Korea and the World Economy, Vol. 16, No. 2 (August 2015) 253-267

Determinants of Imports of Petroleum-based Refinery Goods in South Korea: Network Structure and the Heckscher-Ohlin Theory*

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Theoretically, the larger the network a petroleum refinery has, the more conveniently importers are connected to a few exporters. This paper applies network structure to estimate the imports of petroleum-based refinery goods of South Korea using a dataset from 1980 to 2003. Using the H-O model, we found that the network variable is interactive. Although the international trade of petroleum refinery goods by South Korea was not largely explained by the differences in the ratio of countries' resources, the network structure of these goods rendered H-O theory statistically significant. In addition, the network index had the strongest effects on imports. The decreasing network index implies that petroleum products become normal goods that can be produced in many countries.

JEL Classification: F10, F14, Q37
Keywords: network, H-O model, petroleum refinery goods, resources differences, unbalanced panel

* Received February 10, 2015. Revised May 26, 2015. Accepted August 3, 2015. The Authors thank for valuable comments of two anonymous referees. Any remaining errors, however, are our own. This work was supported by the research grant of Chungbuk National University in 2014.
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1. INTRODUCTION

The Heckscher-Ohlin (H-O) model predicts that a country will export goods that require intense production, and import others. Thus trade compensates for the uneven geographical distribution of productive resources. The H-O model is obvious for some goods but not obvious for others as has been reported by Leontief (1953), Bowen *et al*. (1987), and Grubel and Lloyd (1975). In response to these negative findings, Brander, Dixit, Grossman, Helpman, and Krugman focused on economies of scale and strategic interactions to explain why trade occurs. However, several contributions have tried to reconcile the H-O model with data because the model remains a workhorse model. In this paper, we contribute to the literature with an explanation for the poor empirical performance of the H-O model using the hitherto neglected network theory.[1)]

Since network theory, first derived in physical science fields, began to be applied to economics (Baskaran and Brück, 2005; Blöchl, Theis, Vega-Redondo and Fisher, 2010; Schweitzer *et al*., 2009), many economists have attempted to demonstrate its usefulness in economics (Arthur, 1999; Wilhite, 2001; Baskaran *et al*., 2011). Baskaran *et al*. (2011) examined networks in social systems by looking at each good's different trading networks and showed that endowment differences are associated with bilateral trade for dense network connections. They explained that H-O theory can predict bilateral trade better in a more competitive world markets and demonstrated the importance of networks in international trade by explicitly showing that the H-O model is less important in concentrated networks. Thus, we investigated whether the import of petroleum increases with the networks' index.

Rauch (1999) argued that differentiated products are traded in networks but that homogeneous goods are traded on markets. Serrano and Boguna (2003), Garlaschelli and Loffredo (2005), Fagiolo *et al*. (2010), and Kali and

[1)] The H-O model explains trade with different factor endowment ratio. Our empirical specification is to test whether difference in the factor endowment ratio in the industry can explain import behavior in the industry.

Reyes (2007) explicitly considered network structures with more sophisticated topological properties than did Rauch (1999), to perform empirical tests with aggregated trade data. Baskaran *et al*. (2011) estimated the trading system as a scale-free network for 28 product groups and suggested that H-O theory is less important for goods traded in concentrated networks. Feijoo and Das (2014), Geng and Fan (2014), An *et al*. (2014), and Behmiri *et al*. (2012) studied oil trade relationships related to the energy economy. This paper is an extension of country-specific studies that examined imports from petroleum refineries in South Korea.

Because petroleum refineries have a few well-known exporters and an infinite number of importers, we used the H-O model in conjunction with network theory to investigate how the networks work with the H-O model in the field of petroleum refineries. We for the first time in literature examined how the petroleum refineries in Korea are exposed to trade and then tested whether the network structure can explain the situation better than the H-O model. The rest of this paper is organized as follows. Section 2 introduces a brief description of the theoretical network model for empirical analysis. Section 3 shows our empirical results with the network variable and discusses the results. Section 4 presents our conclusions.

