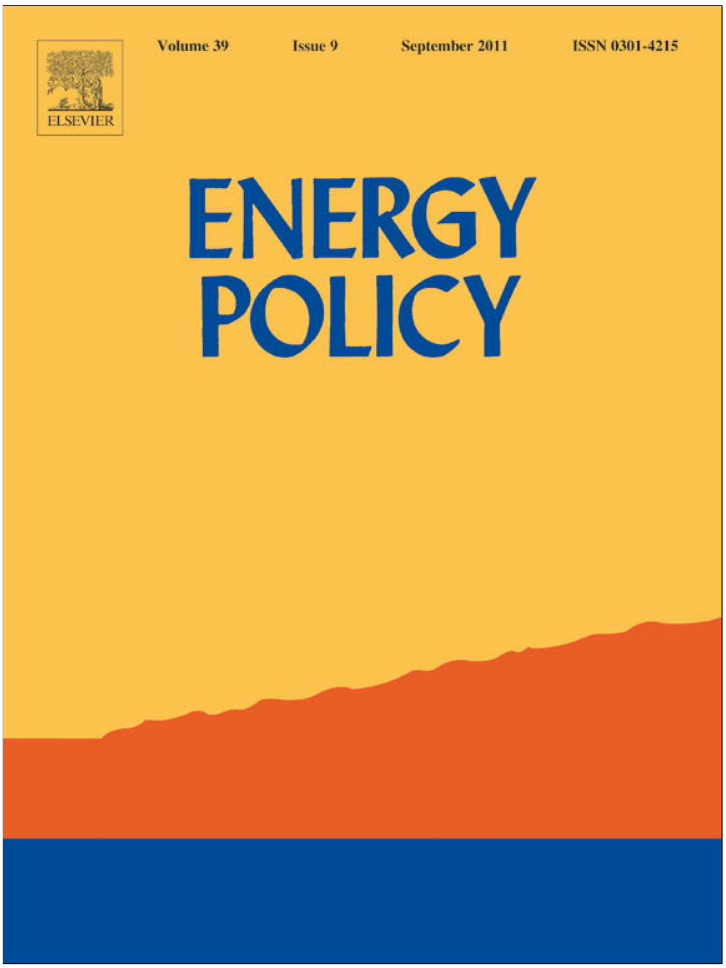

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Measuring energy security: Trends in the diversification of oil and natural gas supplies ☆

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ABSTRACT

We present evidence on one facet of energy security in OECD economies—the extent of diversification in sources of oil and natural gas supplies. Viewed from the perspective of the energy-importing countries as a whole, there has not been much change in diversification in oil supplies over the last decade, but diversification in sources of natural gas supplies has increased steadily. We document the considerable cross-country heterogeneity in the extent of diversification. We also show how the extent of diversification changes if account is taken of the political risk attached to suppliers; the size of the importing country; and transportation risk.

1. Introduction

The pursuit of energy security gained world-wide impetus after the tripling of the international price of crude oil in October 1973. One of the consequences of this shock "was to put energy security and, more specifically, security of oil supply at the heart of the energy policy agenda of most industrialized nations" (LaCasse and Plourde, 1995). The run-up in oil prices over 2007–2008 again raised the profile of energy security policies. Over 180 bills with the term "energy security" in the text of the bill were introduced into the U.S. Congress during the 111th Congress (2009–2010) and over 200 bills were introduced during the Congress that preceded it. In other countries around the globe as well, energy security is a key policy concern—see the special issue of *Energy Policy* on the topic (Loschel et al., 2010a summarize the papers).

Policymakers often equate the attainment of energy security with 'energy independence.'[1] Rising imports as a share of total consumption is thus taken to imply lower energy security, without an analysis of a country's vulnerability to supply disruptions or energy price increases. Equating security with independence also leads policymakers to focus primarily on promoting expanding domestic supplies – for example through subsidies or quotas on domestic production – rather than on efficient methods to manage risk by diversifying suppliers or enhancing substitution among fuel types.

A multi-faceted measure of energy security would help make better policy decisions, and also provide a way to track how policy decisions raise or lower energy security. Luckily, there is a growing literature on the measurement of energy security. Many papers seek to quantify the security of energy supplies for importing countries, using – in addition to the degree of import dependence – measures such as the extent of diversification in sources of supply and the distance between the source of the supplies and the point of consumption (Blyth and Lefevre, 2004; Le Coq and Paltseva, 2008, 2009; Gupta, 2008). One major study conducted for the European Union focused on the interaction between climate change policies and energy security (Lefevre et al., 2009). This paper contributes to this literature on the measurement of the short-run security of energy supplies. Our specific contributions are the following:

- First, we provide evidence of the variation over time from 1990 to the present in energy supply security for a broad set of

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[1] There has been an explosion of popular books in the US dealing with the elusive quest for energy independence, such as Bryce (2008), Hakes (2008) and Sandalow (2008)—see Loungani (2009) for a review of these books. Concerns about energy security are also prevalent among European policymakers. See, e.g., European Commission (2000, 2006) and Van der Linde et al. (2004).

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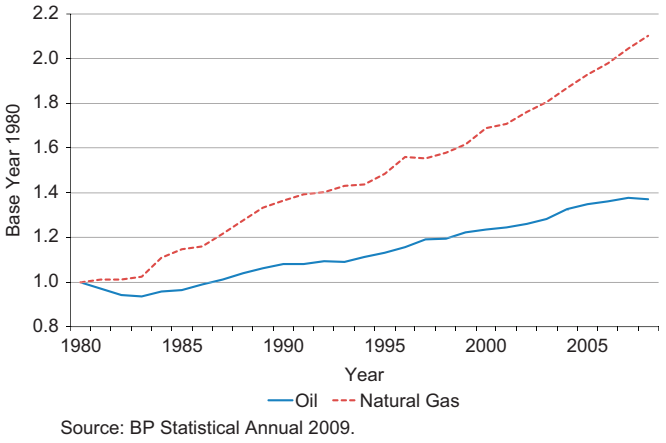
countries, viz., the oil[2] importers among the OECD (2004) countries.[3] Other studies have tended to provide evidence for a single year (e.g. Le Coq and Paltseva provide evidence for 2006 and Gupta for 2004).

- Second, while many previous studies have focused on oil, we also provide evidence on security for natural gas, another major energy source. This is important given the growing importance of natural gas in world energy consumption (see Fig. 1). The globalization of energy markets is only likely to grow as natural gas grows in importance. Traditionally, natural gas has been traded in regional, intra-continental, markets.[4] But as the costs of transporting natural gas have fallen, trade in natural gas has increased dramatically; the IEA estimates that international spot trade of gas has grown by a factor of 10 over the last decade (Rosendahl and Sagen, 2009). In addition, major improvements to shale gas exploration and production technologies have led to large increases in proved reserves of natural gas both within and outside the United States.[5]



Source: BP Statistical Annual 2009.

Fig. 1. Normalized global consumption of oil and natural gas.

