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Welcome

The Economic Society of Australia warmly welcomes you to the Gold Coast, Queensland, Australia for the 37th Australian Conference of Economists.

The Society was formed 83 years ago in 1925. At the time, the Society was opposed to declarations of policy and instead focused on open discussions and encouraging economic debate. Nothing has changed today, with the Society and the conference being at the forefront of encouraging debate.

This year we have a large number of papers dealing with Infrastructure, Central Banking and Trade.

Matters of the greatest global importance invariably boil down to be economic problems. Recent times have seen an explosion of infrastructure spending, after world-wide population growth has seen demand outpace aging supply. The world has become more globalised than at any time since World War I but the benefits of this (and the impact on our climate) has been questioned by some.

At the time of preparing for this conference we could not have known that it would have been held during the largest credit crisis since the Great Depression. The general public and politicians both look to central banks for the answers.

We are also very pleased to see a wide selection of papers ranging from applied economics to welfare economics. An A – Z of economics (well, almost).

Another feature of this conference is that we have gone out of our way to bring together economists from all walks of life, in particular from academia, government and the private sector. We are grateful to all of our sponsors, who are as diverse as the speakers.

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Vulnerability of Natural Gas Supply in the Asian Gas Market

Helen Cabalu and Chassty Manuhutu[**]

Abstract

Gas supply interruptions, increasing gas prices, transportation and distribution bottlenecks, and a growing reliance on imports over longer distances have renewed interest on gas vulnerability in Asia. Japan, Korea and Taiwan are heavily reliant on LNG imports for their gas supplies from Malaysia, Brunei, Indonesia, Australia and the Middle East. Countries like Malaysia, Thailand and Singapore import gas via trans-border pipelines. This paper examines the relative vulnerability of eight gas-importing countries in Asia for the year 2006 using four market risk indicators and two supply risk indicators. Using principal component analysis, a composite index of gas vulnerability is estimated by combining the individual indicators. The analysis demonstrates inter-country differences with respect to individual and overall indicators of gas vulnerability and two individual indicators were more significant than the others in influencing the overall gas vulnerability results.

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1. INTRODUCTION

Natural gas has become an increasingly valuable resource. Its consumption is expected to increase into the future because of its low environmental impact, ease of use and an increase in the number of natural gas-fired power plants. It is one of the fuels that drive the economy. The demand for it, as a replacement for more expensive, less environmentally-friendly and less efficient resources, has significantly increased. The world is dependent on natural gas for power generation. In 2006, it fulfilled more than 23 per cent of the total global primary energy demand (BP, 2007). OECD countries accounted for 52 per cent of gas use, transition economies, especially Russia, used about 23 per cent with developing countries accounting for the rest. Natural gas is forecast to be the fastest growing energy source by 2025, with global consumption rising by almost 70 per cent from 92 trillion cubic feet to 156 trillion cubic feet. The emerging markets of Asia will be the centre of this growth where gas consumption is projected to triple by 2025 (EIA, 2005).

Natural gas is also becoming an increasingly global commodity. In the past, gas has tended to be used in the region where it is produced because of the relatively high transport costs. However, technical developments have led to a drastic reduction in gas liquefaction and transport costs making liquefied natural gas (LNG) competitive with traditional pipeline gas. The rapid growth in LNG use and its greater flexibility is already beginning to create a global market for gas. In 2006, approximately 26 per cent of the global natural gas supply was internationally traded with LNG shipments showing strong

growth, well above the ten-year average and making up more than 28 per cent of total export volume (IEA, 2007a). The remaining share of gas sold on the world energy market is distributed via gas pipelines. The imbalances between supply and demand drive international trade in natural gas. On the one hand are northeast Asian countries (i.e. Japan, Korea, Taiwan and China), which holds less than 2 per cent of world's reserves but account for almost 7 per cent of the demand. On the other hand, the Middle East (particularly Iran and Qatar) and Russia have two-thirds of the world's reserves and account for around 25 per cent of the demand in 2006 (BP, 2007).

The international gas trade has three major markets: North America, Europe and Asia-Pacific. Selling and distribution conditions vary greatly from one market to the other. North America has been largely self-sufficient, with Canada being an important exporter of natural gas to the United States. The United States imported 19 per cent of its gas requirements in 2006, mainly from Canada via gas pipelines. North American gas reserves are rapidly declining, and as a result, the United States has increasingly imported LNG from the Arab-Persian Gulf and Africa. American domestic production is supplied by 6,800 producers, including 21 major suppliers. It is a very fragmented and competitive market where gas is negotiated through spot contracts and medium-term contracts of 1 or 2 years which are index-linked to spot prices. The European gas market relied for almost 40 per cent of its gas requirements on imports from Russia, Algeria and Norway through pipeline and LNG in 2006. Imported gas exchanges are based on long term contracts of 20 to 25 years and indexation clauses where the gas price is directly linked to the price of crude oil, including relatively strict clauses such as take-or-pay clauses which require

importers to pay for the gas even if their deliveries are interrupted. In the Asia-Pacific, gas market requirements are met through imports of LNG from Malaysia, Brunei, Indonesia, Australia and the Middle East. Japan and Korea are almost entirely dependent on LNG imports for their gas supplies. Gas prices are linked to oil in Japan and Korea, but with a formula that differs from that of European gas users. In Australia and New Zealand, prices are set by gas-on-gas or gas-on-coal competition (IAEE, 2007; IEA, 2007a; BP 2007).