2. NETWORK INDEX

Dealing with the network, power-laws have prominence in network theory. The power-law distribution, $p(x) = x^{-\gamma}(\sum_{x=1}^{\infty} x^{-\gamma})^{-1} = x^{-\gamma}(\varsigma(\gamma))^{-1}$, is considered, where p, x and γ denote a power law, the number of the connections per node, and the number of networks, respectively and $(\sum_{x=1}^{\infty} x^{-\gamma})$ is $\varsigma(\gamma)$ of the Riemann Zeta-function. The distribution of trading links is assumed to follow a power-law if a few countries export whereas almost every other country imports.

We assume that petroleum refineries are traded in network structures, which follow the power laws, and countries are considered nodes. Following descriptive evidence for the existence of power-law distributions of Barabási and Albert (1999), Jeong *et al*. (2001), or Newman (2003) and the context of log-log plots of observed frequencies as seen in Barabási and Albert (1999) and Clauset *et al*. (2009), taking the logarithm on both sided of $p(x) = x^{-\gamma}(\varsigma(\gamma)\ )^{-1}$. We find

$$\log p(x) = -\gamma \log x - \log(\varsigma(\gamma)). \tag{1}$$

In addition to different endowment ration identified by the H-O model, the γ variable in equation (1), can be understood as a determinant factor of international trade as seen in Baskaran *et al*. (2011). It is because that if one good is not so differentiated and thus produced by a large number of countries, then the network variable, γ, for this good will be small and conversely, if the other good is produced by a large amount of many countries, then the γ variable will tend to be large.

To estimate the network variable for petroleum refineries, after taking the logarithm of the probability of the likelihood of the data, $L = \prod_{i=1}^{n} x_i^{-\gamma}(\varsigma(\gamma))^{-1}$, we can maximize the following logarithmic function of the likelihood

$$\log L = \sum_{i=1}^{n}[-\gamma \log(x_i) - \log(\varsigma(\gamma))] = -\gamma \sum_{i=1}^{n}[\log(x_i)] - n \log(\varsigma(\gamma)). \tag{2}$$

After differentiating the equation (2) of the log-likelihood function with respect to γ and setting the corresponding derivative to zero, the following equation is derived:

$$\frac{d \log L}{d\gamma} = -\sum_{i=1}^{n}[\log(x_i)] - n \frac{1}{\varsigma(\gamma)} \frac{d\varsigma(\gamma)}{d\gamma} = 0. \tag{3}$$

Rearranging equation (3), the final equation is obtained for simulation:

$$\frac{1}{\varsigma(\gamma)}\frac{d\varsigma(\gamma)}{d\gamma}=\frac{1}{n}\sum_{i=1}^{n}\ln(x_i). \quad (4)$$

x denotes the number of the connections per each country out of 110 countries from 1980 and 2003, γ, called the network indent, is derived from Newton iteration by inserting the number x to equation (4) and is used as independent variable for investigating the effect of the network index. The variable γ is derived by implementing a numerical algorithm such as in the Newton iteration method. The Mathematica program is used for calculating the estimate of γ. Because more countries began to take part in refining petroleum, the values of the network continued to increase from 1.35 in 1980 to 1.37 in 1989 and then declined to 1.31 in 2003. However, the number of countries importing from South Korea continued to increase from 29 countries in 1980 to 107 in 2003.

3. DATA AND EMPIRICAL TEST

The panel trade data for petroleum refineries are taken from the Trade and Production Database of the CEPII.[2)] Data on distance are taken from http://www.mapcrow.info. The data used in this study covers 110 countries and Korea for the period from 1980 to 2003.

To estimate the H-O model with network index, we have a unbalanced panel[3)] including the exports of petroleum refineries from South Korea to country i at time t, the distance, the product of per capita GDP in two countries, the product of GDP of South Korea and GDP of the other country, the absolute value of the difference in the capital-labor ratio, and network

2) http://www.cepii.fr/anglaisgraph/bdd/TradeProd.htm

3) We have unbalanced panel and thus used the unbalanced panel dataset. The unbalanced panel we used was not because of disregarding the 0 trade (import) value but because of no data available. The use of balanced panel would reduce the sample size dramatically by either shorting the period examined or decreasing the number countries examined. Rather, we decided to include all the data available in our analysis.