2. Diversification in sources of energy supply

Casual empiricism suggests that diversification in sources of energy supply has been increasing. Much of that diversity is coming from natural gas suppliers. In 1992, the US and Russia produced more than half of the world's natural gas supply. In 2009, these two countries are still the two largest suppliers of natural gas, but together produce only 38 percent of the world's supply. There has been a corresponding increase in the diversity of oil suppliers as well over time as well, as discussed below.

Figs. 2 and 3 show the distribution of major producers and net exporters of oil and gas in the last year of our sample period compared with that in 1992. The main source of data is the International Energy Agency. The top panel of Fig. 2 shows that the major change among producers of oil has been the decline in the share produced by the United States. Among net exporters (shown in the bottom panel), the major changes over time have been the decline in the shares of Saudi Arabia, Iran, UAE, Indonesia and Mexico and a corresponding increase in the shares of Russia and Angola. Among gas producers, the biggest changes, as shown in the top panel of Fig. 3, have been the declines in the shares of Russia and the US. Among net exporters (bottom panel), the main developments have been the growing importance of Norway and the emergence of several new producers such as Qatar, Nigeria, Egypt and Australia.

Diversification indices can provide a summary statistic of these changes over time. The basic idea of a diversification index is borrowed from portfolio theory in finance: holding other things constant, the overall risk to energy supplies is smaller if there is a diversified portfolio of suppliers. Diversification in sources of supply can reduce vulnerability to supply disruptions from a particular source. Moreover, even in the absence of supply disruptions, diversification reduces the market power of any one supplier, lowering the "risks of higher prices and/or inferior products and services" (Blyth and Lefevre, 2004).

This idea can be quantified in a number of different ways. Much of the literature (Blyth and Lefevre, 2004; Le Coq and Paltseva, 2008, 2009; Gupta, 2008; Loschel et al., 2010b) uses the Herfindahl–Hirschmann index (HHI) to measure diversification. This index is equal to the sum of the squares of each supplier's market share. Thus the more concentrated the market, the higher is the value of the index; the maximum value of the index is achieved when there is only one supplier.

We construct a global diversification index using each producing country's share of total production[6]:

$$DI\ (global) = \sum_i \left(\frac{X_i}{X}\right)^2 \times 100$$

where X_i/X is country i's share in either world production or world net exports. Separate indices are constructed for oil and natural gas. These indices are shown in the left hand panels of Figs. 4 and 5, respectively, for oil and natural gas.

The *DI* (*global*) measure assumes that the risk of disruption is the same across energy suppliers. This of course need not be the case. While there is no easy way of quantifying risks associated with a particular supplier (or of measuring the correlation of risks among suppliers), a common practice in the literature is to proxy it by a broader measure of country risks. The most widely used measure, and the one used in this paper, is a country's political risk rating as computed by the Political Risk Services Group and reported in the International Country Risk Guide (ICRG). The political risk rating provides a means of assessing the political stability of the countries covered by ICRG on a comparable basis.

$$DI_{pol}\ (global) = \sum_i \left[\left(\frac{X_i}{X}\right)^2 \times POL_i \times 100\right]$$

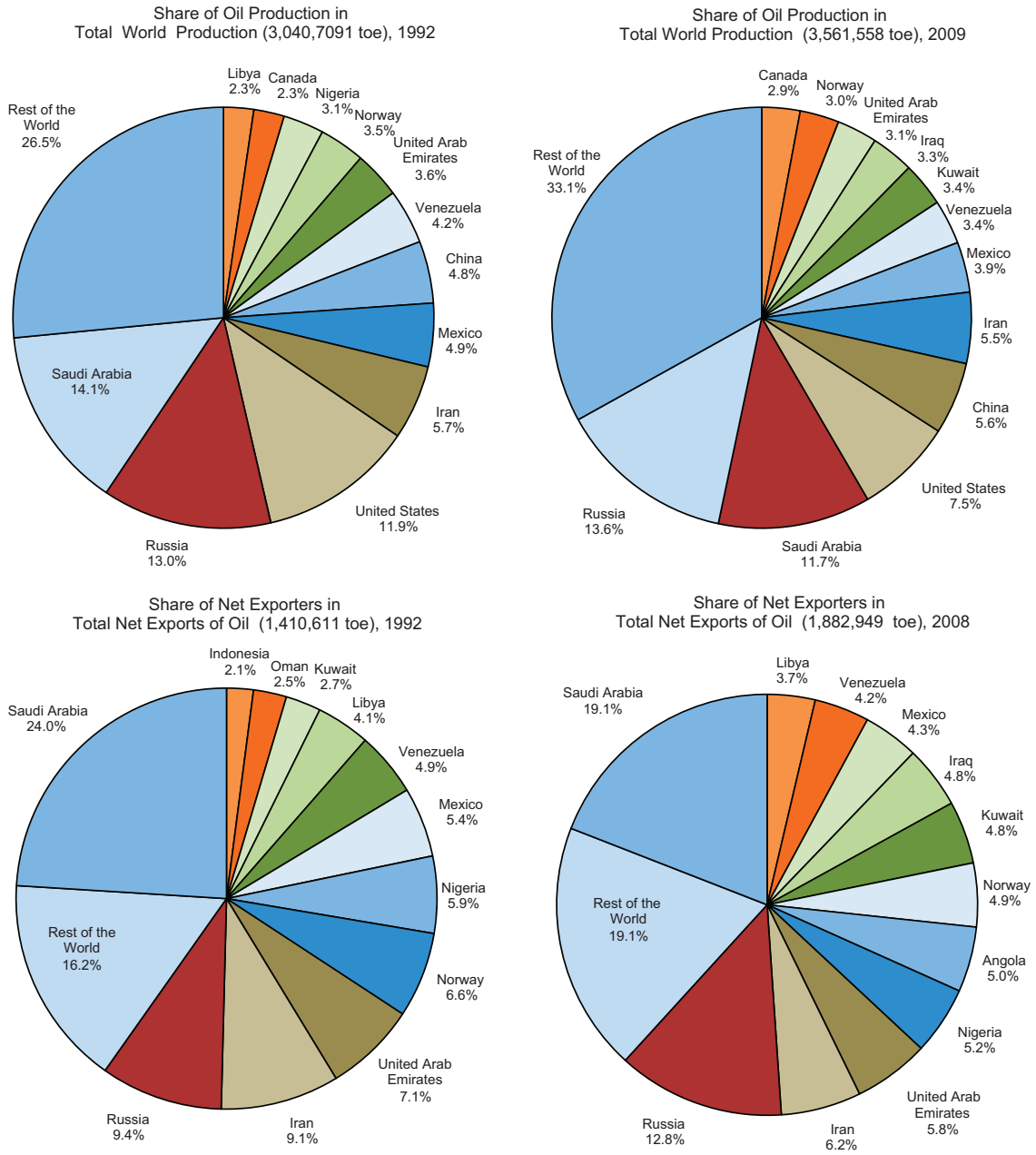
[2] The word "oil" in the text refers to crude oil and its equivalents. Ideally, imports of refined oil products should also enter the diversification measurement. However, including refined products would distort the diversification measure because the underlying vulnerability comes from the country that supplies the crude oil.