Gas supply interruptions, increasing gas prices, transportation and distribution bottlenecks, and a growing reliance on imports over longer distances have rekindled a debate on gas vulnerability. Gas-importing countries have started to examine available responses to short- and medium-term disruptions. A number of studies (Gupta, 2008; APERC, 2007; UNDP, 2007) have examined the relative oil vulnerability of oil-importing countries on the basis of various factors but none on gas vulnerability of gas-importing countries in Asia.

The objective of this paper is to quantify and assess the relative gas vulnerability of eight gas-importing countries in Asia for the year 2006 on the basis of four market risk indicators — (1) ratio of value of gas imports to gross domestic product (GDP), (2) gas consumption per unit of GDP, (3) gas consumption per capita and (4) gas share in total primary energy demand; and two supply risk indicators — (1) ratio of domestic gas production to gas consumption, and (2) exposure to political risk as measured by diversification of supply sources and political stability risk in gas–supplying countries.

The eight net gas-importing countries included in this study are Japan, Korea, Taiwan, China, India, Singapore, Malaysia and Thailand, which together account for more than 60 per cent of the total gas consumption in the Asia–Pacific in 2006 (BP, 2007).

The composite gas vulnerability index (GVI) is computed using a multivariate technique of principal component analysis (PCA). The various indicators of gas vulnerability are interrelated and that the GVI derived using PCA provides a composite quantitative measure of gas vulnerability by taking into account the interactions and interdependence between the identified set of indicators. The GVI captures the sensitivity of the Asian economies to developments in the international gas market, with a higher index indicating higher vulnerability. Unlike conventional methods of index construction, the PCA does not assign subjective ad hoc weights to the indicators. The weights are the result of multivariate statistical analysis of the proposed indicators (Gupta, 2008; Nagar and Basu, 2002).

The paper proceeds as follows. Section 2 describes the current state of the natural gas market in the eight selected Asian countries. A description of the vulnerability indicators and data sources are provided in Section 3. Section 4 derives the GVI using the principal component technique. Thereafter, Section 5 presents our results on vulnerability based on the PCA and the final section concludes.

2. THE NATURAL GAS MARKETS IN SELECTED ASIAN COUNTRIES

Japan, Korea and Taiwan use natural gas primarily for power generation purposes. They have been pioneers in the use of gas to fuel large power plants. None of these economies has significant domestic natural gas reserves, and gas is imported in the form of LNG (APEC, 2006).

Japan's demand for natural gas has been increasing rapidly at an average annual growth rate of 4.8 per cent between 1980 and 2006. In 2006, Japan imported 96 per cent of its gas requirements and domestic demand was met almost entirely by LNG. LNG imports into Japan comprised 39 per cent of total world LNG trade, which mostly come from Indonesia, Malaysia, Brunei Darussalam and Australia. Natural gas is mainly used for electricity generation, reticulated city gas and industrial fuels. Since Japan has placed priority on the stable and secure supply of LNG, Japanese LNG buyers have been in general paying a higher price than buyers in Europe or the United States under the long-term take or pay contracts with rigid terms on volume and price. Japan lacks a national pipeline network which could interconnect its consuming areas. The possibility of a significant disruption at one LNG terminal in Japan poses a potential supply vulnerability issue.

To reduce the economy's dependence on imported oil, Korea introduced LNG in the 1980s to power its natural gas-based city gas to the residential sector. Since then, natural gas use has grown rapidly. Korea relies on imported LNG for most of its natural gas,

though it began producing a small quantity of natural gas from one offshore field in 2004. Korea is the second largest importer of LNG worldwide accounting for 16 per cent of total imports in 2006. The bulk of Korea's LNG imports come from Qatar, Indonesia, Malaysia, and Oman, with smaller volumes coming from Egypt, Brunei Darussalam and Australia, and occasional spot cargoes from elsewhere. Korean natural gas demand is shared almost evenly between the electricity sector and the residential heating sector, with a smaller amount consumed in petrochemical plants. With demand growing at an average annual growth rate of 35 per cent between 2003 and 2006, Korea continues to sign contracts for additional supplies, though most of the new LNG term contracts in the past few years have included more flexibility for the purchaser in terms of the ability to lower volumes if necessary. To ensure stable supply for gas, Korea is also increasing LNG storage capacity at its existing terminals (EIA, 2007a).

