new technology path has two main effects. As the technology enters the market, it takes away market share from natural gas, which directly reduces gas demand. Because the alternative technology has a lower cost, it also produces a lower long term price for natural gas. Rational producers, knowing that future prices will be lower, exploit gas resources more aggressively in the near term.[18] This transfers the lower future prices back to earlier periods, although time discounting diminishes the impact as we move further from the year in which the cost of the alternative technology effectively pegs the gas price. In addition, some gas that would have been produced in the Reference Case

[18] This is a basic result of the depletable resurce economics. If there exists an alternative that can be made available at a lower price, the opportunity cost of mining the depletable resource is reduced. If one thinks of the depletable resource as an asset, lower long term prices will render some of the resource valueless. Thus, we will maximize the value of the portion of the asset that is economically competitive by extracting as much as we can in the finite time it will be used.

never gets produced under the Alternative Technology assumption, simply because prices are never high enough to justify development.

Figure 9 illustrates how the Alternative Technology Case changes the demand for the backstop technology up to 2040. Countries with the largest changes have been separately identified, while countries with a change of less than 0.05 tcf in each year between 2002 and 2040 have been grouped into the “remaining” category. The type of pattern we see in Russia could result if increased adoption of the backstop in natural gas importing markets displaces gas back to the producing country. Aside from resulting in fewer resources being developed, this lowers the price of gas in Russia and makes it competitive with the alternative for a longer period of time. In fact, with more rapid adoption of the alternative technology, long term import requirements to supply-deficit locations are diminished, and natural gas is primarily consumed only in locations where it is relatively abundant.

Relative to the Reference Case, we see that aggregate gas supply declines after 2020 (see Figure 10). Prior to 2020, however, it increases in most years as production is accelerated. In a few countries, notably Iran, Venezuela and Norway, supply expands substantially. As with previous scenarios, these expansions result primarily from local substitutions between suppliers. For example, Iran expands exports in the near term by replacing resources from Saudi Arabia since resource development in Saudi Arabia is more sensitive to the lower prices.

The growth of Iranian and Qatari LNG exports in the face of declining Saudi exports, illustrated in Figure 10, follows a similar pattern to one discussed in detail above for the Gas-OPEC Case. In Iran, the increase in production appears primarily as LNG. This occurs as the development of Iranian supply is shifted forward in time relative to the Reference Case.[19] Since most of the expanding LNG sources ship into the Atlantic Basin,

[19] It is worth noting here that in the Reference Case Iranian production does grow in years beyond 2040. However, we do not focus on those results as the analysis herein is concerned only with years up to 2040.

marginal suppliers in that basin, such as Nigeria, reduce output. The changes in supply from major Pacific Basin LNG suppliers, such as Australia and Indonesia, are generally smaller and increase in some years while decreasing in others. Some of the expanded Middle East supply, however, is transported to the Pacific Basin as Japan and China increase LNG imports somewhat, particularly from the mid-2020s.

While the United States imports less LNG between the mid-2010s and the mid-2020s, it imports more in other years, and substantially so into the Atlantic coast after the mid-2030s. Some other Atlantic Basin importers, particularly the U.K. and Ireland show reduced LNG imports in most years. Italy, Belgium, Spain, Mexico and Argentina display a more variable pattern of responses with LNG imports increasing in some years and declining in others.

As Figure 4 shows, prices in the Alternative Technology Case are not affected systematically until after 2020, at which point they begin a steady decline relative to the Reference Case. This steady decline is facilitated by increasing adoption of the backstop technology seen in Figure 9.

## CONCLUDING REMARKS

Although the basic patterns of natural gas supply and demand in the Reference Case do not differ dramatically from those in the Base Case, some interesting generalizations can be made about demonstrated impacts. Since higher required returns delay new investments but do not affect the use of existing infrastructure, supply declines most in countries with high required returns and little infrastructure in place. Another general result is that developed economies with relatively low rates of return tend to produce more as high risk regions curtail supply, causing prices to increase. Higher prices also tend to reduce demand everywhere.

The World Bank data showed that required returns vary considerably from one country to the next, while the regression showed that political risk played a significant role in determining these return differentials. In so far as these political risk factors remain fixed over the time horizon under consideration, it is more realistic to construct alternative scenarios taking those risks into account.

To indicate the types of analyses that can be performed with the BIWGTM, we chose four scenarios. Several of these reflect political issues that were highlighted by the historical case studies and which may be relevant to the future development of a global natural gas market. This is not meant to imply that other scenarios might not be equally as likely or carry as large an impact.

We began with two policy-motivated scenarios that initially affect supply. The first prohibits the development of a pipeline network in Northeast Asia, thereby precluding the flow of gas from East Siberia to China and the Korean peninsula and constraining the development of East Siberian reserves. With this pipeline option closed off, a larger percentage of the resources must flow to the west, which raises the costs of getting them to market. Thus, East Siberian development must be delayed until prices increase sufficiently to support the needed infrastructure. In addition, Northeast Asia turns increasingly to LNG to sate demand, which raises LNG prices everywhere and stimulates increased production from marginal suppliers of LNG, particularly in the Pacific Basin.