[3] In principle, one could also study the energy vulnerability of the major oil exporters. Bryce (2008) notes that in 2005 the "Saudis *imported* 83,000 barrels of gasoline and other refined oil products per day" and Iran imports 40 percent of its gasoline needs.

[4] Due to the lack of sufficient LNG terminals, long-distance pipelines and local distribution systems, the structure of natural gas markets in most Asian countries is more complicated than in North American or European markets.

[5] According to the U.S. Energy Information Administration (2011a, 2011b), natural gas proved reserves increased by 11 percent in 2009 due to major improvements in shale gas exploration and production technologies. Natural gas prices are expected to remain low due to the continued exploration and development of shale gas resources, with shale gas estimated to increase from 16 percent of total US gas production in 2009 to nearly half by 2035. The recent development of shale gas as a viable resource has occurred both within the United States as well as in 31 other countries. Along with the development of shale gas, the Canadian oil sands have also become an important part of the global energy picture and may change the outlook for oil supplies in the future. According to Yergin (2009), Canada's estimated recoverable reserve of petroleum is second only to Saudi Arabia's. Canada is the largest foreign supplier of oil to the US market and its placid political environment could make it a reliable source of future energy supply.

[6] A diversification index based on each country's share of net exports yields similar results (see the working paper version of this paper, Cohen et al., 2011).



Source: International Energy Agency.

Note: The units "toe" refer to metric tons of oil equivalent (41.868 gigajoules).

Fig. 2. Oil production and net exports by major countries. *Note:* The units "toe" refer to metric tons of oil equivalent (41.868 gigajoules).)

where POL_i is computed as

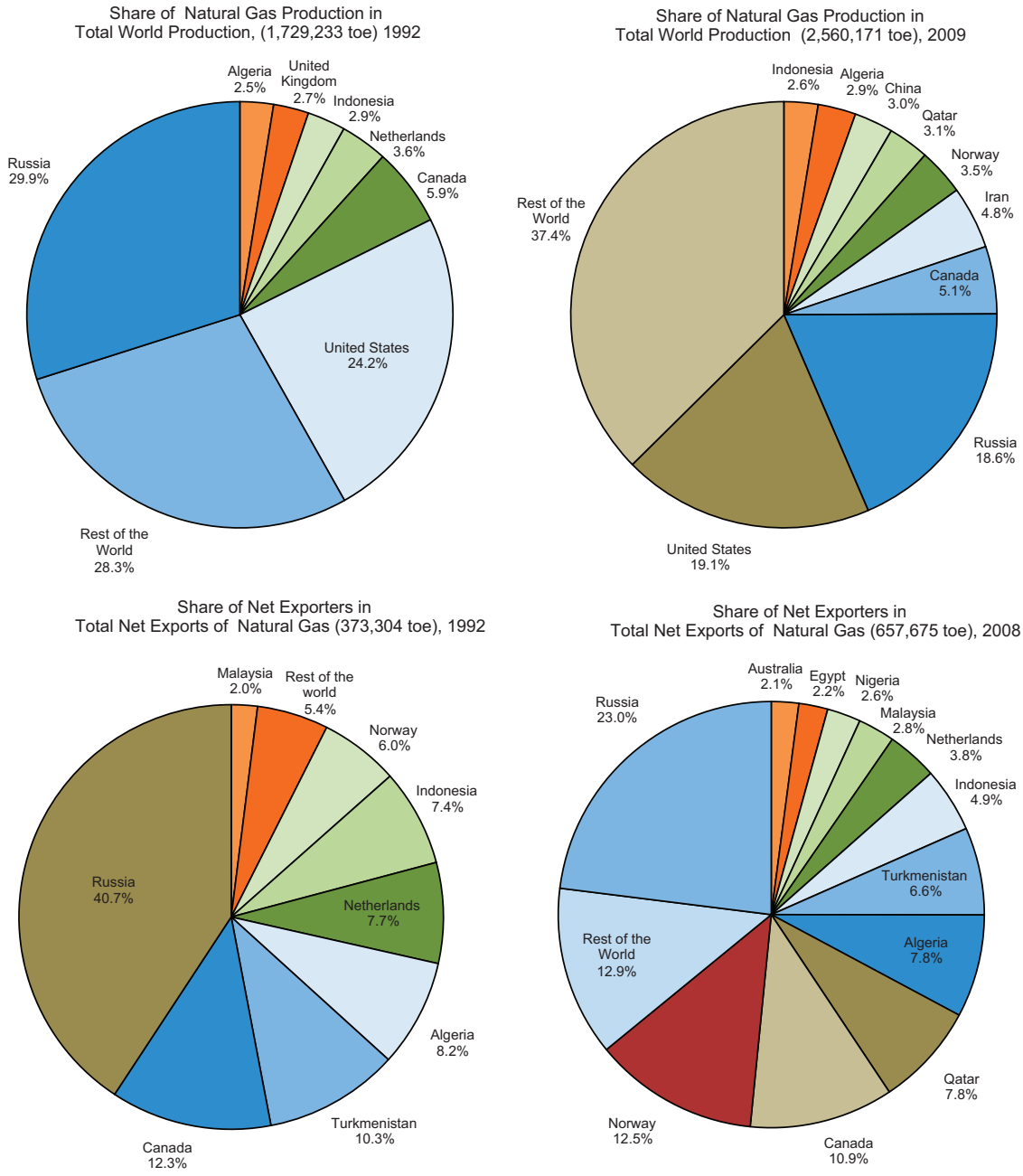
$$POLi = [100 - ICRGi/100]$$

Since $ICRG_i$ is on a (0, 100) scale where high values indicate low political risk, the transformation above is made to ensure that DI_{pol} (*global*) moves in the same direction as *DI* (*global*).

Fig. 4 shows the diversification over time in the sources of oil production (left hand panel). As shown, there was an increase in diversification in oil supplies between 1992 and around 2000, but it has essentially leveled off since then. The adjustment for political risk, shown in the right hand panel of Fig. 4, does not make a big difference, suggesting that though there have been many changes in the sources of production and net exports over this time, the risk factors of the countries whose shares have increased has roughly balanced out the risk factors of those whose shares have fallen.

Fig. 5 shows that the picture for natural gas is quite different from that for oil. There has been a steady decline in the values of the index, indicating increased diversification in sources of production and net exports. Adjustment for political risk does not alter this trend.

To summarize, the global perspective shows little change in diversification in oil supplies over the last decade but a steady increase in diversification in natural gas supplies, leading to an increase in overall energy security. Of course, the picture from the perspective of an individual energy-importing country could look quite different, depending on its relative use of oil and natural gas, its dependence on imports relative to domestic production, the particular countries from which it imports, and the political risk attached to the sources of those imports. The next section presents our country-level results on diversification. In addition to adjustments to political risk, we also adjust the diversification



Source: International Energy Agency.
Note: The units "toe" refer to metric tons of oil equivalent (41.868 gigajoules).