Table 1 Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
T	50,937.51	147,848.1	0.4790684	1,379,785
D	50.45827	11.52822	9.865596	73.10973
PY	159.158	195.9254	2.02202	1,525.774
Y	2.36e+11	7.64e+11	6.08e+07	1.17e+13
E	44,105.97	30,920.94	24	145,970
γ	1.346057	0.0208217	1.31117	1.37265

Notes: T_{it} is the imports of petroleum refineries from South Korea to country *i* at time *t* (unit: $1,000). *D* is the distance (unit: 1km). *PY* is the product of per capita GDP in two countries (unit: $1,000,000). Y_{it} is the product of GDP of South Korea and GDP of country *i* at time *t* (unit: $1,000,000). *E* is the absolute value of the difference in the capital-labor ratio. γ is the number of networks.

index. Descriptive statistics is provided in table 1.

We also tested significance of the correlation between variables. The results are in table 2. The *T* (imports of petroleum refineries from South Korea to country *i* at time *t*) is negatively correlated with *D* (distance) and γ (the number of networks), while it is positively with *PY* (the product of per capita GDP in two countries) and *Y* (the product of GDP of South Korea and GDP of country *i* at time *t).* The number of networks is negatively correlated with *E* (the absolute value of the difference in the capital-labor ratio), but correlation coefficient is very small (–0.0619).

Two of the most popular classical trade theories are the gravity model and the H-O model. The gravity model predicts that the closer the distance between two countries and the higher the national income, the more they trade. The H-O model says that the bigger the difference between two cross-country capital-labor ratios, the larger the trade volume. The two classical models are extended by incorporating network theory. The network index varies over each year but not between countries. By including the network index as a variable, we can investigate its effects on the imports in the gravity and H-O models. We predict that the network index accelerates the effects of distance, national income, and capital-labor

Table 2 The Correlation Significance Test

	T	D	PY	Y	E	γ
T	1.0000					
D	–0.1861* (0.0000)	1.0000				
PY	0.2180* (0.0000)	–0.1378* (0.0000)	1.0000			
Y	0.2707* (0.0000)	–0.1218* (0.0000)	0.3213* (0.0000)	1.0000		
E	0.0017 (0.9581)	–0.0147 (0.4987)	–0.0785* (0.0003)	–0.3036* (0.0000)	1.0000	
γ	–0.0625* (0.0347)	–0.0023 (0.9069)	–0.0047 (0.8277)	–0.0619* (0.0044)	–0.0671* (0.0020)	1.0000

Notes: * indicates rejection of null of correlation at 5% level. Values in parentheses indicate *p*-values. T_{it} is the imports of petroleum refineries from South Korea to country i at time t (unit: \$1,000). D is the distance (unit: 1km). PY is the product of per capita GDP in two countries (unit: \$1,000,000). Y_{it} is the product of GDP of South Korea and GDP of country i at time t (unit: \$1,000,000). E is the absolute value of the difference in the capital-labor ratio. γ is the number of networks.

ratio on the exports from petroleum refineries in South Korea. That is, when the network index is introduced, imports from South Korea to other countries would increase further with changes in GDP and differences in the capital-labor ratio, and would decrease with distance between South Korea and other countries. It is because of this that the network values of petroleum refineries are larger than those of popular and homogeneous products, and the differentiated goods of petroleum refineries positively confirm the gravity and H-O models. The empirical model that includes both the gravity and the H-O models is:

$$\begin{aligned}\ln T_{it} = {} & \beta_1 \ln(D_i) + \beta_2 \ln(Y_{it}) + \beta_3 \ln(PY_{it}) + \beta_4 \ln(E_{it}) \\ & + \beta_5(\gamma_t) + \beta_6(\gamma_t \times \ln(E_{it})) + \varepsilon_{jt},\end{aligned} \tag{5}$$

where T_{it} is the imports of petroleum refineries from South Korea to country *i* at time *t*, Y_{it} is the product[4)] of GDP of South Korea and GDP of country *i* at time *t*, *PY* is the product of per capita GDP in two countries, *D* is the distance, *E* is the absolute value of the difference in the capital-labor ratio between South Korea and country *i*, γ is the network structure, and ε is the error term.