The second policy-motivated scenario involves the formation of a gas cartel. A higher required return on transport infrastructure from OPEC member nations generally reduces production in those countries. The major exception is Iran, where a leveling of the competitive landscape between Persian Gulf nations favors Iranian production relative to the Reference Case. Reduced aggregate production from OPEC members raises price everywhere and stimulates competing supply in Russia in particular, as well as many other regions. While cartelization in the manner examined here has some impact on global gas prices, the availability of relatively close substitutes moderates the impact.[20]

We then considered two scenarios that examined changes in assumptions regarding economic variables affecting the demand for natural gas. In the first, we allowed China to grow at a faster rate, which substantially raises long term gas demand. This demand is met by both increased pipeline imports from Russia and increased LNG imports. The net effect is an increase in global prices, which promotes increased production by major LNG suppliers as well as demand reductions by many LNG importing nations.

The second demand-side scenario postulated a more rapid adoption of a competing backstop technology, driven by assuming it will be available at a lower price. This accelerates production in many regions and generally lowers price beyond 2020. Eventually, substitution to the backstop results in natural gas being consumed primarily in regions where it is produced. Interestingly, LNG flows are slightly higher than in the Reference Case, driven largely by acceleration of production in Iran.

While the scenarios examined here are by no means exhaustive, they indicate the types of impacts perturbations could have on the development of a global gas market. The experiments confirm predictions that increased gas trade will enhance interactions between regional gas markets and promote arbitrage and global pricing over time. For example, it is apparent that supply infrastructure and demand growth in Northeast Asia will significantly influence the developing global market for natural gas. As another example, cartelization among OPEC member nations can affect global markets, but absent any other disturbances marginal supply potential is significant enough to minimize the cartel's effect on price in the intermediate term. Given the role of electricity generation in expanding gas demand, alternative technologies could dramatically alter the

[20] Given the manner in which Russia responds to reduced OPEC member output, including Russia in the cartel could produce a more substantial impact on global gas prices.

evolution of the gas market. This highlights the role of natural gas as a transition fuel. Further research could focus on combinations of scenarios of particular interest to policy-makers, such as Gas-OPEC combined with political barriers to key pipeline routes.

