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U.S. Natural Gas Exports and their Global Impacts

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Keywords

natural gas, exports, shale, general equilibrium, international

JEL Classification

E17, F47, Q31, Q43

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U.S. NATURAL GAS EXPORTS AND THEIR GLOBAL IMPACTS ^{☆,☆☆}

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Abstract

We evaluate potential global impacts of increase in U.S. natural gas exports as a result of the shale gas boom. To our knowledge this is the first such analysis using a global economic model to understand this timely policy issue. Our primary conclusion is that world economic activity is higher through most of the simulation period [2014-2035] when U.S. natural gas exports rise. The overall U.S. results mirror the global ones, but the magnitude of income gains depends upon how the rate of increase and level of exports are determined, and the price elasticity of natural gas supply. The U.S. benefits more when export increases and levels depend on natural gas production rather than when they are pre-determined by assumption. The economic impacts on other natural gas importers and exporters can change as well based on how export levels are determined. The effects on natural gas prices, consumption, and production in individual countries vary with the scenarios and model parameter values.

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1. Introduction

The Natural Gas Act of 1938 requires U.S. Department of Energy (DOE) authorization to import or export natural gas to or from the United States. Although the U.S. has exported limited amounts of natural gas via pipeline to Canada and Mexico for many years, recent developments in U.S. natural gas production due to shale have changed the export picture considerably. As of September 2013 there have been 32 applications to export domestically produced liquefied natural gas (LNG). Twenty-five of these applicants have also requested approval to export to countries with which the U.S. does not have a free trade agreement (non-FTA countries), and four of the non-FTA applications have been approved.³ The potential for further rises in U.S. natural gas exports has led to a robust debate about the economic costs and benefits of such trade.

In this paper we consider the economic impacts of various U.S. natural gas export scenarios. To our knowledge this is the first such analysis using a global economic model to understand this important policy issue. Our primary goal is to assess the potential costs and benefits for the U.S., natural gas

[☆]The analysis and conclusions expressed here are those of the authors and not necessarily those of the EIA, CSIRO, or CAMA.

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³The Natural Gas Act of 1938 was amended in 1992 so that exports to countries with which the U.S. has an FTA are considered in the national interest and fast-tracked for approval. See <http://energy.gov/fe/downloads/summary-lng-export-applications> for details on LNG export applications and approvals.

importers, and natural gas exporters using a global framework. We also seek to perform a variety of sensitivities on key modeling choices to understand what is driving the magnitude and direction of the results. Although we do not use a model specific to the natural gas industry, we are able to consider global trade in all goods and services to evaluate the broader economic impact of U.S. natural gas export scenarios.

To date, the debate surrounding increased U.S. natural gas exports has focused on their consequences for domestic natural gas prices and economic activity. The consensus is that allowing more natural gas exports will lead to higher prices, and that these higher prices will depress economic activity in energy-sensitive sectors according to the Congressional Research Service (CRS) [1].⁴ The disagreement revolves around whether the benefits of exports in terms of employment and investment are large enough to offset the losses from higher natural gas prices.⁵ This is a quantitative issue that has been studied extensively in both model and non-model based reports (see the next section for a review).

Because of their specific nature, there have been four key aspects missing from most of the model-based reports: (i) an assessment of the global economic impacts of U.S. natural gas exports; (ii) consideration of how U.S. export levels are determined; (iii) scenarios that consider pipeline exports; and (iv) sensitivity analysis on key parameter values. We attempt to address each of these by using a global macroeconomic model under various scenarios and assumptions about exports and parameter values.

To allow for comparison, we begin by replicating U.S. LNG export scenarios based on the January 2012 report prepared for the DOE by the U.S. Energy Information Administration (EIA) [9]. We then consider alternatives that solely incorporate pipeline exports to Canada and Mexico. For each group of scenarios we vary our assumptions regarding the driver of U.S. natural gas export and the price elasticity of U.S. natural gas supply.⁶ Results are presented for the U.S.; Japan, the EU25, and Mexico (natural gas importers); Canada, Russia, and OPEC (natural gas exporters); and (where applicable) the world.

The overall results show that the manner in which export levels are determined and assumptions about the price elasticity of U.S. natural gas supply are important ingredients in determining the magnitudes of world and U.S. income gains. For natural gas importers and exporters the results change sign depending upon these assumptions.