Taiwan has very limited domestic energy resources and relies on imports for most of its energy requirements. There is no coal and oil reserves and natural gas resources are limited at around 7.7 billion cubic metres. In 2006, Taiwan had to import around 98 per cent of its energy requirements. Domestic demand for natural gas was met almost entirely by LNG imports, which mostly come from Indonesia and Malaysia. Taiwan also receives small amounts of LNG imports from Nigeria, Oman, Egypt and Australia. To facilitate supply and expand the use of natural gas, Taiwan has completed transmission and distribution network along the country's west coast, which includes main trunk pipeline and regional distribution stations. To diversify its LNG supply, Taiwan has signed a 25-

year LNG purchase agreement with RasGas of Qatar and has been constructing a new LNG import terminal in Taichung to expand import capacity (IEA, 2007a; EIA, 2007b).

China is rich in energy resources, particularly coal. For power generation and industrial development purposes, coal and oil resources have been utilised more extensively than natural gas. Natural gas is primarily used as a feed stock for chemical fertiliser and to operate oil and gas fields. China's major gas fields are located in the western part of the country, making transport to eastern demand centres difficult. Gas use in China is still small but is expected to double by 2030 (Komiyama, Zhidong and Ito, 2005; APERC, 2008). This growth will be driven mainly by the increased use of gas for power generation and increased residential consumption in urban areas. While some of the rising demand will be fulfilled through increases in domestic production, a large portion will come from pipeline and LNG imports. China received its first-ever LNG cargo in mid-2006 under a long-term contract with Australia. Its second terminal in Fujian is due to start receiving cargoes from Indonesia in 2008. Another regasification terminal in the Shanghai area will import LNG from Malaysia by 2009. In the northern inland areas of China, natural gas supply is likely to come from Siberia, Turkmenistan, Sakhalin and Sakha.

In India, natural gas represents less than 9 per cent of total primary energy demand. Like China, India rely more on coal for power generation. However, India's current consumption of natural gas has risen faster than any other fuel. The power and fertiliser industries are the key demand drivers for natural gas. Despite major new natural gas discoveries in recent years, India's domestic natural gas supply is not likely to keep pace

with demand, and the country will have to import either via pipeline or as LNG. The bulk of India's natural gas production comes from the western offshore regions, especially the Mumbai High basin. The onshore fields in Assam, Andhra Pradesh, and Gujarat states are also major producers of natural gas. In 2006, around 20 per cent of supply came from imported LNG. Currently, there are two regasification terminals located on the Western coast of India, Dahej and Hazira. The Dahej terminal is being supplied from Qatar under a long term contract, supplemented by spot cargoes from other sources. A possible source of supply for Hazira terminal is Australia's Gorgon LNG project. By 2010, India intends to have two more import terminals, Dabhol — Ratnagiri and Kochi. A contractual agreement on the pricing formula for gas has been signed and plans to import gas through the Iran-Pakistan-India pipeline have progressed. Other possible sources of imported gas are Bangladesh and Burma. The natural gas reserves of Bangladesh could be linked into the Indian gas grid while new natural gas find in Burma could be supplied via pipeline running across Bangladeshi territory to West Bengal in India provided agreement could be reached among parties concerned (EIA, 2008).

In 2006, natural gas accounted for almost 12 per cent of Singapore's total primary energy demand. Singapore relies entirely on imports to meet its natural gas requirements which are mainly used for power generation and petrochemical production. Around three quarters of Singapore's fuel demand for electricity production come from natural gas. With gas representing such a large share of electricity production, diversification of supply is an important issue. Currently, all of Singapore's piped natural gas imports come from Malaysia and Indonesia. However, the Energy Market Authority of Singapore is

currently studying the viability of building an LNG import terminal, thereby freeing itself from dependence on neighbouring states for its natural gas supply. An agreement was also signed to supply LNG to the import terminal on Singapore's Jurong Island by 2012.

Malaysia is well endowed with conventional energy resources such as oil, gas and coal, along with renewables such as hydro, biomass and solar energy. Natural gas production has been rising steadily, with the Malaysia – Thailand Joint Development Area (JDA) being the most recent, although relatively small area for gas exploration and development. Malaysia also has the world's largest liquefaction centre in a single location, Bintulu LNG. Malaysia is Southeast Asia's second largest exporter of LNG, after Indonesia. Its major markets for its LNG exports are Japan, Korea and Taiwan while a small percentage of gas is exported to Singapore by pipeline. Domestically, gas is used as fuel for electricity generation as well as feedstock in the petrochemicals industry. In 2006, natural gas accounted for more than 54 per cent of Malaysia's total primary energy demand. Surprisingly, Malaysia is also an importer of gas from Indonesia. In 2007, gas imports represent 23 per cent of total gas supplies through the Peninsular Gas Utilisation (PGU) pipeline network (APERC, 2008).