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## APPENDIX

## Table 1: Risk premium adjustments

| Country | GIRI | Predicted premium | Relative to US | Country | GIRI | Predicted premium | Relative to US |
|---|---|---|---|---|---|---|---|
| Albania | 5.8 | 7.19 | 3.96 | Algeria | 4.7 | 8.60 | 5.38 |
| Angola | 5.2 | 7.98 | 4.76 | Argentina | 5.3 | 7.87 | 4.64 |
| Armenia | 5.3 | 7.87 | 4.64 | Australia | 8.8 | 3.05 | -0.17 |
| Austria | 9.1 | 2.66 | -0.57 | Azerbaijan | 5.7 | 7.30 | 4.08 |
| Bahamas | 8.1 | 4.01 | 0.79 | Bahrain | 7.6 | 4.64 | 1.42 |
| Bangladesh | 4.5 | 8.88 | 5.66 | Belarus | 5.5 | 7.58 | 4.36 |
| Belgium | 8.5 | 3.50 | 0.28 | Bolivia | 5.8 | 7.13 | 3.91 |
| Botswana | 7.0 | 5.49 | 2.27 | Brazil | 5.5 | 7.58 | 4.36 |
| Brunei | 8.5 | 3.39 | 0.17 | Bulgaria | 6.9 | 5.60 | 2.38 |
| Burkina Faso | 5.8 | 7.19 | 3.96 | Cameroon | 4.3 | 9.11 | 5.89 |
| Canada | 8.9 | 2.94 | -0.28 | Chile | 8.0 | 4.18 | 0.96 |
| China | 6.5 | 6.17 | 2.94 | Colombia | 5.2 | 7.98 | 4.76 |
| Congo Rep. | 5.2 | 7.98 | 4.76 | Congo, Dem. Rep. | 2.9 | 11.04 | 7.82 |
| Costa Rica | 6.8 | 5.77 | 2.55 | Cote d'Ivoire | 3.9 | 9.73 | 6.51 |
| Croatia | 7.6 | 4.69 | 1.47 | Cuba | 6.3 | 6.45 | 3.23 |
| Cyprus | 8.2 | 3.90 | 0.68 | Czech Republic | 7.6 | 4.64 | 1.42 |
| Denmark | 9.2 | 2.49 | -0.74 | Dominican Republic | 5.2 | 7.98 | 4.76 |
| Ecuador | 5.0 | 8.21 | 4.98 | Egypt | 6.3 | 6.39 | 3.17 |
| El Salvador | 5.8 | 7.19 | 3.96 | Estonia | 6.8 | 5.71 | 2.49 |
| Ethiopia | 5.3 | 7.75 | 4.53 | Finland | 9.8 | 1.75 | -1.47 |
| France | 7.8 | 4.41 | 1.19 | Gabon | 5.5 | 7.47 | 4.25 |
| Gambia, The | 6.6 | 6.00 | 2.78 | Germany | 8.8 | 3.11 | -0.11 |
| Ghana | 5.0 | 8.15 | 4.93 | Greece | 7.2 | 5.20 | 1.98 |
| Guatemala | 5.5 | 7.53 | 4.30 | Guinea | 5.2 | 7.98 | 4.76 |
| Guinea-Bissau | 4.0 | 9.51 | 6.29 | Guyana | 5.4 | 7.64 | 4.42 |
| Haiti | 3.7 | 10.02 | 6.80 | Honduras | 5.7 | 7.30 | 4.08 |
| Hong Kong | 8.2 | 3.84 | 0.62 | Hungary | 8.1 | 3.96 | 0.74 |
| Iceland | 9.5 | 2.09 | -1.13 | India | 6.1 | 6.73 | 3.51 |
| Indonesia | 4.3 | 9.22 | 6.00 | Iran | 5.8 | 7.19 | 3.96 |
| Iraq | 3.1 | 10.81 | 7.59 | Ireland | 9.5 | 2.15 | -1.08 |
| Israel | 7.0 | 5.43 | 2.21 | Italy | 7.4 | 4.92 | 1.70 |
| Jamaica | 6.0 | 6.90 | 3.68 | Japan | 9.0 | 2.77 | -0.45 |
| Jordan | 6.8 | 5.71 | 2.49 | Kazakhstan | 6.5 | 6.22 | 3.00 |
| Kenya | 4.8 | 8.49 | 5.27 | Kuwait | 7.2 | 5.20 | 1.98 |
| Latvia | 7.3 | 5.15 | 1.93 | Lebanon | 6.3 | 6.51 | 3.28 |
| Liberia | 3.8 | 9.85 | 6.63 | Libya | 5.7 | 7.24 | 4.02 |
| Lithuania | 7.0 | 5.49 | 2.27 | Luxembourg | 9.6 | 1.98 | -1.25 |
| Madagascar | 4.8 | 8.49 | 5.27 | Malawi | 5.3 | 7.81 | 4.59 |
| Malaysia | 6.8 | 5.77 | 2.55 | Mali | 5.0 | 8.26 | 5.04 |
| Malta | 8.4 | 3.62 | 0.40 | Mexico | 6.2 | 6.62 | 3.40 |
| Moldova | 6.3 | 6.39 | 3.17 | Mongolia | 6.7 | 5.94 | 2.72 |
| Morocco | 7.4 | 4.98 | 1.76 | Mozambique | 5.4 | 7.64 | 4.42 |
| Myanmar | 4.3 | 9.17 | 5.95 | Namibia | 7.3 | 5.15 | 1.93 |
| Netherlands | 9.0 | 2.71 | -0.51 | New Zealand | 9.2 | 2.49 | -0.74 |
| Nicaragua | 5.3 | 7.81 | 4.59 | Niger | 4.8 | 8.54 | 5.32 |
| Nigeria | 2.8 | 11.21 | 7.99 | North Korea | 5.4 | 7.64 | 4.41 |
| Norway | 9.2 | 2.49 | -0.74 | Oman | 7.5 | 4.81 | 1.59 |
| Pakistan | 5.1 | 8.04 | 4.81 | Panama | 6.3 | 6.51 | 3.28 |
| Papua New Guinea | 5.0 | 8.21 | 4.98 | Paraguay | 4.6 | 8.71 | 5.49 |
| Peru | 5.0 | 8.21 | 4.98 | Philippines | 6.3 | 6.39 | 3.17 |
| Poland | 7.7 | 4.58 | 1.36 | Portugal | 8.3 | 3.67 | 0.45 |
| Qatar | 7.5 | 4.86 | 1.64 | Romania | 5.8 | 7.07 | 3.85 |
| Russia | 5.5 | 7.53 | 4.30 | Saudi Arabia | 7.2 | 5.26 | 2.04 |
| Senegal | 5.1 | 8.04 | 4.81 | Sierra Leone | 4.5 | 8.83 | 5.61 |
| Singapore | 9.6 | 1.98 | -1.25 | Slovakia | 7.5 | 4.81 | 1.59 |
| Slovenia | 7.8 | 4.47 | 1.25 | Somalia | 2.3 | 11.89 | 8.66 |
| South Africa | 5.5 | 7.47 | 4.25 | South Korea | 7.1 | 5.37 | 2.15 |
| Spain | 8.3 | 3.67 | 0.45 | Sri Lanka | 5.6 | 7.41 | 4.19 |
| Sudan | 4.1 | 9.45 | 6.23 | Suriname | 5.5 | 7.53 | 4.30 |
| Sweden | 9.4 | 2.20 | -1.02 | Switzerland | 9.1 | 2.66 | -0.57 |
| Syria | 6.5 | 6.22 | 3.00 | Taiwan | 7.7 | 4.58 | 1.36 |
| Tanzania | 6.0 | 6.90 | 3.68 | Thailand | 6.8 | 5.77 | 2.55 |
| Togo | 4.3 | 9.17 | 5.95 | Trinidad & Tobago | 6.0 | 6.85 | 3.62 |
| Tunisia | 7.0 | 5.54 | 2.32 | Turkey | 5.7 | 7.24 | 4.02 |
| U.K. | 9.0 | 2.71 | -0.51 | U.S. | 8.7 | 3.22 | 0.00 |
| Uganda | 6.0 | 6.85 | 3.62 | Ukraine | 5.0 | 8.26 | 5.04 |
| United Arab Emirates | 7.5 | 4.81 | 1.59 | Uruguay | 6.4 | 6.34 | 3.11 |
| Venezuela | 4.3 | 9.22 | 6.00 | Vietnam | 6.4 | 6.28 | 3.06 |
| Yemen, Rep. | 4.9 | 8.37 | 5.15 | Yugoslavia | 5.0 | 8.15 | 4.93 |
| Zambia | 5.0 | 8.21 | 4.98 | Zimbabwe | 3.0 | 10.98 | 7.76 |