Our primary conclusion is that world economic activity is higher through most of the simulation period [2014-2035] when the U.S. exports additional natural gas. U.S. national income rises through 2030 when either LNG or pipeline exports are exogenously specified, but falls below zero after this point. Under endogenously specified exports U.S. income changes are always positive, and the magnitude of U.S. national income increases is highest when natural gas supply has elastic responses to price changes. In contrast, when exports are exogenous the largest U.S. income gains occur under inelastic natural gas supply. With the exception of Mexico, natural gas importers are better-off under exogenous U.S. exports, while the results for natural gas exporters vary.

⁴Darmstadter [2], Deloitte [3], Ebinger et al. [4], ICF [5], and Medlock [6], among others, argue that the price impacts of additional U.S. natural gas exports will be small-to-moderate, while CRA [7] and Sarica and Tyner [8] take the opposite view. EIA [9] and NERA [10] occupy a middle ground.

⁵How natural gas prices affect the U.S. economy is a different question that has not seen extensive empirical study. However, the results in Kliesen [11] and Arora et al. [12] suggest that the impact may not be large, even in energy-intensive industries. Additionally, the analysis in Arora and Lieskovsky [13] indicates that the response of natural gas production to exports will have the largest influence on subsequent U.S. economic activity.

⁶Other sensitivities that include changing how natural gas exports are implemented in the model and varying the degree of substitutability of natural gas in trade between regions (Armington elasticities) have also been performed. They do not change the main results of the paper and so are not shown for brevity.

2. Literature Review

Our paper fits into a relatively large research area that considers the interactions between energy and economic activity as in Sharma [14], energy market integration and economic growth as in Sheng and Shi [15], and how energy may constrain growth as in Nel and Zyl [16]. More specifically, we focus on the impact of natural gas on economic growth as in Apergis and Payne [17], although we use a model-based approach. In similar work, Wakamatsu and Aruga [18] consider how shale gas impacts natural gas markets, while Logan et al. [19] focus on how shale may influence the U.S. power sector. However, none of these papers consider the potential global economic impacts of U.S. natural gas exports. Paltsev et al. [20] do model such exports, but they concentrate on how the integration of international natural gas markets may or may not influence the volume of U.S. exports. Because this topic is a relatively new area of research, the majority of related analysis has been done by either government agencies or consulting firms, although the focus has U.S. centric.

The recent debate surrounding potential impacts of U.S. natural gas exports has seen the use of varying models and methods. EIA's January 2012 report, in response to a DOE request, considers four pre-selected scenarios of increased natural gas exports under different assumptions about U.S. natural gas supply and economic activity [9].⁷ EIA uses the National Energy Modeling System (NEMS), which includes both a U.S. natural gas model as well as a U.S. economic model in generating its conclusions. The report concludes that U.S. natural gas prices will be higher under any of the export scenarios, but does not evaluate the corresponding domestic macroeconomic impacts. NERA Economic Consulting followed-on with a report using a computable general equilibrium (CGE) macroeconomic model alongside a world natural gas model that does evaluate the economic impacts on the United States [10]. Using the same natural gas export scenarios as EIA, NERA finds that increasing natural gas exports will lead to small net economic benefits for the U.S. economy.⁸

Charles River Associates (CRA) challenged these results in a February 2013 study [7].⁹ Using a non model-based approach, they argue that greater exports will lead to higher natural gas prices, and these prices will have a negative impact on the U.S. manufacturing sector and overall economic activity. This view was supported by Sarica and Tyner [8], who use the MARKAL-Macro model to show that permitting additional natural gas exports can cause small reductions in U.S. GDP. ICF International counter this view using another model-based approach, finding that greater U.S. natural gas exports will lead to positive employment and GDP impacts in the U.S. [5].¹⁰ None of the three aforementioned studies use the DOE export scenarios.

To simplify, proponents of allowing increased U.S. natural gas exports argue that the economic benefits to energy and related industries outweigh the costs, while opponents counter that both American firms and households will be hurt by higher natural gas prices.

3. Model, Scenarios, and Calibration

This section begins by reviewing the model used in our analysis, including a detailed description of its unique features. It then outlines the U.S. natural gas export scenarios used to generate simulation results and describes the variations. The section concludes by explaining the calibration procedure for each of the scenarios.

⁷See http://www.fossil.energy.gov/programs/gasregulation/reports/fe_eia_lng.pdf.

⁸See http://www.fossil.energy.gov/programs/gasregulation/reports/nera_lng_report.pdf.

⁹See http://www.crai.com/uploadedFiles/Publications/CRA_LNG_Study_Feb2013.pdf.

¹⁰See <http://www.api.org/~media/Files/Policy/LNG-Exports/API-LNG-Export-Report-by-ICF.pdf>.