Thailand is endowed with reserves of natural gas, about 94 per cent of which is found in the Gulf of Thailand. Supply sources of natural gas are both from domestic fields and piped imports from Myanmar, though LNG remains a long-term option for Thailand. Imports of LNG have been confirmed with the planned construction of a receiving terminal on the east coast of the country by 2011, with supply coming from Iran.

Additional supply of natural gas is also expected from the Malaysia – Thailand Joint Development Area (JDA) (EIA, 2007c).

3. Gas vulnerability and its indicators

The oil shocks in the 1970s demonstrated how vulnerable the world's economy was to supply interruptions and price volatility. Any energy infrastructure, oil, coal or natural gas, is often vulnerable to disruption by insufficient supply, accident or malice. Terrorism, technical mishap, or natural disasters that damage the energy system could be nearly as devastating as a sizeable war. Inadequate financial resources also increase vulnerability by limiting supply, transmission, and reliability. Today, vulnerability has both economic and environmental components. Economically, expensive energy imports adversely affect the macroeconomic balance of payments, contribute inflationary pressures, and displace other consumption and investment because short-term demand is inelastic. Environmentally, most fossil fuels impose regional air pollution burdens and costs related to climate change and global warming (Andrews, 2005).

To date, the literature on energy vulnerability has concentrated on oil vulnerability of oil-consuming countries (Gupta, 2008; APERC, 2008; UNDP, 2007). Following the literature on oil vulnerability, this paper highlights two major risks that contribute to the overall gas vulnerability of an economy—market (or economic risk) and supply risk. Market risk of an economy refers to the risk of macroeconomic effects due to shortage of gas supply and price changes in gas markets while supply risk refers to risks of physical disruptions in gas supplies.

Exposure to market risks such as increase in inflation and unemployment and adverse effects on balance of payments of higher gas prices make economies vulnerable. However, the degree of impact depends on the share in national income of the cost of gas, degree of dependence on imported gas, gas consumption per unit of gross domestic product (GDP), share of gas in energy supply and strategic gas reserves. High import bills relative to GDP or high gas intensity of GDP result in larger macroeconomic adjustments costs and hence larger economic effect. In addition, the higher the share of gas in total energy supply the more vulnerable an economy is to international gas developments. However, the larger gas reserves or domestic production capabilities a country has, the lesser are the likely macroeconomic impacts.

Exposure to supply risks such as insufficient supply due to dwindling domestic reserves and production or supply disruption due to geopolitical insecurities contributes to vulnerability. A number of indicators have been used in the literature to measure supply risk. These include factors such as level of domestic reserves relative to consumption, domestic production relative to gas consumption, level of imports, diversification of supply sources, political risk in the supplying countries, and market liquidity. The higher is the ratio of domestic reserves relative to consumption or domestic production relative to consumption, the lower is vulnerability. The same is true for lower level of imports means lower level of exposure to disruption. These also indicate that dependence on domestically-sourced gas supply is preferred over imported gas, as it avoids geopolitical

uncertainties. Diversification of supply sources, particularly politically stable supply sources also reduces the risk and vulnerability to disruption.

For the principal component analysis, we have selected four market risk indicators and two supply risk indicators for the eight Asian gas-importing economies of Japan, Korea, Taiwan, China, India, Singapore, Malaysia and Thailand for 2006.

The selected market risk indicators are:

- VGI/GDP (cost of imported gas in national income): This is measured as the ratio of value of gas imports to GDP. Its unit is in percentage.

- GI (gas intensity): This is measured as the ratio of gas consumed in an economy to its GDP and expressed as cubic meter per unit of GDP or m^3/GDP.

- GC (gas consumption per capita): This is measured as the ratio of gas consumed in an economy to population and expressed as cubic meter per capita.

- GS (gas share): It is expressed as the ratio of gas consumption to total primary energy consumption. Its unit is in percentage.

The selected supply risk indicators are:

- DP/DC (domestic production relative to total domestic consumption): This is measured as the ratio of domestic gas production to total domestic gas consumption.[1]

- GR (geopolitical risk): This represents the exposure of an economy to political risk and is measured on the basis of two factors: (1) diversification of gas import sources and (2) political stability in gas-exporting countries. ECN (2004) has suggested a methodology for quantifying such risk using the adjusted Shannon diversity index. The following formula describes such index.

$$S = -\sum_i \left(h_i m_i \ln m_i \right)$$

where:

S = Shannon index of import flows of gas, adjusted for political stability in exporting country i;

h_i = extent of political stability in country i (the exporting country), ranging from 0 (extremely unstable) and 1 (extremely stable); and

m_i = share of gas imports from country i in total gas imports.