Figure 1: Reference case results

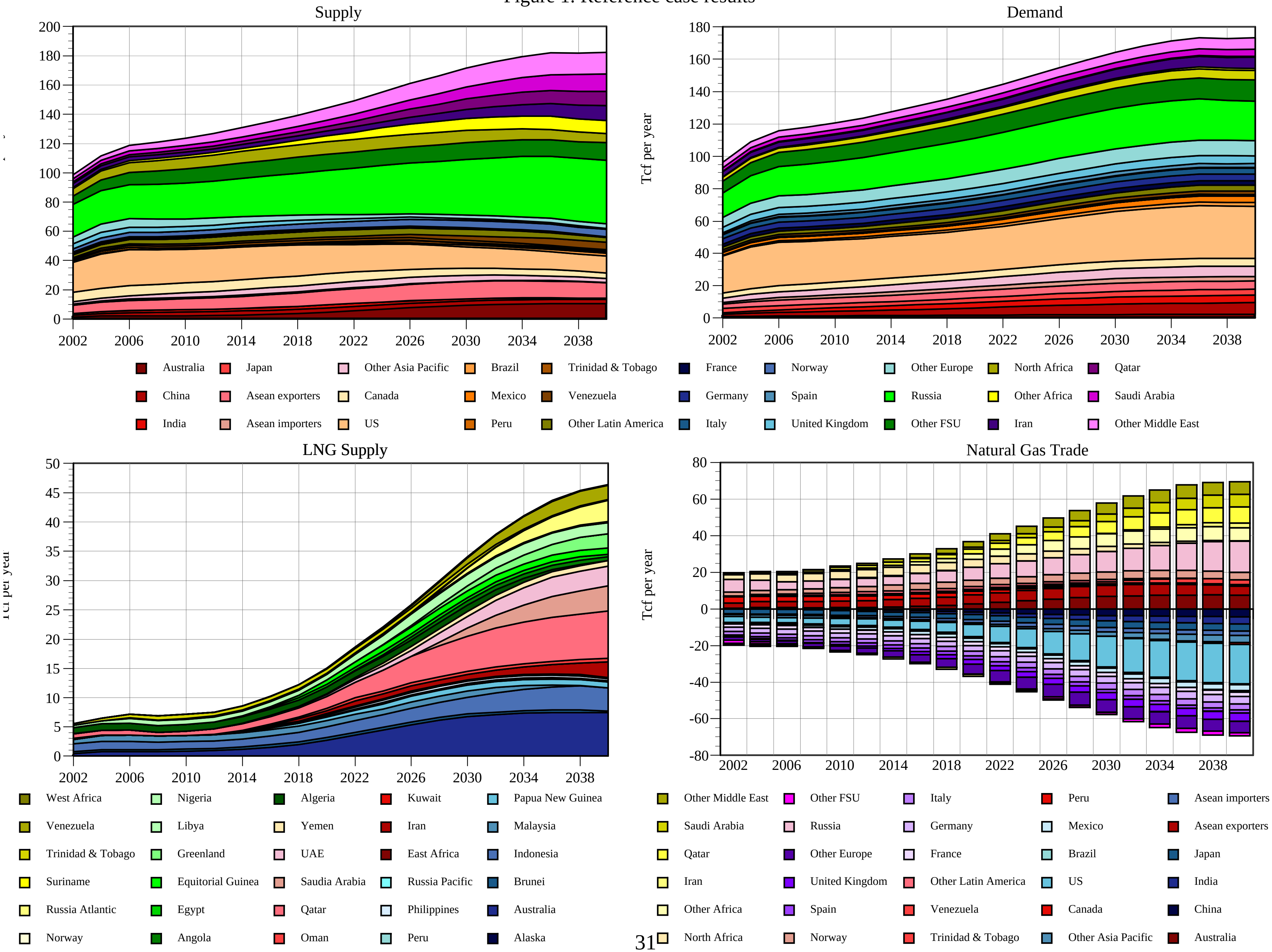

Figure 2: Reference Case Selected Prices

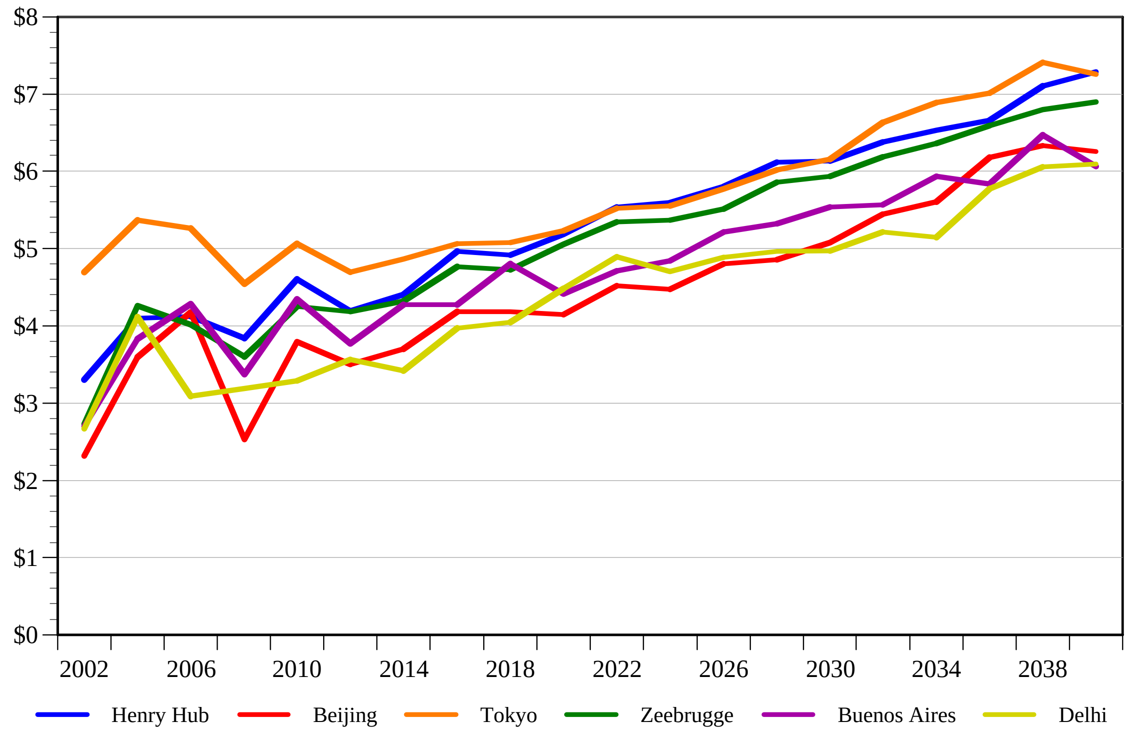