3.1. Model

The CSIRO Trade and Energy/Environment Model (CTEM) is a global multi-sector recursive dynamic computable general equilibrium (CGE) model designed to analyze economic tradeoffs associated with production and use of fossil fuels, and greenhouse gas emissions [21]. The model combines the features of computable general equilibrium models and energy and environmental models into a unified framework for integrated assessment of global energy issues.

Our application of CTEM uses an aggregation that has nine regions¹¹ and a representation that covers 19 different economic sectors¹² in each of these regions. In addition to the various sectors, each region has one household that stands in for all regional households, as well as a government. The household is assumed to allocate after-tax income to either consumption or savings.

This household income is the same as the market value of final goods and services produced in each regional economy. And the regional economy is defined to include production by the nationals of each country, making the proper measure of economic activity in the model gross national product (GNP) instead of the more standard gross domestic product (GDP, which measures production within a country/region). More technically, the income measure in each region includes net factor payments from abroad which better captures the economic contribution of export increases, and so the results presented below use GNP instead of GDP.

The regions interact with each other through trade and capital flows, and regional households consume both domestic and imported goods. Capital investment takes place across regions, so households can allocate their savings either domestically or internationally. In contrast, factors of production (land, labor, natural resources) are available only domestically. The overall structure of CTEM is similar to other multi-regional CGE models [see for example Hertel [22], but CTEM is unique in terms of assumptions about production technologies.

The standard practice when constructing CGE models is to assume that each economic sector is represented by a price-taking firm producing a homogenous good. In general the production technologies in each sector are the same in such models, and differences are in the relative use of factors of production and intermediate inputs. To differentiate between production technologies, CTEM separates industries between those that have a menu of technologies that may be used and those which only have one. The industries that have the potential to use different technologies are called “technology bundle” (TB) industries. There are three TB industries in our application of CTEM: electricity, terrestrial transportation, and iron and steel.

The electricity industry has three emission-intensive technologies (coal, oil and gas) and seven emission-free technologies (nuclear, hydro and geothermal, wind, solar, biomass, waste, and other renewable). Coal and gas are further divided into conventional coal and gas sub-technologies, and their counterparts with carbon capture and storage (CCS). The terrestrial transportation industry has two fossil-fuel-intensive technologies (rail and internal combustion) and three more alternatives (advanced internal combustion, hybrid, and electric). The iron and steel industry has two technologies (blast furnace and electric arc).

Although only three of the 19 sectors we use are TB industries, each plays an important role in how the various U.S. natural gas export scenarios affect overall economic growth. Because these sectors use energy intensively, any changes in the relative prices of energy can lead to substitution to and from different fuels, and the fuel mix is one important component that determines investment. Additional details on the overall model, production industries, and technology bundles are available in Cai et al. [21], along with diagrams and descriptions.

¹¹They are U.S., EU, Japan, China, Canada, Mexico, Russia, OPEC, and the rest of the world

¹²They are coal, oil, gas, petroleum, electricity, petrochemical, iron and steel, non-ferrous metals, non-metallic minerals, other mining, manufacturing, water transport, air transport, terrestrial transport, crops, livestock, fishing and forestry, processed food, and services.

3.2. Export Scenarios

We consider two different groups of scenarios as shown in Figure 1: (i) [DOE scenarios] based on the January 2012 report prepared for the DOE by EIA; and (ii) [Pipeline scenarios] based on increasing pipeline exports above the levels specified in EIA’s Annual Energy Outlook 2013 (AEO2013). In its 2012 study, EIA evaluated four different paths for U.S. natural gas exports that vary in the level and rate of increases:

1. 6 billion cubic feet per day (Bcf/d), phased in at a rate of 1 Bcf/d per year (low/slow scenario);
2. 6 Bcf/d phased in at a rate of 3 Bcf/d per year (low/rapid scenario);
3. 12 Bcf/d phased in at a rate of 1 Bcf/d per year (high/slow scenario); and
4. 12 Bcf/d phased in at a rate of 3 Bcf/d per year (high/rapid scenario).

For each of the scenarios we test two alternative assumptions regarding the driver of U.S. natural gas exports. In the first test, we assume that the increase in US natural gas exports is driven by greater foreign demand. We refer to this test as "exogenous U.S. exports", because U.S. natural gas export levels are forced on the model, and domestic production adapts to meet the increased foreign demand. The numerical implementation is conducted by applying a uniform demand shock to all other regions. In the second test, U.S. natural gas production is raised by the same amount as in the first test, while changes of export levels are determined within the model. We assume that the increase in U.S. natural gas exports is driven by the higher domestic production, and then domestic consumption and exports adjust to these production changes. We refer to this test as "endogenous U.S. exports", and the numerical implementation is conducted by applying a productivity shock to the U.S. gas sector.