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[1] Domestic production is a better indicator of the importer's capacity to cope with short–term supply disruption than domestic reserves as production excludes gas from stranded reserves which cannot be tapped immediately.

Table 1. Volume and price of gas imports for selected Asian countries, 2006

Country	Gas import price ($/MMBtu)	Volume of gas imports (bcm)
Japan	7.18	81.86
Korea	8.75	34.14
Taiwan	9.21	10.20
China	3.20	1.00
India	4.87	7.99
Singapore	10.00	6.61
Malaysia	2.59	2.53
Thailand	3.07	8.98

Source: For Japan and Korea average gas import price in 2006 was from International Energy Agency's Energy Prices & Taxes Quarterly Statistics (2007b); For the rest of the countries, import price was constructed based on available information about long–term contracts.

Table 2. Political risk rating of gas-producing countries (2006)

Country	Political Stability
Algeria	19.2
Australia	76.9
Brunei	92.8
China	33.2
Egypt	20.2
India	22.1
Indonesia	14.9
Japan	85.1
Korea	60.1
Malaysia	58.7
Myanmar	24.0
Nigeria	3.8
Oman	65.4
Qatar	77.9
Singapore	94.7
Taiwan	63.5
Thailand	16.3
Trinidad & Tobago	41.3
United Arab Emirates	65.9
United States	57.7

Source: World Bank, 2007, *Worldwide Governance Indicators* downloaded from http://info.worldbank.org/governance/wgi2007/; Political risk ratings range from 0 for high risk to 100 for low risk.

The data on GDP and population in 2006 were taken from World Economic Outlook Database (IMF, 2007). Data for gas consumption and total primary energy consumption were sourced from BP Statistical Review of World Energy (2007). The value of gas import for an economy is computed by multiplying its gas import with associated price

found in literature and market reviews (Table 1).[2] Data for domestic production, domestic consumption and trade movements were taken from BP Statistical Review of World Energy (2007). In this study, the percentile rank of an exporting country in the World Bank's Worldwide Governance Indicators for political stability in 2006 was used to determine h_i (Table 2).

4. Constructing GVI using PCA

Principal components analysis (PCA) is a multivariate statistical approach that essentially transforms a set of correlated variables into a set of uncorrelated variables, termed components. The uncorrelated components are linear combinations of the original variables. PCA has in practice been used to reduce the dimensionality problems and to transform interdependent coordinates into significant and independent ones. The Nagar–Basu methodology is used to estimate the gas vulnerability index (GVI).

Gas vulnerability is regarded as a variable that can not be observed directly. The GVI is assumed to be linearly related with the selected four market risk indicators, two supply risk indicators and a disturbance term capturing error, represented by Equation (1):

$$GVI_k = \beta_1 X_{1k} + \beta_2 X_{2k} + \beta_3 X_{3k} + \beta_4 X_{4k} + \beta_5 X_{5k} + \beta_6 X_{6k} + \varepsilon \tag{1}$$

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[2] It is important to note that there is no international price for natural gas and most trade is based on long–term contracts. Hence, prices were based on the value of these contracts, where available. For Japan and Korea; average LNG import price in 2006 was from International Energy Agency's Energy Prices & Taxes Quarterly Statistics (2007b).

where GVI_k is the GVI of country k; $X_{1k}...X_{6k}$ is the set of risk indicators corresponding to country k; and ε is the error term. The total variation in the GVI is composed of two orthogonal parts: variation due to selected risk indicators and variation due to error. The four market risk indicators are individually normalised and made positively related with gas vulnerability using Equation (2a). The two supply risk indicators which are negatively related to gas vulnerability are normalised using Equation (2b).

$$ x_{ik} = \frac{X_{ik} - Min(X_i)}{Max(X_i) - Min(X_i)} \qquad \text{for VGI/GDP, GI, GC, GS} \qquad (2a) $$

$$ x_{ik} = \frac{Max(X_i) - X_{ik}}{Max(X_i) - Min(X_i)} \qquad \text{for DP/DC and GR} \qquad (2b) $$

The above adjustment transforms all the selected variables on the 0–1 scale. The value of 0 is assigned to the country with the lowest value of the selected risk indicator and the value 1 is assigned to the country with the highest value of the selected indicator (Table 3).

Table 3. Normalised risk indicators

Country	DP/DC	GR	VGI/GDP	GI	GC	GS
Japan	0.97	0.00	0.27	0.00	0.42	0.23
Korea	1.00	0.20	0.67	0.08	0.45	0.21
Taiwan	0.85	0.65	0.55	0.05	0.33	0.13
China	0.00	1.00	0.00	0.01	0.00	0.00
India	0.19	0.73	0.09	0.10	0.00	0.11
Singapore	1.00	0.80	1.00	0.12	0.98	0.18
Malaysia	0.05	1.00	0.09	1.00	1.00	1.00
Thailand	0.28	1.00	0.27	0.51	0.29	0.57

A 6 X 6 correlation matrix R is calculated from the normalised indicators (Table 4). We then solve for the determinantal equation |R - λI| = 0 for λ. This provides a sixth degree polynomial equation in λ and hence six roots. These roots are the eigenvalues of correlation matrix R. Next, λ is arranged in descending order of magnitude, as $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6$.