Figure 3: Some NE Asia Pipes Disallowed

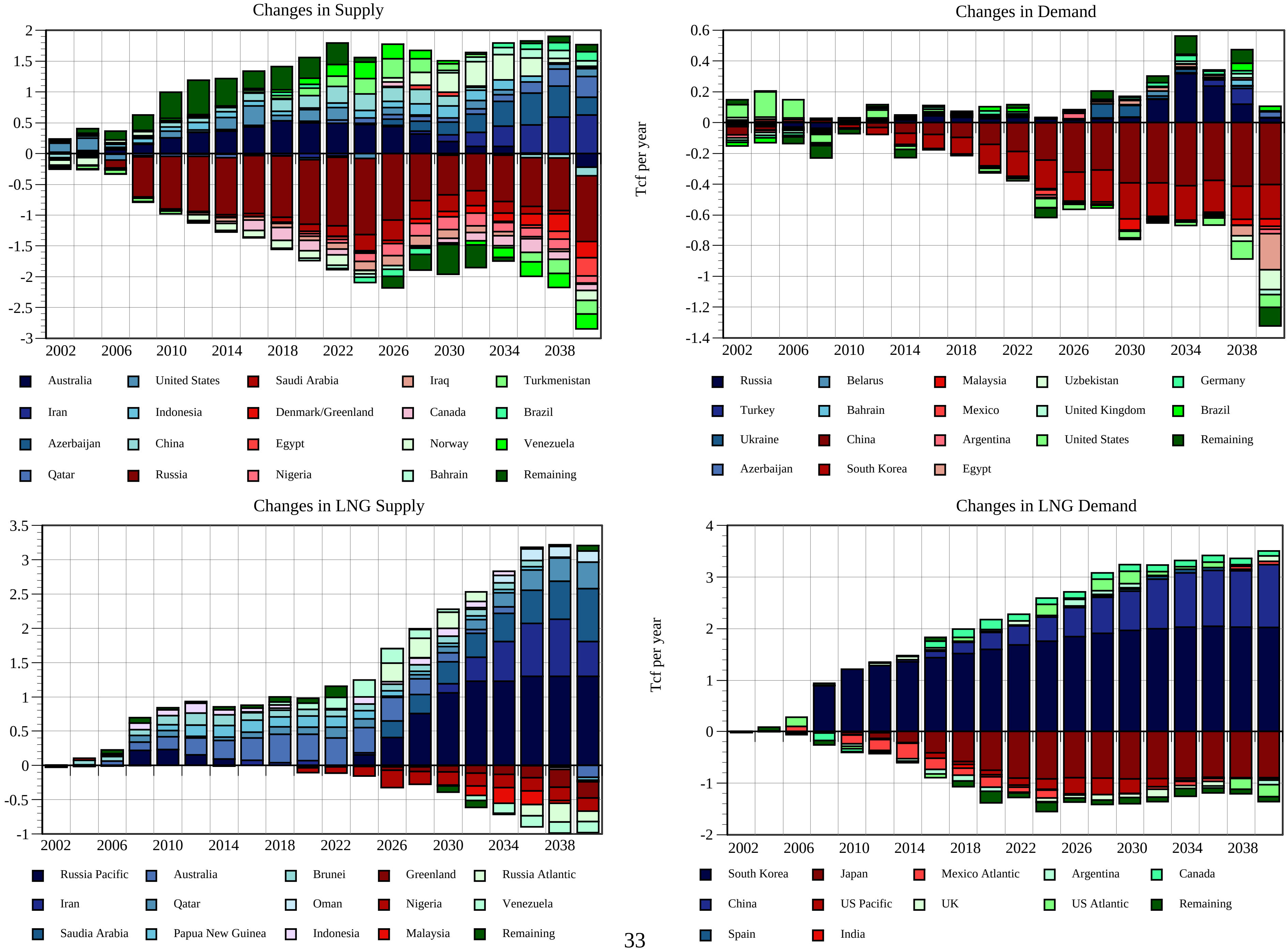

Figure 4: Decadal Average Price Changes from the Reference Case

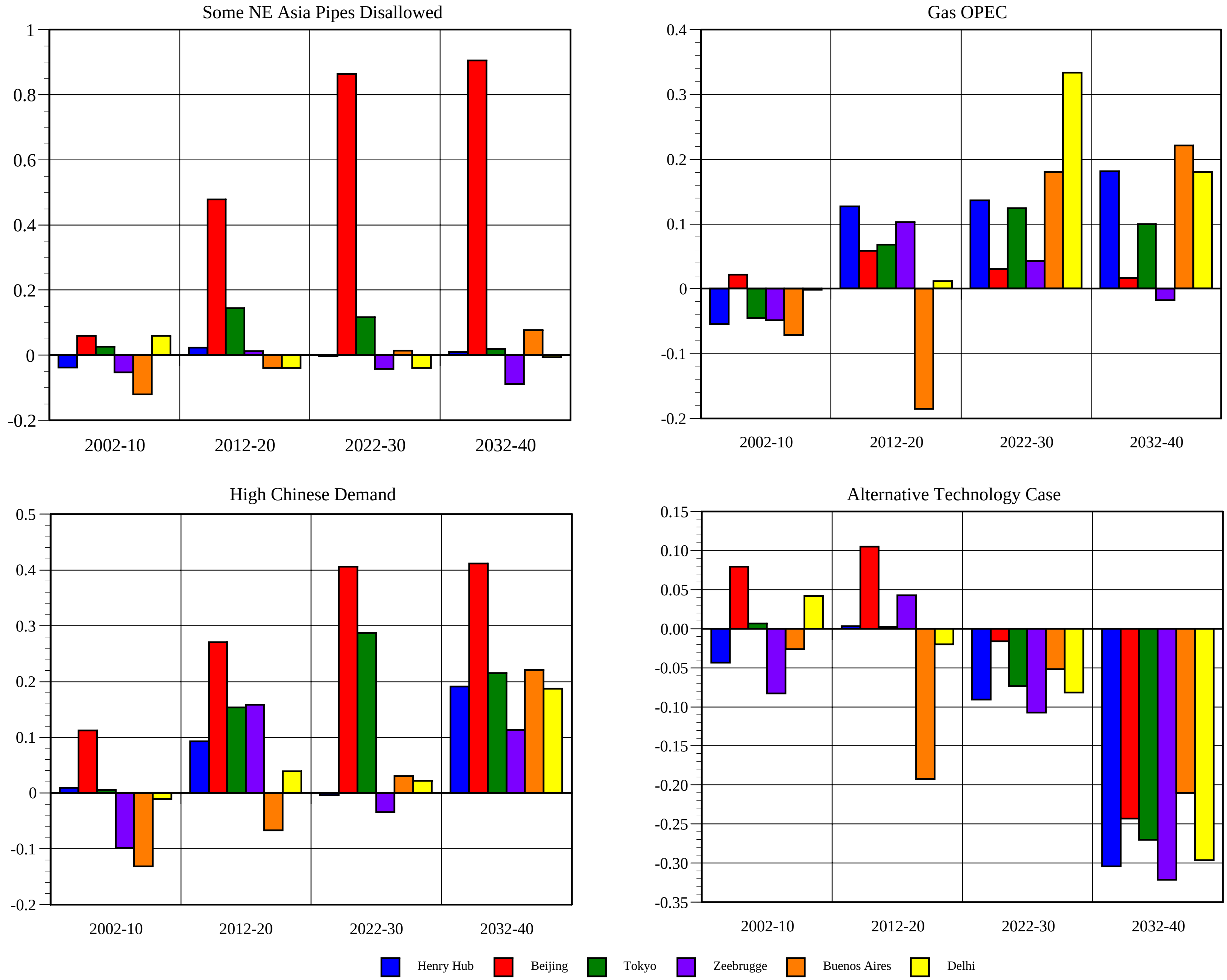