Within each of the tests we also vary the price elasticity of U.S. natural gas supply between low, middle, and high values. The spreads for price elasticities of U.S. natural gas supply, defined here as the percentage change in natural gas production per a one percentage point change in the natural gas price, are consistent with the estimates in Arora [23], and also cover the range of recent estimates outlined in that paper. In the inelastic supply case, the long term U.S. natural gas price elasticity of supply is set to 0.25, with a short term value of 0.008. We call this inelastic supply because there is a small response of natural gas production to a change in the natural gas price relative to the other elasticities used. In the reference elasticity case, the long term U.S. natural gas price elasticity of supply is 0.50, and the short-run value is 0.016. The elastic supply case has a long term price elasticity of supply equal to 1.0 and a short term equivalent of 0.032.

[Figure 1 about here.]

While the first group of scenarios considers the world-wide market for U.S. LNG exports, the second group of scenarios focuses on pipeline exports to Canada and Mexico. Again, we implement two tests: "exogenous U.S. exports" and "endogenous U.S. exports". In the first, U.S. natural gas pipeline exports to Canada and Mexico are increased smoothly from 2014-2035, such that in 2035 they are three times those in the AEO2013. In the second, U.S. natural gas production is raised by the same amount as in the first test, while changes of export levels are determined in the model. These simulations provide an alternative view of economic impacts that are not contingent on how the DOE chose to specify their scenarios with a focus on pipeline exports. We consider the same variations in the price elasticities of U.S. natural gas supply in this group of scenarios as with the DOE scenarios.

3.3. Calibration

The model is built using the latest GTAP database [24]. Calibration of each export scenario is focused on the energy sector of the model. The economic growth assumptions are obtained from the continuing project of Chappuis and Walmsley [25], which follow the recent IMF World Economic

Outlook (available up to 2017) and is extrapolated assuming a constant growth rate, equal to the growth rate for the latest available data. Both the population and labor supply estimates are taken from the United Nations' World Population Prospects (2010 Revision) population projection database.¹³ We adopt the medium variant from the projection database, and the labor supply covers ages 15-65.

U.S. natural gas consumption and production in the baseline are calibrated to be as close as possible to AEO2013 projections. For natural gas consumption, this is achieved by iterating on shocks to economy-wide U.S. energy efficiency. The natural gas production estimates are approximated through a 1% annual output productivity improvement in the U.S. natural gas sector. With this trajectory of output productivity shocks U.S. natural gas production will be broadly consistent with the AEO2013 projection. We cannot exactly match AEO2013 reference case natural gas production because the model is unable to solve when the price elasticities of natural gas supply are lowered substantially for sensitivity analysis. In the exogenous export simulations, U.S. natural gas export levels result from iterating on preference shocks to foreign demand for U.S. natural gas. In the endogenous simulations, natural gas production is raised to the same level as that of the corresponding exogenous export simulations.

We make several assumptions on annual fuel efficiency improvements. These are based on Riahi et al. [26] [see especially Figure 7 on page 47], and they play an important role in transmitting the impacts of changes in the price of natural gas in the simulations. Specifically for production technologies, the annual fuel efficiency improvement is 0.5% for conventional gas and coal, 1% for CCS gas and coal, and 1.5% for all other clean power generating technologies. This improvement is 1% for rail and internal combustion, 1.5% for advanced internal combustion, and 2% for hybrid and electric. The iron and steel sector sees 1% gains in fuel efficiency, and all other sectors grow 0.5%. In terms of private consumption, we assume that annual fuel economy improves by 1%.

4. Results

The results for each of the two groups of scenarios are presented in this section. The first sub-section gives results for the DOE scenarios, while the second outlines those from the Pipeline scenarios. Each of these are also further divided between exogenously and endogenously determined U.S. natural gas export levels. Simulation results are presented for the U.S., Japan, the EU25, Mexico, Canada, Russia, OPEC, and (where applicable) the world. These countries or regions are chosen because they represent common price reference points in the natural gas market (Japan and the EU25), are importers of U.S. natural gas (Mexico), and also to understand possible impacts on natural gas exporters (Canada, Russia, and OPEC).