Table 4. Correlation matrix R of normalised indicators

Indicators	DP/DC	GR	VGI/GDP	GI	GC	GS
DP/DC	1.000	-0.746	0.828	-0.508	0.300	-0.357
GR	-0.746	1.000	-0.287	0.517	0.041	0.329
VGI/GDP	0.828	-0.287	1.000	-0.297	0.505	-0.241
GI	-0.508	0.517	-0.297	1.000	0.539	0.974
GC	0.300	0.041	0.505	0.539	1.000	0.593
GS	-0.357	0.329	-0.241	0.974	0.593	1.000

Corresponding to each value of λ, the matrix equation $(R - \lambda I)\alpha = 0$ is solved for the 6 x 1 eigenvectors α, subject to the condition that α'α = 1 (normalisation condition). We then compute for the six principal components (PCs) by using the following:

$$P_{1k} = x_k \alpha_1,$$
$$.$$
$$.$$
$$.$$
$$P_{6k} = x_k \alpha_6,$$

(3)

where $x_k = [x_1, x_2,...x_6]$ is a vector of normalised indicator for country k.

The GVI is estimated as the weighted average of 6 principal components, where the weights are the eigenvalues of the correlation matrix R and it is known that

$$\lambda_1 = var (P_1), \lambda_2 = var (P_2),... \lambda_6 = var (P_6)$$

(4)

Thus, the gas vulnerability index is:

$$GVI_k = \frac{\sum\limits_{n=1}^{6} \lambda_n P_{nk}}{\sum\limits_{n=1}^{6} \lambda_n} \qquad (5)$$

In a nutshell, the estimator of the GVI is computed as the weighted sum of the principal components, where weights are equal to variances of successive principal components. Finally, we normalise the GVI value by the following procedure:

$$GVI_k = \frac{GVI_k - Min(GVI)}{Max(GVI) - Min(GVI)} \qquad (6)$$

Where k represents a country included in the study and then re-scaled the index value from 0 to 10 where 0 is the best performing state and 10 worst performing state in the sample of eight gas-importing countries in Asia.

5. Empirical results and discussion

The degree of vulnerability depends on many factors. One way to highlight the relative vulnerability of countries in our sample is to analyse individual indicators. Table 5 ranks countries in increasing order of vulnerability and provides the values of individual indicators for selected Asian countries.

Ratio of value of gas imports to GDP (VGI/GDP). Singapore, Korea and Taiwan are relatively more vulnerable in terms of above average VGI/GDP ratios than the other countries in the sample. Singapore, Korea and Taiwan are highly dependent on imports, with over 80 per cent of their gas requirements being sourced from overseas. Taiwan and Singapore, in particular, have very limited domestic gas resources.

18

Table 5. Ranking of countries based on individual risk indicators (in ascending order of vulnerability)

Market risk indicators				Supply risk indicators	
VGI/GDP (%)	GI (m³/$)	GC (m³/capita)	GS (%)	DP/DC (%)	GR
China (0.004)	Japan (0.019)	India (36)	China (2.95)	China (98)	Japan (1.188)
Malaysia (0.157)	China (0.021)	China (42)	India (8.45)	Malaysia (94)	Korea (0.948)
India (0.159)	Taiwan (0.033)	Thailand (465)	Taiwan (9.46)	India (80)	Taiwan (0.420)
Thailand (0.477)	Korea (0.039)	Taiwan (522)	Singapore (11.90)	Thailand (71)	India (0.316)
Japan (0.481)	India (0.045)	Japan (662)	Korea (13.64)	Taiwan (15)	Singapore (0.242)
Taiwan (0.978)	Singapore (0.050)	Korea (708)	Japan (14.63)	Japan (3)	Thailand (0.0)
Korea (1.201)	Thailand (0.148)	Singapore (1496)	Thailand (31.97)	Korea (0)	China (0.0)
Singapore (1.786)	Malaysia (0.270)	Malaysia (1526)	Malaysia (54.04)	Singapore (0)	Malaysia (0.0)
Average (0.655)	Average (0.078)	Average (682)	Average (18.38)	Average (45)	Average (0.389)