Figure 5: Gas OPEC Scenario

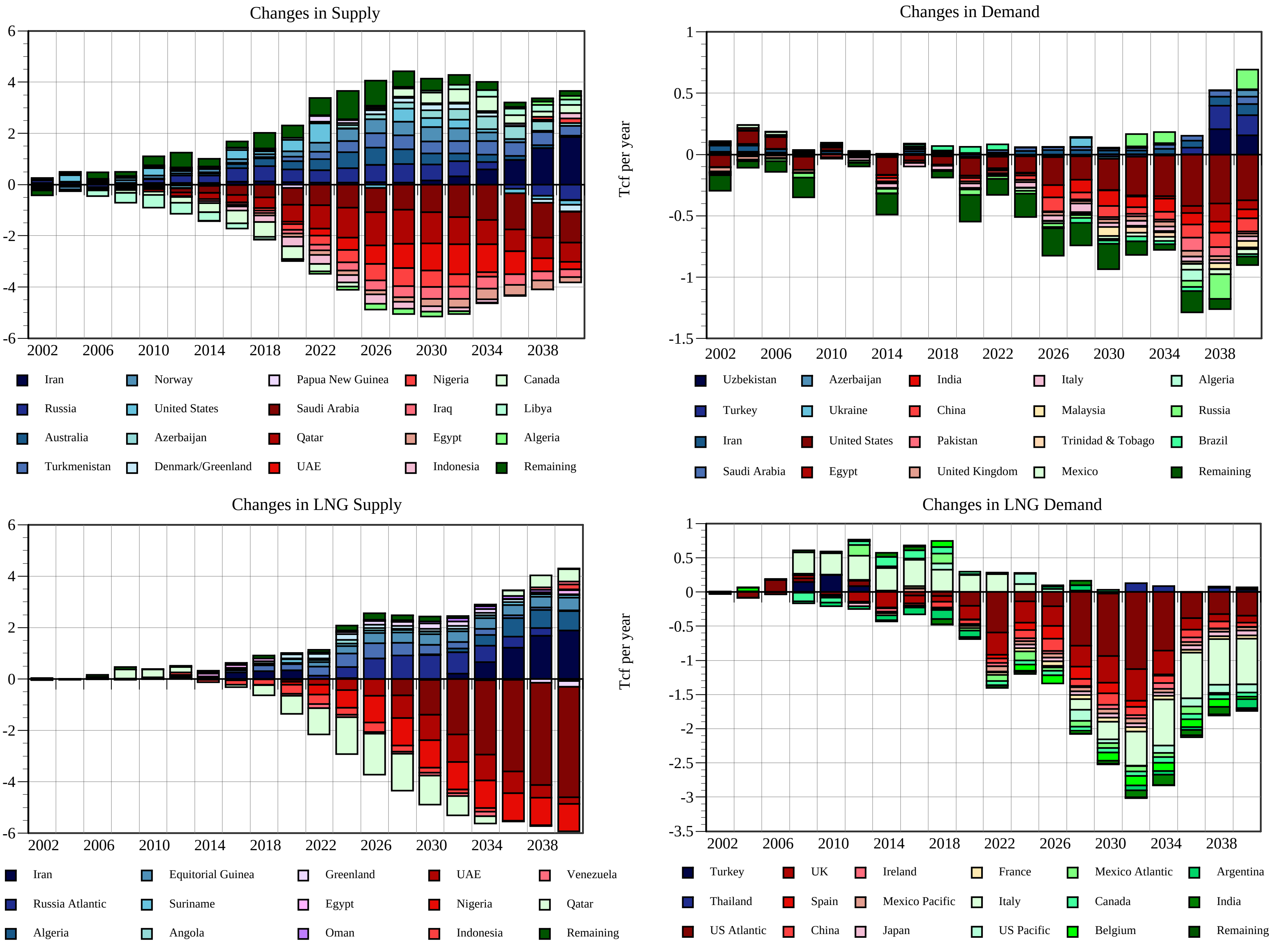

Figure 6: Gas supply in Iran, Saudi Arabia and Qatar in three scenarios

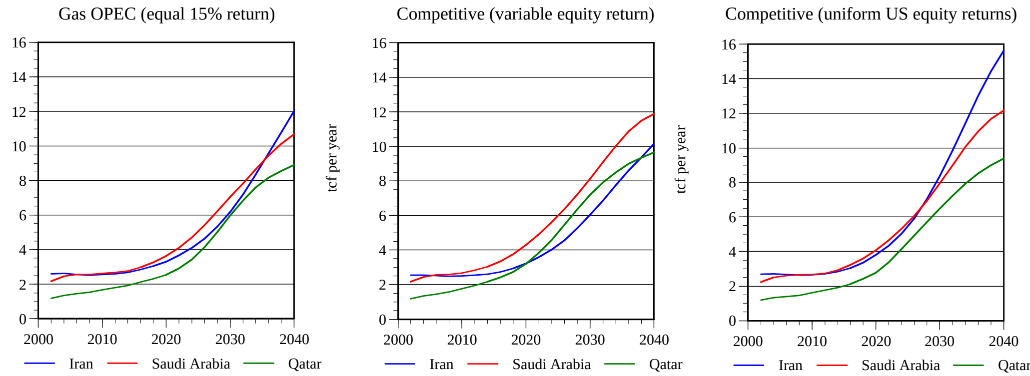