4.1. DOE Scenarios

These scenarios vary LNG exports from the U.S., consistent with the pace and levels of the DOE scenarios outlined above. For brevity only the results for the high/rapid case are shown. The other cases lead to similar conclusions in that the changes are in the same direction, and although the magnitudes of the short and long-term impacts vary, they do so in a consistent manner. This essentially reflects the symmetry of the cases in spite of the fact that there are differences in terms of both the speed and level of increases in U.S. LNG exports. In the short-run the impacts are larger with faster increases in the speed of exports (the rapid cases), while the long-run responds more to the level of exports (the high cases). For this reason the high/rapid case can encompass the other responses and is shown in the various results.

¹³See <http://esa.un.org/wpp/>.

4.1.1. Exogenous U.S. Exports

Figure 2 shows the price and consumption responses in percent changes from the baseline over the period 2014-2035 for the U.S., Japan, the EU25, and Mexico under the high/rapid DOE scenario with exogenously specified export levels.

[Figure 2 about here.]

The results in each case fit conventional wisdom. U.S. prices rise, and they rise the most when supply is inelastic with regards to the natural gas price. This is up to 35% greater than baseline levels by 2020. And the greater is the price rise, the more that U.S. natural gas consumption falls. For Japan and the EU25 domestic natural gas prices fall due to greater availability of global supply, and consumption correspondingly increases.

Mexico is somewhat different from Japan or the EU25 in that prices initially rise before falling below zero by 2035, and consumption has the opposite profile. This occurs because the U.S. export price for natural gas is higher (even though world prices in general are lower). Given that Mexico imports natural gas primarily from the U.S., the Mexican import price initially rises, and consumption correspondingly falls. Over time U.S. exports grow, Mexican natural gas production picks up, and Mexico also begins to import from other natural gas producers so that prices slide and consumption rises.

Prices show the largest rise in the U.S. under the inelastic supply assumptions. This is because the domestic natural gas producers are slow in adjusting to meet increasing demand. In the case of Japan, the EU25, and Mexico, prices show the largest fall under the elastic supply assumptions. The reason for the steeper price falls with elastic supply have to do with U.S. natural gas production increasing quickly to meet export demands, which are shown in Figure 3. This figure shows the production and export responses in percent changes from the baseline over the period 2014-2035 for the U.S., Canada, Russia, and OPEC under the high/rapid DOE scenario with exogenously specified export levels.

[Figure 3 about here.]

Both natural gas production and exports are lower in Canada, Russia, and OPEC due to greater U.S. exports. This indicates that American exports displace other major natural gas producers to a large extent with respect to Japanese and EU25 consumption. This is why both production and exports in these other exporters are down further. Although the decreases in Russian and OPEC natural gas exports are large on a percentage basis, in terms of actual amounts the decreases are relatively small. Exports decline substantially in both regions over the simulation period in the baseline.

Figure 4 shows the deviations of real GNP (in 2007\$) from the baseline over the period 2014-2035 for the U.S., Japan, EU25, Mexico, Canada, Russia, OPEC, and the world under the high/rapid DOE scenario with exogenously specified export levels. The main conclusion is that greater U.S. natural gas exports eventually lead to greater income for the world and natural gas importers, save Mexico. U.S. income is higher through 2030, Canadian GNP falls through the simulation period, while Russia and OPEC initially fall but see income gains by 2035.

[Figure 4 about here.]

Japan and the EU25 have higher income in all cases through most of the simulation period. These results stem from the fact that each region has lower energy costs under any of the export scenarios, leading to lower energy and goods prices. Mexico suffers GNP losses because they are importing higher cost natural gas from the U.S.

The income losses of Canada reflect the reduction in the world price of natural gas because of greater supply, as well as the addition of a competitor. Russia and OPEC initially see GNP declines

for the same reason, but their economies recover because additional domestically produced gas is used in energy-intensive industries, raising output. More specifically, with cheaper energy available, petrochemical production of these countries is projected to be more than 3% higher than the baseline. Similarly, the electricity, iron and steel, and mining industries all see significant growth.¹⁴

U.S. income rises in the early years because of increased investment supporting natural gas production and related industries along the supply chain. Higher natural gas production itself also boosts national income early in the projection period. The effects begin to reverse over time, as investment falls and the growth of natural gas production slows. U.S. GNP initially rises the most when supply is inelastic to price, but also falls the most in this case later in the simulation period. The reason for this is that export levels are assumed to be exogenous and prices are higher than with more responsive production, so by definition national income will rise. Initially, the negative impact of the greater natural gas prices does not off-set the increased value of exports in the U.S., but this changes past 2030.