Fig. 3. Gas production and net exports by major countries.

indices for the size of the importing country and the distance between the importing country and the source of its imports (as a proxy for transportation risks).

3. Cross-country variation in diversification

3.1. Measuring diversification

We again follow the literature in using diversification indices to measure the risk of disruption to an individual country's energy supplies. Le Coq and Paltseva (2008, 2009) use the actual market share of each supplier to the specific country being assessed. Blyth and Lefevre (2004) argue that what matters are the potential exports of each supplier, taking account of the potential for importers to switch suppliers. There are pros and cons of each approach. Le Coq and Paltseva (2009) argue that using potential exports "may not reflect the short-term threats in the *actual* energy market faced by the country in question." While they agree that the Blyth and Lefevre approach "could be better suited for reflecting the possibility of switching to a different supplier in the case of a disruption," they view their approach as preferable if the interest is in describing a country's ability to carry out "a short-run adjustment to shocks in which case a change in supplier is highly relevant."[7]

[7] Alternatively, Neumann (2004, 2007) uses a Shannon–Wiener concentration index, which is calculated by summing market shares for each participant multiplied by logged values of each participant's market share (rather than summing squared market shares as in an HHI). This index gives greater weight to the impact of the smaller participants, whereas an HHI gives greater weight to

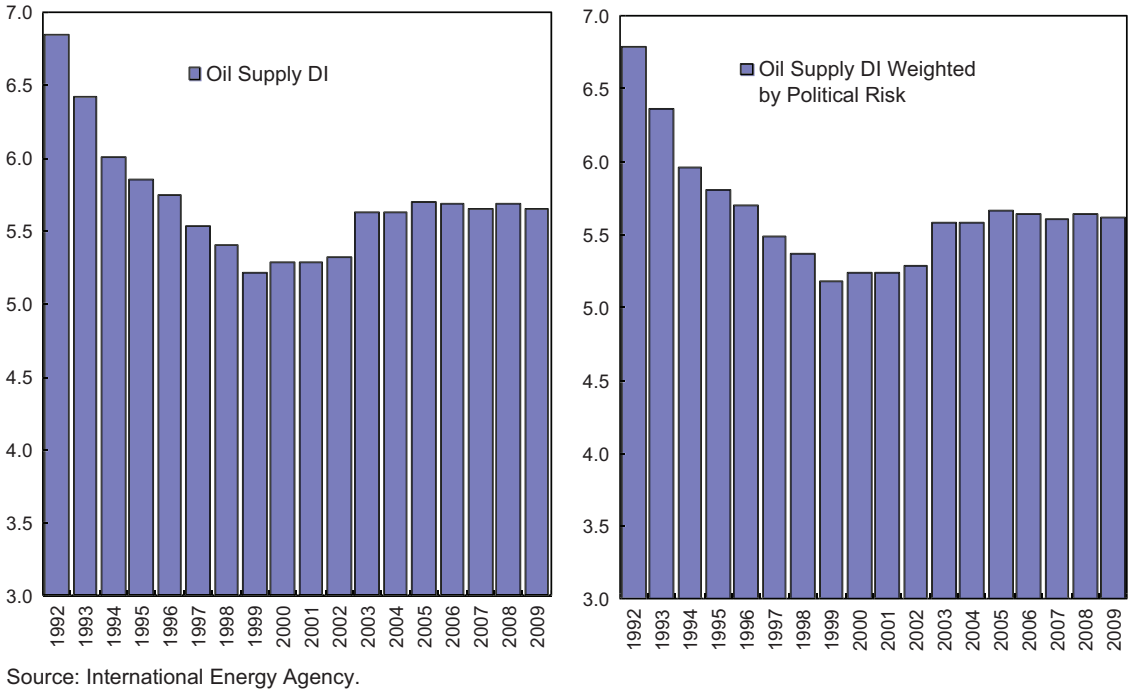


Fig. 4. Oil Diversification Index (DI), 1992–2009.

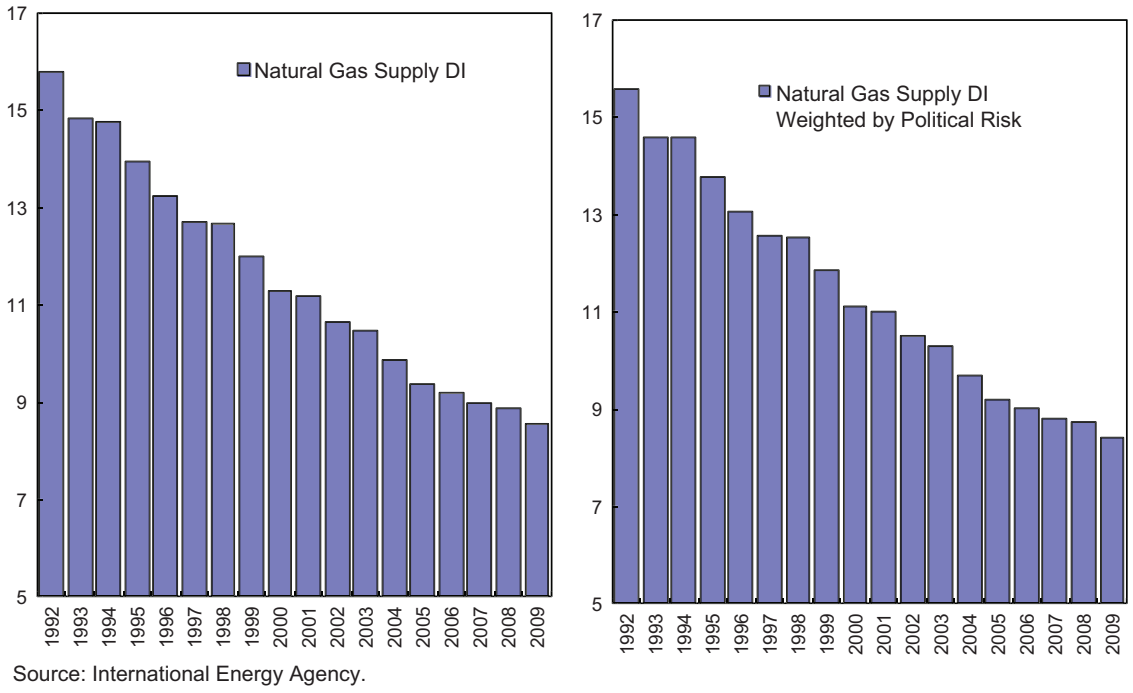


Fig. 5. Natural gas diversification index (*DI*), 1992–2009

While each measure thus highlights a different facet of diversification, our work in this paper is based on the HHI as defined by Le Coq and Paltseva (2008, 2009). Specifically, we compute a country-specific diversification index for suppliers as

$$CDI = \sum_i \left(\frac{NPI_i}{C}\right)^2 \times 100$$

where C is country j's total consumption of the fuel. NPI_i, the net positive imports from country i to country j, are defined as

$$NPI_i = \max\{0, M_{ij} - X_{ij}\}$$

M_{ij} is imports of energy from country i to j and X_{ij} is exports of energy from country j to i. As noted earlier, smaller values of CDI

(*footnote continued*)
the larger suppliers. The argument for the former index is that it is the smaller suppliers that are more likely to be able to provide options for switching between energy sources in the event of a disruption to another supply source. Le Coq and Paltseva (2008) argue that an HHI, with its emphasis on the larger suppliers is "better suited to capture the risks associated with the non-diversified energy portfolios."

indicate more diversification and hence lower risk; in the case of only one supplier, CDI takes on its maximum value of 100. It is important to note that, other things equal, CDI will be lower in countries where net imports form a smaller part of consumption. Hence CDI is likely to be correlated with the measures of "import dependence" that are commonly used.