Figure 7: LNG supply in Iran, Saudi Arabia and Qatar in three scenarios

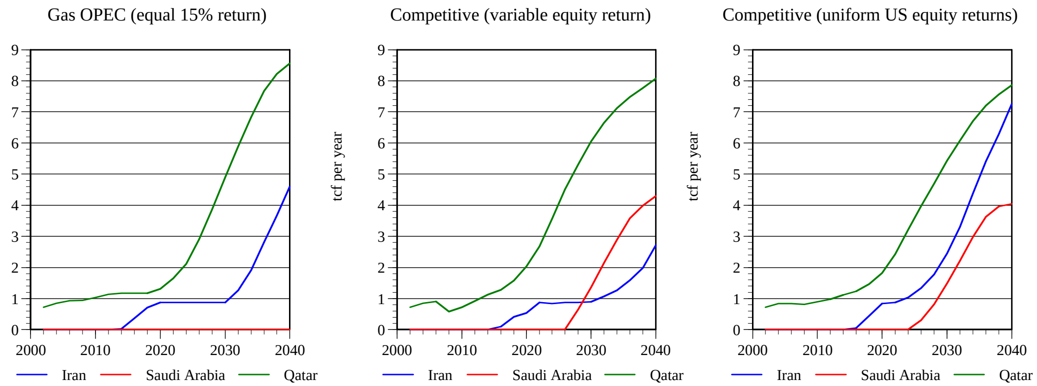

Figure 8: High Chinese Demand Scenario

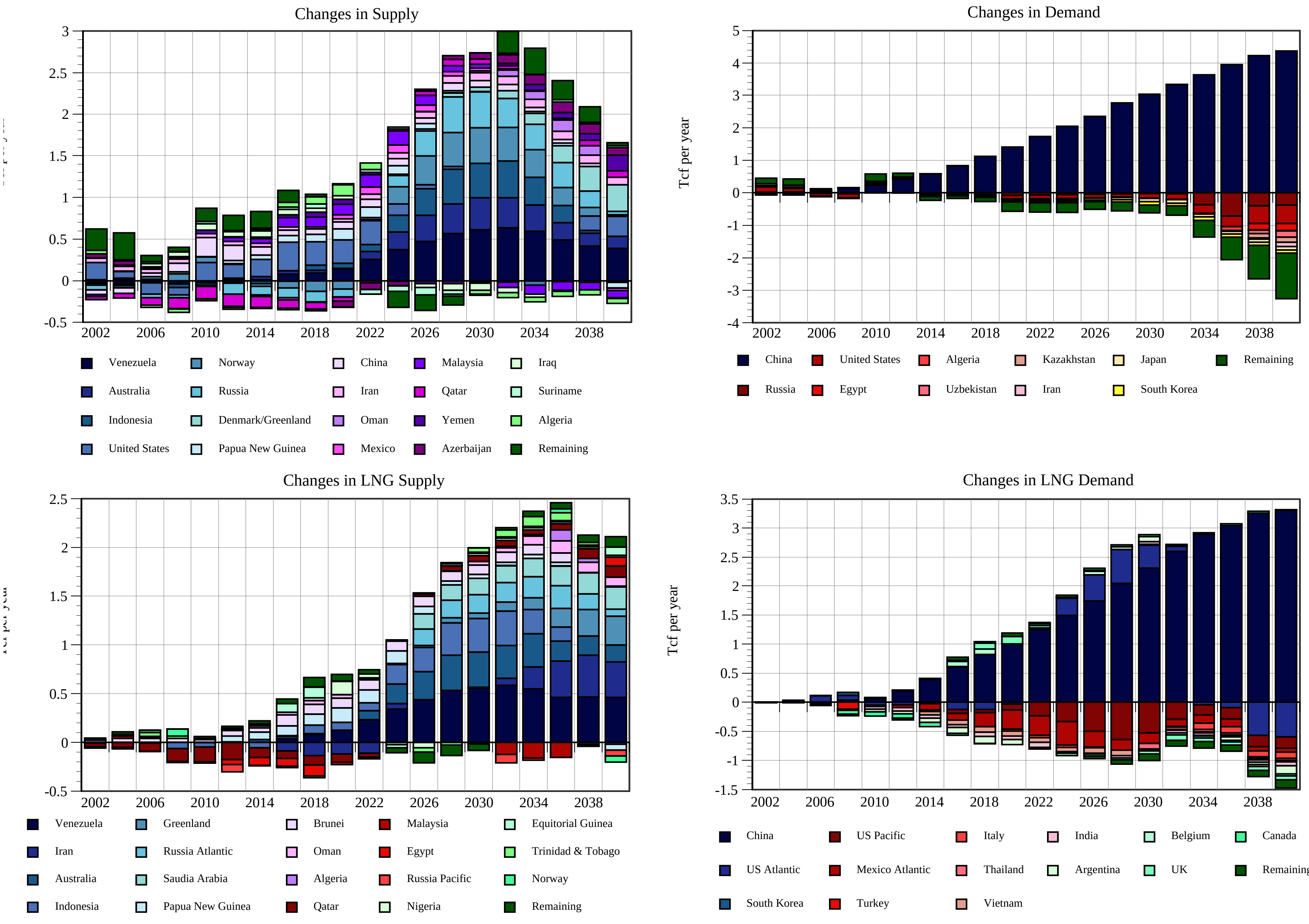