4.1.2. *Endogenous U.S. Exports*

In this sub-section we relax the assumption that U.S. natural gas exports have to meet a pre-specified level. Instead, we raise U.S. natural gas production by the same amount as in the exogenous case and allow the model to determine outcomes in the remainder of the natural gas market. Figure 5 shows the price and consumption responses in percent changes from the baseline over the period 2014-2035 for the U.S., Japan, the EU25, and Mexico under the high/rapid DOE scenario with endogenous export levels.

[Figure 5 about here.]

Domestic natural gas prices in each of the countries/regions now fall, and consumption rises. For the U.S. this is because the initial push for exports comes from a shift in natural gas supply rather than imposing an increase in foreign demand as was done above. And Mexico benefits because its imported natural gas price does not rise as a consequence. Japan and the EU25 have similar responses to the exogenous case.

Figure 6 shows the production and export responses in percent changes from the baseline over the period 2014-2035 for the U.S., Canada, Russia, and OPEC under the high/rapid DOE scenario with endogenous export levels.

[Figure 6 about here.]

The basic picture is the same, in that U.S. production and exports rise while those of the natural gas exporters fall. Canada is the exception, as Canadian exports are higher, likely because a portion of U.S. exports to Mexico are re-exports of Canadian natural gas. Figure 7 shows the deviations of real GNP (in 2007\$) from the baseline over the period 2014-2035 for the U.S., Japan, EU25, Mexico, Canada, Russia, OPEC, and the world under the high/rapid DOE scenario with endogenous export levels.

The results from these simulations also are generally consistent with the exogenous case: greater income for the world and natural gas importers (including Mexico), while some natural gas exporters initially pay a small price in terms of income. With endogenous exports, however, U.S. income gains stay positive over the entire simulation period.

[Figure 7 about here.]

¹⁴Simulation results are available upon request.

In summary, allowing the model to endogenously determine export levels does not change the main results of the previous section, particularly with regards to GNP, although there are differences in natural gas price responses and consumption.

4.2. Pipeline Export Scenarios

These scenarios vary pipeline exports from the U.S., consistent with the Pipeline scenarios outlined above.

4.2.1. Exogenous U.S. Exports

Figure 8 shows the price and consumption responses in percent changes from the baseline over the period 2014-2035 for the U.S., Japan, the EU25, and Mexico under the Pipeline scenario with exogenously specified export levels. Unlike the DOE scenarios, domestic prices increase in each country/region over the simulation period, with corresponding falls in natural gas consumption.

[Figure 8 about here.]

As before, the inelastic case shows the largest movements in prices and consumption. In fact, U.S. natural gas prices increase over 35% in the inelastic case by 2035 with higher pipeline exports. Figure 9 shows the production and export responses in percent changes from the baseline over the period 2014-2035 for the U.S., Canada, Russia, and OPEC under the Pipeline scenario with exogenous export levels.

[Figure 9 about here.]

U.S. natural gas production increases consistently over the simulation period, rising by almost 16% in the inelastic supply case by 2035. There are also slight gains in the production of natural gas exporters by 2035.

Interestingly, Canadian exports hold steady through 2020 before declining, while Russian and OPEC natural gas exports are higher. This reflects the fact that only U.S. pipeline exports have risen, although these have an impact on world natural gas prices as shown in Figure 8. Thus Canadian exports to Mexico are eventually displaced, and higher natural gas prices induce greater production in Russia and OPEC.

[Figure 10 about here.]

Figure 10 shows the deviations of real GNP (in 2007\$) from the baseline over the period 2014-2035 for the U.S., Japan, EU25, Mexico, Canada, Russia, OPEC, and the world under the Pipeline scenario with exogenous export levels.

As before, one primary conclusion is that world GNP rises by around 2030 after declining post 2020. The U.S. profile is similar to the DOE scenarios, although the income gains are smaller. And with the pipeline exports natural gas importers take income losses while exporters are better off, due primarily to the price increases.

4.2.2. Endogenous U.S. Exports

[Figure 11 about here.]

Figure 11 shows the price and consumption responses in percent changes from the baseline over the period 2014-2035 for the U.S., Japan, the EU25, and Mexico under the Pipeline scenario with endogenously specified export levels. In contrast to the scenarios with exogenous export levels, natural gas prices fall across the four countries/regions while natural gas consumption rises. This is consistent with the endogenous export results from the DOE scenarios [Figure 5].

Figure 12 shows the production and export responses in percent changes from the baseline over the period 2014-2035 for the U.S., Canada, Russia, and OPEC under the Pipeline scenario with endogenous export levels.

[Figure 12 about here.]

U.S. production and exports are higher, while Canadian, Russian, and OPEC production is lower. Both Russian and OPEC exports also fall, but Canadian exports rise. This likely reflects greater re-exports through the U.S. to Mexico, as Mexican consumption is higher because of lower prices.