Ratio of gas consumed to GDP or gas intensity (GI). Malaysia and Thailand have relatively above average gas intensities which makes them vulnerable to supply disruptions. Malaysia's use of gas has increased twelve-fold among non-power consumers such as steel mills, small- and medium-scale industries and residential-commercials sectors. Of the total gas consumption, 80 per cent is consumed by the power sector and the rest is used as fuel in the industrial sector and as feedstock for gas separation plants. Thailand has been self sufficient in gas supply for many years. However, since 1998 it has become a net gas importer despite the increasing production from its own fields and the development of the Malaysia-Thailand Joint Development Area. Thailand's use of gas is not entirely for its power sector; it is also being used as a feedstock for gas separation plants, the products of which have resulted in less plastic imports and in export of petrochemical products (APERC, 2000). On the other hand, Japan and China are among the least vulnerable countries in terms of gas intensity as they

19

greatly rely on oil and coal as primary energy sources. Japan is one of the least energy-intensive countries due to the fact that Japanese energy costs are among the highest in the world. This has led the country's heavy industry, formerly a major energy consumer, to streamline its energy use. In addition, Japan has continued to shift away from energy-intensive industries and has developed extensive energy efficiency programs.

Ratio of gas consumed in an economy to population (GC). Malaysia and Singapore appear to be relatively vulnerable to supply disruption on the basis of their above average gas consumption per capita. With a pipeline infrastructure in place, gas can be transported continuously to different consumers with ease which results in high gas consumption per capita. Peninsular Malaysia has a well-developed pipeline transmission system which has facilitated more domestic utilisation of natural gas in the industrial and residential-commercial sectors. Households benefit from the existence of pipelines as direct gas supply from a reticulation system to their homes. A similar situation exists in Singapore where gas demand by residential and commercial sectors is met through reticulation network. Gas is utilised for space cooling, water heating and cooking (APERC, 2000; APEC, 2006).

Ratio of gas consumption to total primary energy consumption (GS). This indicator is closely related to GI and hence yields similar results. Malaysia and Thailand have above average shares of gas in total primary energy consumption which makes them relatively vulnerable. The large increase in the share of natural gas in energy demand is a direct

result of Malaysia's initiatives to cut down its high reliance on oil and oil products for electricity generation. Malaysia has increased its natural gas share of electricity production surpassing oil consumption. It has successfully transformed 60 per cent of its power plants to gas-fired, compared to 98 per cent oil-fired fifteen years ago and domestic consumption is for fuelling combined-cycle power plants. Similarly, Thailand has completely converted its oil-fired electric power plants to natural gas. In 2006, natural gas met almost 32 per cent of Thailand's total primary energy demand, with much of it being used in generating electricity (APERC, 2008).

Ratio of domestic gas production to total domestic gas consumption (DP/DC). Singapore and Korea are the most vulnerable countries in our sample in terms of gas production to gas consumption ratio. Both countries have no domestic production of gas and rely entirely on imports for their natural gas requirements. Korea's imports are in the form of LNG while Singapore imports through the Malaysian Peninsular Gas Utilisation (PGU) pipeline.

Geopolitical risk (GR). Being largely determined by the degree of diversification of gas import sources and the associated political stability of these sources, it is expected that Japan is the least vulnerable country to geopolitical gas risk. Japan is the largest LNG importer in the world, sourcing its gas requirements from major suppliers such as Indonesia, Malaysia, Brunei Darussalam, and Australia but other suppliers include Qatar, UAE, Oman, United States, Trinidad and Tobago, Egypt and Nigeria. It has the most diversified import sources among our sample countries. On the other hand, Malaysia,

China and Thailand are equally the most vulnerable countries to geopolitical gas risk as they source their imports from one country.

The analysis done so far is based on individual gas vulnerability indicators which is important to understand the relative positions of countries. However, it is also important to know how countries rank based on the aggregate GVI. The final values of GVI for our sample gas-importing countries in Asia are shown in Figure 1. Overall, Japan is the most vulnerable country with a gas vulnerability index of 10 while Malaysia is the least vulnerable country with GVI of 0.