Figure 9: Major changes in backstop demand in the alternative technology case

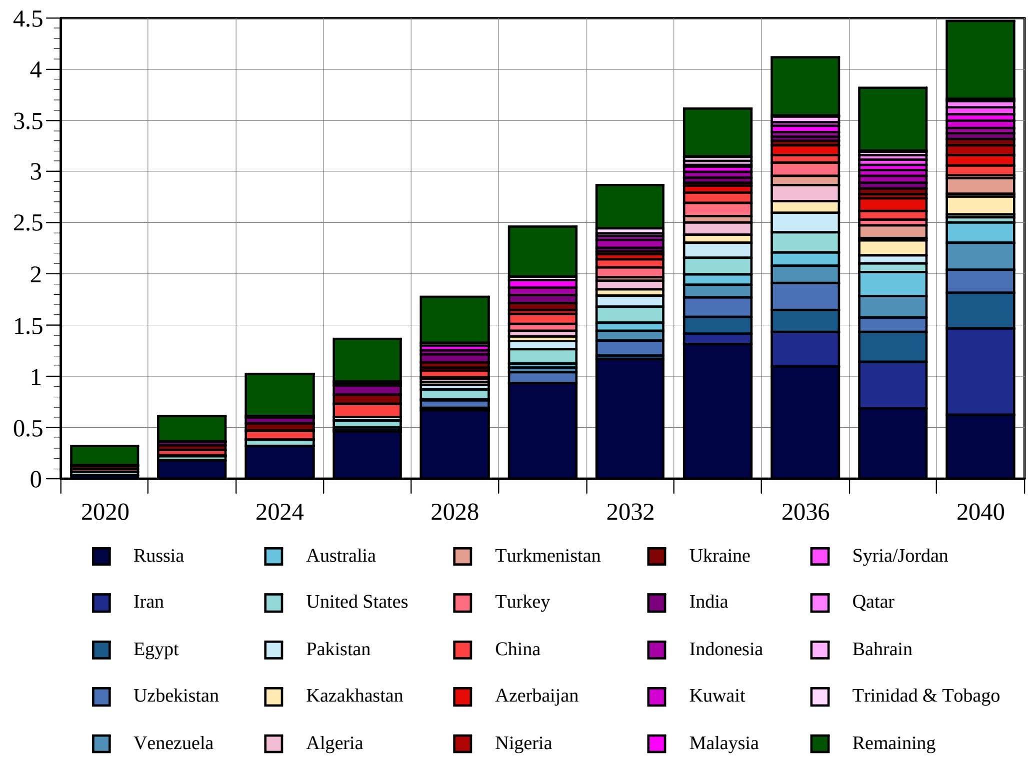

Figure 10: Alternative Technology Case Scenario