3.2. Adjusting for political risk and country size

As with the global measure, we use the International Country Risk Guide (ICRG) risk rating to adjust for political risk:

$$CDI_{pol} = \sum_i \left[\left(\frac{NPI_i}{C} \right)^2 \times POL_i \times 100 \right]$$

where, as before, POL_i is computed as

$$POL_i = [100 - ICRG_i/100]$$

Since $ICRG_i$ is on a scale where high values indicate low political risk, the transformation above is made to ensure that CDI_{pol} moves in the same direction as *CDI*. CDI_{pol} takes values in the range (0, 100).

Thus far, the indices do not take into account differences in country size, and therefore in the size of their consumption (or imports) relative to world consumption (or imports). Blyth and Lefevre suggest that this can be an important factor in determining the potential vulnerability of an importing country. Other things constant, the smaller is the importing country's draw on the market, the easier it is for the country to switch suppliers in the event of a disruption from one source. Constraints to switching suppliers raise the vulnerability to energy shocks and lower a country's energy security. We proxy this country size effect by constructing a variable, *SIZE*, which is the ratio of a county's consumption of a fuel divided by total world consumption of that fuel source expressed in percent terms[8]:

$$CDI_{size} = \sum_i \left[\left(\frac{NPI_i}{C} \right)^2 \times e^{SIZE} \times 100 \right]$$

Following Blyth and Lefevre, the size of a country's consumption and imports relative to world consumption has a multiplicative effect on a country's energy security. Thus, *SIZE* is included in the overall index in an exponential function. Countries with a relatively small share of world consumption (i.e. *SIZE* close to zero) will not have their risk assessment altered very much. Countries whose draw on available world supply is significant, and thus will have more difficulty in replacing supply in the event of a disruption, will have their security risk scaled up quite a bit.

The last adjustment, following Le Coq and Paltseva (2009), is to "construct a measure of the distance between the supplier and the consuming country as a proxy for the potential risks of energy transportation." They argue that the "safety of delivery to the consuming country declines with the distance to the energy source." In practice, they use the distance between the capitals of the consuming and supplying countries to construct an adjusted *CDI*:

$$CDI_{dist} = \sum_i \left[\left(\frac{NPI_i}{C} \right)^2 \times D_i \times 100 \right]$$

where $D_i=1$ if the distance between the capital of the importing country and the supplying country is less than 1500 km; $D_i=2$ if the distance is between 1500 and 4000 km; and $D_i=3$ if the distance exceeds 4000 km. Given the scaling of the D_i variable, CDI_{dist} takes on values in the range (0, 300).

For each of the diversification indices described above, we provide the ranking of countries for the last sample year, which classifies their measured vulnerability from lowest to highest. To give a sense of the overall impact of the three adjustments, we look at the mean of the ranks adjusted for political risk, size and distance.

Table 1
Country-specific diversification index (*CDI*) for oil.
Source: International Energy Agency.

Country	1990	1995	2000	2008	2008 Ranking
Australia	0.47	1.20	3.80	5.43	3
Austria	5.58	9.52	10.95	11.75	9
Belgium	15.54	23.18	17.64	21.60	17
Canada	1.13	2.15	7.80	5.42	2
Czech Republic			68.43	47.58	21
Denmark	4.93	13.01	12.45	8.56	5
Finland	4.28	22.61	29.70	73.37	23
France	7.44	13.22	12.45	8.47	4
Germany	6.11	13.41	15.67	15.31	12
Greece	28.12	26.13	24.74	27.33	19
Hungary			65.96	90.89	25
Ireland	64.30	74.06	100.00	33.53	20
Italy	13.40	15.88	12.76	13.83	10
Japan	10.88	13.82	16.33	17.46	15
Korea		17.06	13.40	17.44	14
Netherlands	8.56	15.78	14.84	14.33	11
New Zealand	15.34	11.04	8.56	10.08	7
Poland			82.39	82.29	24
Portugal	12.45	16.16	15.48	10.57	8
Slovak Republic				99.82	26
Spain	11.42	10.63	9.67	8.83	6
Sweden	23.18	29.56	26.11	22.81	18
Switzerland	26.20	30.93	32.17	53.75	22
Turkey	13.52	17.69	11.56	21.59	16
United Kingdom	2.35	2.13	14.16	15.70	13
United States	2.14	3.23	4.30	4.89	1

3.3. Diversification in sources of supply: results

The results are presented in Tables 1–8; the first four are for oil and the next four for natural gas. In each table, results are presented for the years 1990, 1995, 2000 and the most recent year available, which is 2008 in the case of oil and 2007 in the case of gas. The number of countries is 26 for oil and 20 for gas. Of the six fewer countries for natural gas, four countries, Australia, Canada, Denmark and New Zealand, are net exporters of natural gas. The other two countries, Korea and Turkey are excluded because of missing data. The main sources of the data are Eurostat for the European members of the OECD and the International Energy Agency (IEA) for the other countries.[9]

Table 1 contains basic CDI indices. Looking first at the variation over time, it is the case that, for many countries, the value of the index has increased over time, that is, in the direction of lower security. This reflects the fact that, for most countries, imports have become a more important part of their overall consumption. Recall that the way our index is computed, this translates into a higher value for the index. A second noteworthy feature of Table 1 is the large cross-country variation in values of the index. In 2008, for instance, this variation spanned the range of CDI values from approximately five in the case of the US to 100 in the case of the Slovak Republic. The last column, 2008 Ranking, orders the countries from lowest (US) to highest (Slovak Republic) in terms of vulnerability. The ranking column will facilitate comparisons across adjustments.

Table 2 shows that the adjustment for political risk alters the perception of cross-country differences in vulnerability. For many

[8] Using the ratio of world imports of a fuel source to the country's imports gave us similar results.

[9] At the time this paper was written, IEA did not have a complete set of data so Eurostat was used to supplement the data.

Table 2
Country-specific diversification index (*CDI*) for oil, adjusted for political risk.
Source: International Energy Agency.