Figure 13 shows the deviations of real GNP (in 2007\$) from the baseline over the period 2014-2035 for the U.S., Japan, EU25, Mexico, Canada, Russia, OPEC, and the world under the Pipeline scenario with endogenous export levels.

Again, world GNP rises by the end of the simulation period. U.S. income shows the largest gains in terms of magnitude under this combination of scenarios, gaining nearly \$40 billion by 2035 under an assumption of elastic supply. Japan and the EU25 show small income gains, Mexico slightly larger, while Canada and Russia have small losses for much of the simulation period.

[Figure 13 about here.]

4.3. Summary of Differences

The various scenario results have similarities, but also show important differences. In this subsection we summarize the results both within each scenario (exogenous versus endogenous) and also across scenarios.

There are clear divergences in results within both the DOE and Pipeline scenarios when comparing between exogenous and endogenous U.S. natural gas exports. The most obvious is with respect to prices. In either the DOE or Pipeline scenarios U.S. prices rise under exogenous U.S. exports, but fall under endogenous exports. This occurs because in the exogenous setting U.S. natural gas export levels are forced to increase in the model, while domestic production only adapts slowly to meet the increased foreign demand. This also leads to a higher domestic price of U.S. natural gas, and less domestic consumption. In the endogenous setting, U.S. natural gas production is increased to the same level as in the exogenous case, while domestic consumption and exports adapt to the changed production levels. The increased production is driven by higher productivity, which results in a lower price for U.S. natural gas. In the DOE scenarios Japanese and EU25 prices fall in both cases, but with pipeline exports Japanese and EU25 natural gas prices rise with exogenous exports and fall when these are endogenous to the model. The exogenous Pipeline case results in EU25 and Japanese price rises because higher U.S. production and pipeline exports squeeze Canadian natural gas exports and other major natural gas exporters only slightly raise their production. The result is a small reduction in supply for the European and Asian markets.

The other primary difference within each scenario between the exogenous and endogenous simulations is the magnitude and distribution of income gains and losses. In each scenario the U.S. income deviations fall below base after 2032 when exports are exogenous, but remain above base through 2035 when they are endogenous. This is because income changes are driven by short-term demand growth in the exogenous setting, but by long-term productivity growth in the endogenous setting. For natural gas importers endogenous exports result in higher income under any scenario and under the DOE scenarios with exogenous exports, but lower income with pipeline exports that are exogenous. This is because there are higher prices in all importing countries in this case. The impacts on natural gas exporters are mixed within each scenario.

Another difference between scenarios is that U.S. export levels can vary considerably. For example, under the Pipeline scenarios exogenous exports, U.S. export levels can be up to 160% whereas this only reaches 60% above base in the Pipeline scenarios with endogenous exports. As we have discussed

above, domestic price of U.S. natural gas is higher with exogenous exports, and there is less domestic consumption; whereas domestic price is lower with endogenous exports, and there is more domestic consumption, leading to fewer U.S. natural gas exports.

5. Conclusions

Our primary conclusion is that world economic activity is higher through most of the simulation period [2014-2035] when the U.S. exports additional natural gas. This is true under any assumption about the price elasticity of U.S. natural gas supply, whether U.S. natural gas exports are exogenous or endogenous to the model, or the type of exports [LNG versus pipeline]. The dynamics and magnitude of the income changes are also similar across the cases in each of the scenario groups.

For the U.S. we find similar results, although the magnitude of income gains depends crucially on how scenarios are specified and assumptions regarding the price elasticity of U.S. natural gas supply. U.S. GNP rises through 2030 when either LNG or pipeline exports are exogenously specified, but falls below zero after this point. Under endogenously specified exports income changes are always positive. And the magnitude of GNP increases is highest under an elastic supply of natural gas when exports are endogenous, but rises most for an inelastic supply curve with exogenous exports.

The impacts on natural gas importers and exporters also vary depending on the same assumptions. With the exception of Mexico, natural gas importers are better-off under exogenous U.S. exports (LNG or pipeline), while natural gas exporters gain as a group only with exogenous pipeline exports.

Our analysis is subject to a number of caveats. Importantly, the model we use is not specific to the global natural gas market, but is focused on broader economic issues. This is a particular concern on the supply side of the model where we abstract from specifics such as natural gas rigs, the market power of individual producers, and the importance of longer-term contracts in the global natural gas industry. Another concern is that we do not endogenously represent the evolution of natural gas markets in our model, although we can vary key parameter values to approximate such behavior.