Figure 1. Gas vulnerability index of selected gas-importing countries in Asia (2006)
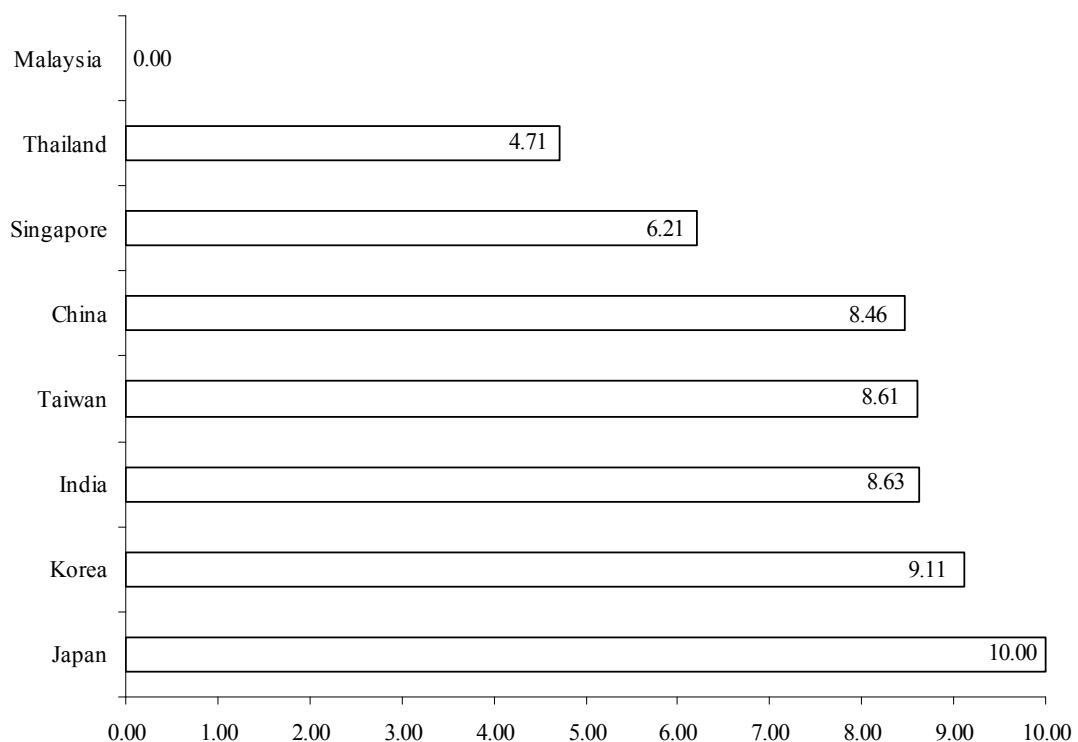
Japan is the most vulnerable among our sample countries whose consumption largely depends on imported gas due to its negligible domestic production and significant gas share in primary energy mix. In 2006, Japan imported more gas than the rest of the sample countries combined, at a relatively high import price. Malaysia is least vulnerable to gas risks as it could rely on domestic production to meet its gas requirements. Despite high geopolitical risk associated with having to import from one source (i.e., Indonesia), its minimal import volume purchased at a low import price exposes Malaysia to less market risk.[3] Thailand is also relatively less vulnerable than the other sample countries but more vulnerable than Malaysia as it has some domestic gas production to meet its consumption, but significantly less than Malaysia's. It also has one cross-border pipeline where supply of gas comes from Myanmar, a country considered to be politically unstable compared to Indonesia, Malaysia's lone source of import.[4] Thailand is also more exposed to market risk than Malaysia because the volume and price of its gas imports are significantly higher as seen in Table 1. The absence of domestic gas production makes Singapore relatively more vulnerable than Malaysia and Thailand. It is also exposed to market risk of having to import gas at a high import price.

China is relatively less vulnerable than its northeast Asian neighbours because of its significant domestic gas production and small share of gas in its energy mix. Taiwan is more vulnerable than China because the volume and price of its gas imports are significantly higher. Taiwan imports ten times more gas than China and pays triple the price for its imports. In addition, the share of gas in primary energy mix in Taiwan is

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[3] Malaysia has the lowest import price (Table 1) and ranks 2nd in VGI/GDP (Table 5).
[4] See Table 2

three times higher than in China. It is evident in the case of Korea that diversifying gas suppliers is not sufficient to prevent vulnerability. Despite Korea's diversified import sources, it is relatively more vulnerable than India because the volume and price of its gas imports are significantly higher. Furthermore, Korean gas consumption per capita is almost twenty fold than that of India.[5]

The analysis highlights inter-country differences with respect to individual and overall indicators of gas vulnerability. The GVI has different sensitivity to various individual indicators and as the principal component analysis confirmed, the ratio of value of gas imports to GDP (VGI/GDP) and ratio of domestic gas production to total domestic gas consumption (DP/DC) turned out to be more significant than the other indicators, in influencing the GVI results. This implies that policy measures which reduce gas vulnerability through diversification of gas supply sources, reduction in overall gas dependence by improving gas efficiency and diversifying energy mix, reduction in gas import demand especially at high import prices, and encouragement of investments in domestic gas exploration and production activities are relatively more important in addressing the problem of gas vulnerability.

6. Conclusion

Many factors determine gas vulnerability of an economy. Domestic production and volume of gas imports are very crucial in determining an economy's vulnerability. Moreover, the import price of gas should also be one of the main considerations in the evaluation of gas vulnerability. If an economy can not rely on its domestic production

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[5] See Table 5

then it should intensify its effort in supply diversification and procurement of affordable imports. As Percebois (2006) and Reymond (2007) summed it, a country which imports the majority of its gas at a sustainable cost and ensures the security of supply by well-diversified and politically-stable sources will not be vulnerable.

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