Country	1990	1995	2000	2008	2008 Ranking
Australia	0.17	0.34	1.41	1.41	4
Austria	2.91	3.73	4.64	3.64	15
Belgium	6.96	5.06	3.72	4.92	18
Canada	0.26	0.42	1.29	1.12	2
Czech Republic			27.64	11.43	22
Denmark	1.72	2.33	1.42	0.76	1
Finland	0.71	3.78	9.00	17.27	23
France	3.00	3.27	2.64	1.74	6
Germany	1.99	3.54	4.82	3.25	12
Greece	15.98	8.32	8.29	6.83	20
Hungary			26.66	21.53	25
Ireland	11.45	9.95	11.40	3.69	16
Italy	7.01	5.30	4.46	3.14	10
Japan	4.62	3.67	4.09	3.40	14
Korea		4.56	3.55	3.39	13
Netherlands	3.97	3.50	3.11	3.23	11
New Zealand	5.90	2.88	2.07	1.98	7
Poland			33.29	19.45	24
Portugal	6.04	5.89	5.73	3.04	9
Slovak Republic				23.65	26
Spain	5.02	3.73	3.57	2.20	8
Sweden	3.64	4.42	3.41	4.39	17
Switzerland	9.63	11.51	12.23	10.15	21
Turkey	8.34	5.21	4.31	5.83	19
United Kingdom	0.40	0.29	1.65	1.55	5
United States	0.82	0.96	1.27	1.17	3

Table 3
Country-specific diversification index (*CDI*) for oil, adjusted for country size.
Source: International Energy Agency.

Country	1990	1995	2000	2008	2008 Ranking
Australia	0.49	1.23	3.90	5.55	1
Austria	5.62	9.58	11.02	11.82	9
Belgium	15.94	23.66	18.05	22.10	17
Canada	1.21	2.25	8.19	5.65	2
Czech Republic			68.70	47.85	21
Denmark	4.96	13.11	12.52	8.61	4
Finland	4.32	22.73	29.92	73.92	23
France	8.01	14.06	13.21	8.96	5
Germany	6.71	14.53	16.82	16.47	12
Greece	28.52	26.44	25.07	27.67	19
Hungary			66.28	91.32	25
Ireland	64.43	74.19	100.20	33.61	20
Italy	14.51	16.87	13.55	14.66	10
Japan	13.20	16.46	18.92	19.81	15
Korea		18.23	14.57	18.86	14
Netherlands	9.00	16.50	15.42	14.82	11
New Zealand	15.41	11.07	8.59	10.11	7
Poland			83.44	83.48	24
Portugal	12.59	16.32	15.60	10.65	8
Slovak Republic				100.21	26
Spain	12.04	11.10	10.06	9.18	6
Sweden	23.58	29.98	26.48	23.13	18
Switzerland	26.28	31.04	32.27	53.93	22
Turkey	13.85	18.08	11.75	21.94	16
United Kingdom	2.54	2.28	15.02	16.57	13
United States	4.28	5.62	7.29	8.19	3

countries, this adjustment takes into account the move towards imports from countries such as Norway and Mexico, which have lower political risk ratings than many countries in the Middle East. Denmark, for example, moves from being ranked 5 (unadjusted) to 1 and the UK moves from 13 (unadjusted) to 5. Both Denmark and the UK purchase the bulk of their crude oil from Norway. For other countries, such as Austria and the US, the adjustment for political risk lowers the ranking of the country.

Table 4
Country-specific diversification index (*CDI*) for oil, adjusted for distance.
Source: International Energy Agency.

Country	1990	1995	2000	2008	2008 Ranking
Australia	1.38	3.51	10.77	15.86	3
Austria	12.80	23.68	26.24	29.27	12
Belgium	37.48	51.65	29.50	44.25	17
Canada	3.38	6.43	22.90	16.17	4
Czech Republic			137.58	95.47	23
Denmark	11.26	15.37	12.45	8.56	1
Finland	6.12	33.61	30.51	73.51	21
France	19.70	30.76	21.38	17.34	6
Germany	10.20	20.46	26.76	26.93	11
Greece	52.85	50.64	49.11	52.25	18
Hungary			131.91	181.79	25
Ireland	64.30	74.06	100.00	35.05	15
Italy	16.95	22.67	19.16	19.57	7
Japan	32.15	41.15	48.94	52.35	20
Korea		51.05	40.18	52.30	19
Netherlands	21.96	36.33	28.62	29.61	13
New Zealand	45.98	32.60	24.23	29.94	14
Poland			82.41	82.30	22
Portugal	27.05	41.15	37.21	23.50	9
Slovak Republic				199.64	26
Spain	29.88	26.08	23.82	22.09	8
Sweden	24.76	33.48	27.48	23.54	10
Switzerland	43.68	69.06	75.47	109.79	24
Turkey	18.67	34.99	19.43	42.48	16
United Kingdom	2.77	2.27	14.41	16.94	5
United States	5.38	7.26	9.59	9.97	2

Table 5
Country-specific diversification index (*CDI*) for natural gas.
Sources: International Energy Agency and Eurostat.

Country	1990	1995	2000	2007	2007 Ranking
Austria	0.05	60.12	43.52	47.48	12
Belgium	37.69	30.37	30.23	28.74	9
Czech Republic		95.97	65.73	64.66	16
Finland		100.00	100.00	100.00	18
France	14.74	24.29	24.98	18.15	5
Germany	8.22	24.30	23.80	29.03	10
Greece			60.53	63.57	15
Hungary		36.35	44.77	36.63	11
Ireland		0.13	52.00	83.55	17
Italy	7.00	17.09	25.48	18.05	4
Japan	50.02	21.89	13.54	24.31	8
Netherlands	0.44	0.54	5.65	0.00	1
Poland		41.30	29.33	20.77	6
Portugal			76.88	53.73	14
Slovak Republic		75.49	97.61	100.00	20
Spain	34.67	40.36	41.15	22.58	7
Sweden	100.00	100.00	100.00	100.00	18
Switzerland	30.01	38.26	50.82	48.37	13
United Kingdom	1.69	0.05	0.01	4.98	3
United States	0.16	0.11	0.28	0.11	2

Austria moves from ranked 9 (unadjusted) to 15. Similarly, the US moves from 1 (unadjusted) to 3.

In contrast to adjustment for political risk, the effect of the adjustment for size has a minimal impact on the relative vulnerability rankings of most countries. One exception to this is in the diversification measures for the United States. As expected, the size correction significantly raises the measure of US vulnerability. In 2008, the size correction moves the ranking of the US from 1 (unadjusted) to 3.

Table 4 presents the results taking into account distance from suppliers. Comparing these numbers with those in Table 1, the main impact is that the values for countries in the Asia-Pacific region (Japan, Korea and New Zealand) increase substantially, as seen in the decline in those countries relative rankings in 2008

Table 6
Country-specific diversification index (*CDI*) for natural gas, adjusted for political risk.
Sources: International Energy Agency and Eurostat.