The strength of our analysis is based on these parameter variations. Our results show that any analysis about the magnitude of global economic impacts of U.S. natural gas exports depends crucially on assumptions regarding scenario specification and the price elasticity of U.S. natural gas supply. These points are well understood, but to our knowledge have not previously been shown quantitatively. We are also able to extend the focus of recent studies to a global scale and consider pipeline as well as LNG exports.

References

- [1] CRS . U.S. natural gas exports: New opportunities, uncertain outcomes. 2013.
- [2] Darmstadter J. The controversy over US coal and natural gas exports. Issue Brief 13-01; RFF; 2013.
- [3] Deloitte . Exporting the American renaissance: Global impacts of LNG exports from the United States. 2012.
- [4] Ebinger C, Massy K, Avasarala G. Liquid markets: Assessing the case for U.S. exports of liquefied natural gas. Policy Brief 12-01; Brookings; 2012.
- [5] ICF . U.S. LNG exports: Impacts on energy markets and the economy. 2013.
- [6] Medlock KB. U.S. LNG exports: Truth and consequence. 2012.
- [7] CRA . US manufacturing and LNG exports: Economic contributions to the US economy and impacts on US natural gas prices. 2013.

- [8] Sarica K, Tyner WE. Economic and environmental impacts of increased U.S. exports of natural gas. 2013. Mimeo.
- [9] EIA . Effect of increased natural gas exports on domestic energy markets. 2012.
- [10] NERA . Macroeconomic impacts of LNG exports from the United States. 2012.
- [11] Kliesen KL. Rising natural gas prices and real economic activity. Federal Reserve Bank of St Louis Review 2006;88(6):511–26.
- [12] Arora V, Gross P, Sendich E. Natural gas and U.S. industrial production: A closer look at four industries. 2013. Mimeo.
- [13] Arora V, Lieskovsky J. Natural gas and U.S. economic activity. The Energy Journal forthcoming;.
- [14] Sharma SS. The relationship between energy and economic growth: Empirical evidence from 66 countries. Applied Energy 2010;87:3565–74.
- [15] Sheng Y, Shi X. Energy market integration and equitable growth across countries. Applied Energy 2013;104:319–25.
- [16] Nel WP, Zyl Gv. Defining limits: Energy constrained economic growth. Applied Energy 2010;87:168–77.
- [17] Apergis N, Payne JE. Natural gas consumption and economic growth: A panel investigation of 67 countries. Applied Energy 2010;87:2759–63.
- [18] Wakamatsu H, Aruga K. The impact of the shale gas revolution on the U.S. and Japanese natural gas markets. Energy Policy 2013;62:1002–9.
- [19] Logan J, Lopez A, Mai T, Davidson C, Bazilian M, Arent D. Natural gas scenarios in the U.S. power sector. Energy Economics 2013;40:183–95.
- [20] Paltsev S, Jacoby HD, Reilly JM, Ejaz QJ, Morris J, O’Sullivan F, et al. The future of U.S. natural gas production, use, and trade. Energy Policy 2011;39:5309–21.
- [21] Cai Y, Newth D, Finnigan J, Gunasekera D. CTEM: A model for integrated assessment of climate change, carbon mitigation and energy transformation. Technical Report; CAWCR; forthcoming.
- [22] Hertel T. Global Trade Analysis: Modeling and Applications. Cambridge University Press; 1997.
- [23] Arora V. Estimates of the price elasticities of natural gas supply and demand in the United States. 2013. Mimeo.
- [24] Narayanan BA, Aguiar A, McDougall R. Global trade, assistance, and production: The GTAP 8 data base. 2012. Center for Global Trade Analysis, Purdue University.
- [25] Chappuis T, Walmsley TL. Projections for world CGE model baselines. Research Memorandum 22; GTAP; 2011.
- [26] Riahi K, Rao S, Krey V, Cho C, Chirkov V, Fischer G, et al. RCP 8.5: A scenario of comparatively high greenhouse gas emissions. Climate Change 2011;109:33–57.

Figure 1: Export Scenarios

Figure 2: Price and consumption responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 3: Production and export responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 4: GNP responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 5: Price and consumption responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports

Figure 6: Production and export responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports

Figure 7: GNP responses for select countries in high/rapid case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports

Figure 8: Price and consumption responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 9: Production and export responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 10: GNP responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with exogenous exports

Figure 11: Price and consumption responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports

Figure 12: Production and export responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports

Figure 13: GNP responses for select countries in pipeline case under different assumptions regarding the price elasticity of natural gas supply with endogenous exports