Country	1990	1995	2000	2007	2007 Ranking
Austria	0.01	23.55	17.24	9.97	12
Belgium	10.35	7.96	6.11	3.63	5
Czech Republic		37.71	25.23	13.58	13
Finland		39.29	40.43	21.89	19
France	4.88	8.05	7.23	2.50	4
Germany	1.09	7.15	7.14	4.87	8
Greece			24.70	13.92	15
Hungary		14.28	17.99	8.01	11
Ireland		0.03	8.13	16.23	16
Italy	2.57	7.34	10.66	3.80	6
Japan	30.69	16.17	10.25	18.63	18
Netherlands	0.06	0.07	0.78	0.00	1
Poland		16.23	11.83	4.53	7
Portugal			33.81	17.09	17
Slovak Republic		29.66	39.46	21.91	20
Spain	15.40	17.59	17.42	5.69	9
Sweden	18.25	13.42	14.05	13.64	14
Switzerland	3.93	6.26	8.19	7.50	10
United Kingdom	0.23	0.01	0.00	0.44	3
United States	0.13	0.08	0.23	0.08	2

Table 7
Country-specific diversification index (*CDI*) for natural gas, adjusted for country size.
Sources: International Energy Agency and Eurostat.

Country	1990	1995	2000	2007	2007 Ranking
Austria	0.05	61.34	44.21	48.08	12
Belgium	39.42	31.40	31.21	29.53	9
Czech Republic		97.96	66.92	65.51	16
Finland		100.89	100.82	100.68	19
France	17.01	26.65	27.21	19.47	4
Germany	11.13	30.01	28.27	33.38	10
Greece			60.77	63.96	15
Hungary		37.41	45.82	37.35	11
Ireland		0.13	52.43	84.20	17
Italy	8.68	19.66	29.27	20.49	5
Japan	51.39	22.13	13.67	24.63	8
Netherlands	0.52	0.60	6.14	0.00	1
Poland		42.49	30.04	21.24	6
Portugal			77.26	54.10	14
Slovak Republic		76.74	98.97	101.00	20
Spain	35.63	41.35	42.68	23.93	7
Sweden	100.32	100.24	100.19	100.17	18
Switzerland	30.28	38.53	51.12	48.60	13
United Kingdom	2.19	0.07	0.01	5.79	3
United States	0.25	0.15	0.35	0.13	2

(Japan drops from 15 to 20; Korea from 15 to 19; New Zealand from 7 to 14). On the other hand, the distance measure reduces the measured vulnerability of the UK from 13 (unadjusted) to 5, reflecting Britain's imports from Norway.

Tables 5–8 present the CDI indices for natural gas. Since these tables are organized similarly to the ones just presented for oil, our discussion can be brief. As discussed above, there are six fewer countries in these tables than in the oil tables. The main features of these tables are as follows. First, as with oil, the cross-country variation is much more significant than the changes for a particular country over time. Two countries, Sweden and Finland, purchase all of their natural gas from one country (Sweden's supplier is Denmark and Finland's supplier is Russia). Thus, these countries show the highest possible value for the unadjusted CDI (CDI equal to 100). For a few countries, Japan in particular, the time series variation is quite significant as well. The Netherlands moves from being an oil importer in the 1990s and early 2000s to being an oil exporter by 2007, so its CDI value drops to 0 in 2007. Second, comparing Tables 6 and 7, the adjustment for political risk again makes a big difference. Looking at the values for 2007, Japan's ranking slips from 7 (unadjusted) down to 17 when adjusting for political risk. Political risk decreases the measured vulnerability for some European countries. This is evident when looking at the change in rankings for Belgium (8 unadjusted to 4), the Czech Republic (15 unadjusted to 12) and Germany (9 unadjusted to 7). Third, the size variable does not have a major impact on any of the countries. Finally, the distance adjustment raises the vulnerability measure for Japan and a number of European countries such as Austria, Greece and Hungary.

Table 8
Country-specific diversification index (*CDI*) for natural gas, adjusted for distance.
Sources: International Energy Agency and Eurostat.

Country	1990	1995	2000	2007	2007 Ranking
Austria	0.05	119.95	85.76	91.91	14
Belgium	55.41	42.14	38.01	32.17	7
Czech Republic		191.93	126.85	125.11	18
Finland		100.00	100.00	100.00	16
France	14.74	36.54	33.33	20.98	5
Germany	8.22	39.12	38.92	45.25	9
Greece			121.05	127.15	19
Hungary		72.71	89.06	73.04	12
Ireland		0.13	52.00	83.55	13
Italy	7.00	23.51	34.42	25.61	6
Japan	150.05	65.66	40.63	72.94	11
Netherlands	0.44	0.54	5.65	0.00	1
Poland		41.3	29.33	20.77	4
Portugal			78.10	96.17	15
Slovak Republic		150.99	195.21	200.14	20
Spain	38.00	45.51	45.07	33.38	8
Sweden	100.00	100.00	100.00	100.00	16
Switzerland	30.01	39.73	50.82	48.37	10
United Kingdom	1.69	0.05	0.01	4.99	3
United States	0.18	0.18	0.34	0.18	2

3.4. Combining the oil and gas diversification indices

We characterize the present vulnerability for 19 countries based on the extent of their diversification in the sources of oil and natural gas, adjusting for political risk, size and distance, in Table 9. Since Australia, Canada, Denmark and New Zealand are net exporters of natural gas, they are not included in Table 9. The two countries with missing data, Korea and Turkey, are also not included in Table 9. Additionally, since the Netherlands was a natural gas exporter in the last year of the sample, we do not include it in Table 9.

In order to take all three adjustments into account, we rank countries based on their average ranks for the three adjustments to obtain an oil ranking between 1 and 26 and natural gas ranking from 1 to 19.[10] We then characterize the top 8 ranked countries for oil as "low vulnerability"; the bottom 8 ranked countries (rankings 19–26) as "high vulnerability"; and the other countries (ranked 9–18) as "medium vulnerability", sorted by rows in Table 9. Since there are 19 countries with natural gas data, we characterize those countries ranked between 1 and 6 to "low vulnerability"; ranked 7–13 to be "medium vulnerability"; and ranked 14–19 as "high vulnerability" with respect to natural gas, sorted by columns in Table 9.

[10] We also used the median of the three rankings to construct our overall ranking with similar results. The biggest impact of using the median rather than the average was for the UK, whose oil ranking rose much higher using the median of the three rankings since the adjustments for political risk and distance move the UK's ranking much higher.

Table 9
Energy diversification based on all CDI adjustments, 2007–2008.
Sources: International Energy Agency and Eurostat.

	Natural gas				
	Vulnerability	1–6 Low	7–13 Medium	14–19 High	Ranking
Crude oil	Low	France, US, UK	Spain, Portugal		1–8
	Medium	Italy	Austria, Germany, Japan, Ireland	Sweden	9–18
	High	Belgium, Poland	Switzerland, Hungary	Czech Republic, Finland, Greece, Slovak Republic	19–26

Three countries, France, the US and the UK, appear to have a low vulnerability in terms of diversification for both fuels. At the other end of the spectrum the Czech Republic, Finland, Greece and the Slovak Republic are highly vulnerable to supply shocks since they are not well diversified for either fuel. Only two countries are found to have low vulnerability for one fuel and high vulnerability for another fuel. Those countries are Poland and Belgium, both of which show measures of high vulnerability for oil and low vulnerability for natural gas. Sweden's sole sourcing of natural gas from Denmark classifies it as highly vulnerable in terms of natural gas while its diversity in oil suppliers classifies it as medium vulnerability in terms of oil. Four countries, Austria Germany, Japan and Ireland, are classified as medium vulnerability in terms of both fuels. Two countries, Switzerland and Hungary have medium vulnerability in terms of natural gas and high vulnerability in terms of oil. Finally, Italy is classified as medium vulnerability for oil and low vulnerability for natural gas.

4. Conclusions

This paper has presented evidence on the measurement and attainment of energy security in OECD economies, with a focus on two major energy sources—oil and natural gas. Following the literature, we take diversification in sources of supply to be an important aspect of this security. Our main results are as follows:

- While there is great heterogeneity at the individual country level, diversification in sources of oil supplies has not increased for most countries since 1990 (Table 1), in contrast to the increase in diversification of natural gas supplies (Table 5).
- This increase in diversification among natural gas suppliers, combined with the increased importance of natural gas in world energy use, suggests an increase in overall energy security.
- An adjustment for the political risk associated with each supplier shows that countries' diversification has indeed increased over time (Tables 2 and 6), consistent with the popular perception. The large impact of this adjustment points to the importance of using alternate measures of risk; it would also be important to look at whether an energy exporter's political risk rating is informative about the risk that it will be the source of an energy supply disruption.
- An adjustment for the country size of the importing country (following Blyth and Lefevre) lowered measured energy security for the United States but did not impact other countries very much (Tables 3 and 7). An adjustment for the distance between energy-consuming and energy-producing countries, intended as a proxy for transportation risk, lowered energy security for countries in the Asia and Pacific regions (Tables 4 and 8).
- An overall table combining the diversification indices for oil and natural gas shows low vulnerability for France, the US and the UK (Table 9), suggesting greater energy security compared with smaller European countries such as the Czech Republic, Finland, Greece and the Slovak Republic. However, an overall index which includes coal and is weighted by energy consumption shares may yield lower measures of vulnerability for countries that are less dependent on oil, such as Poland.

Many authors, such as LaCasse and Plourde, have provided a broader discussion of the importance of the diversification of energy supplies relative to other factors in the attainment of energy security. The most prominent of these other factors are demand-side developments, either through increasing efficiency of energy use or conservation policies. LaCasse and Plourde argue that reductions in the extent to which oil is used an input might be as important to energy security as changes in the composition of energy demand (i.e. away from imports towards domestic energy sources) or the security of physical supplies of energy. However, for energy-producing countries, security of demand is an integral part of energy security. Uncertainty about future oil demand such as that created when oil-consuming countries set energy independence as their goal makes producers unwilling to invest in production capacity increases to meet potential future rises in demand (see Press Trust of India, 2010). Competing goals of energy security for producers and consumers may end up having the opposite effect of what is intended by exacerbating a mismatch between supply and demand.

LaCasse and Plourde also argue convincingly that energy security depends on the likelihood of energy price shocks or energy supply disruptions and on the macroeconomic impacts of these shocks. The macroeconomic impact depends partly on factors such as energy efficiency but can also depend on factors such as the central bank response to energy shocks and on labor market rigidities which can govern the response of the economy to shocks (energy shocks as well as others). This requires stepping outside the narrow framework of the computation of diversification indices and looking more broadly at (1) the likelihood of energy price shocks; (2) the evolving macroeconomic response to energy shocks; and (3) trends in energy efficiency. We plan to do this in future work.

References

Blyth, W., Lefevre, N., 2004. Energy Security and Climate Change: An Assessment Framework. OECD/International Energy Agency Information Paper. Paris, France.
Bryce, R., 2008. The Dangerous Delusions of "Energy Independence". Public Affairs. New York, NY.
Cohen, G., Joutz, F., Loungani, P., 2011. Measuring Energy Security: Trends in the Diversification of Oil and Natural Gas Supplies. IMF Working Paper No. 11/39. Washington, DC.
European Commission, 2000. Towards a European Strategy for the Security of Energy Supply. Green Paper, COM769. Brussels, Belgium.
European Commission, 2006. A European Strategy for Sustainable, Competitive and Secure Energy. Green Paper, COM105. Brussels, Belgium.
Gupta, E., 2008. Oil vulnerability index of oil-importing countries. Energy Policy 36 (3), 1195–1211.
Hakes, J., 2008. A Declaration of Energy Independence: How Freedom from Foreign Oil Can Improve National Security, Our Economy, and the Environment. John Wiley & Sons, Inc., Hoboken, NJ.

LaCasse, C., Plourde, A., 1995. On the renewal of concern for the security of oil supply. Energy Journal 16 (2), 1–23.
Le Coq, C., Paltseva, E., 2008. Common Energy Policy in the EU: The Moral Hazard of the Security of External Supply. SIEPS Report 2008:1. Stockholm, Sweden.
Le Coq, C., Paltseva, E., 2009. Measuring the security of external energy supply in the European Union. Energy Policy 37 (11), 4474–4481.
Lefevre, N. et al., 2009. Analysis of Impacts of Climate Change Policies on Energy Security: Final Report. Ecofys International BV. Utrech, The Netherlands.
Loschel, A., Moslener, U., Rubbelke, D., 2010a. Energy security—concepts and indicators. Energy Policy 38 (4), 1607–1608.
Loschel, A., Moslener, U., Rubbelke, D., 2010b. Indicators of energy security in industrialized countries. Energy Policy 38 (4), 1665–1671.
Loungani, P., 2009. The elusive quest for energy independence. International Finance 12 (2), 291–299.
Neumann, A., 2004. Security of Supply in Liberalised European Gas Markets. Diploma Thesis, European University Viadrina. Viadrina, Germany.
Neumann, A., 2007. How to measure security of supply? Mimeo, Dresden University of Technology. Dresden, Germany.
Organisation for Economic Co-operation and Development (OECD), 2004. Economic Outlook No. 76. Paris, France.
Press Trust of India, 2010. Uncertainty, Volatility Still a Threat to Oil Market, Kuwait City. OPEC 〈http://profit.ndtv.com/news/show/uncertainty-volatility-still-a-threat-to-oil-market-opec-36438〉.
PRS (Political Risk Services) Group, 〈http://www.prsgroup.com/〉.
Rosendahl, K.E., Sagen, E.L., 2009. The global natural gas market: will transport cost reductions lead to lower prices? Energy Journal 30 (2), 17–39.
Sandalow, D., 2008. Freedom from Oil: How the Next President Can End the United States' Oil Addiction. The McGraw-Hill Companies, New York, NY.
U.S. Energy Information Administration, 2011a. Annual Energy Outlook 2011 with Projections to 2035, DOE/EIA-0383(2011), Washington, DC.
U.S. Energy Information Administration, 2011b. World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States. DOE/EIA Report, Washington, DC.
Van der Linde, C. et al., 2004. Study on Energy Supply Security and Geopolitics. CIEP Report, Clingendael International Energy Programme. The Hague.
Yergin, D., 2009. The Long Aftershock: Oil and Energy Security after the Price Collapse. Testimony to the Joint Economic Committee (JEC) of the U.S. Congress on May 20, 2009. Washington, DC.