We estimate two models: the H-O model in a gravity model specification and H-O models with network structures. The Hausman test for the fixed-effect and random effect models shows that we cannot reject the null hypothesis of randomness, which makes the two models follow panel random effects.

Table 3 presents the robustness of H-O theory depending on the inclusion of the network structure. The model including network structure showed greater power in explaining why petroleum refinery products are imported by South Korea: all variables are significantly associated with import volume in that model, whereas only two of the four variables are significantly associated with import volume in the other model. In addition, in the H-O model with network structure, *D* is negatively associated while *E* is positively associated with imports through interactions of the network variable, and the others are positively associated with the import volume. This is consistent with the predictions of the gravity model and the H-O model.

Regarding the gravity model in which trade flows based on the size of the economy (i.e., GDP) and the distance between two countries, the inclusion of the network variable in the gravity model does not change the effect of *D* and *Y* on import volume but it allows for the change in *PY*, significantly and quantitatively.[5)] In the model including the network variable, it can be said that the gravity model with network theory works well for the petroleum-based

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4) The product or multiplication of GDPs functions as a proxy for two countries' economic size in market size. Larger countries are more likely to have large domestic markets and to absorb more imports. The greater the product of the two countries' GDPs, the larger bilateral trade volumes.

5) Kang (2014) showed that the trades of South Korea with many African countries are highly likely to evolve favorably for Korea's exports with Africa's continuous economic growth.

Table 3 Results of the Two Models

Variables	(1)	(2)
D	–1.9460* (1.026)	–1.9561* (1.002)
Y	0.0256*** (0.006)	0.0263*** (0.006)
PY	0.0337 (0.023)	0.0539** (0.025)
E	0.0005 (0.000)	0.0531** (0.024)
γ		20.7558*** (7.785)
$\gamma * E$		–0.0391** (0.018)
Constant	–6.5590 (5.256)	–36.5767*** (12.527)
Number of Countries	93	93
r2_between	0.257	0.263
r2_within	0.097	0.103
Hausman Test		Chi2(4) = 5.57
(H_0: Random)		Prob > chi2 = 0.235

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.10.

refinery goods with all three variables (*D*, *Y*, and *PY*) statistically significant. However, there are quantitative differences among the three variables. While a 1% increase in distance between South Korea and the corresponding country decreases import volume by 1.95%, changes to import volume corresponding to a 1% increase in *Y* and *PY* are trivial at 0.023% and 0.053%, respectively.[6)]

Regarding the H-O model with the network variable, the partial derivative

[6)] Because of the limitation on data and specific characteristics of gravity model, we put robust checks as future research.

of the expected imports with respect to the difference in capital labor ratio is (0.0531–0.039*γ) at a statistically significant level although the values are almost zero. When more countries take part in exports with lower γ, the difference in the endowment ratio increases imports. This is because more countries are able to produce goods themselves. Compared to the model without the network variable, the model with the variable makes *E* statistically significant and its influence increases, but the 1% increase in *E* leads to a less than 0.053% increase. It shows that once the network is introduced, although *E* is meaningful, it does not strongly affect the import volume of petroleum-based refinery goods. Since the average value of γ is 1.35, plugging it into the partial derivative of the expected imports with respect to the difference in capital labor ratio becomes 0.0003, which is similar to the coefficient of *E* in model (1) of table 3. Also, the inclusion of γ*E* (interaction between the number of network and the difference in capital labor ratio) made the *PY* variable significant. It may be because of weak negative correlation between *PY* and *E* variables as in table 2. The effect of the network variable is (20.755–0.039**E*), which are all negative. The effect of the network variable on the import volume is stronger than those of the other variables.

This paper presents two important findings. First, a different endowment ratio on the imports is less effective for the network interaction model than for the other model. This result is less favorable for the H-O model. Because the petroleum refineries produce highly capital-intensive products and most countries are not able to produce them, the difference in the capital-labor ratio is more important. The effect of *E* on imports is different from those on the exports of petroleum-based refinery goods by South Korea. Second, the network value of petroleum refineries decrease over time, implying that petroleum-based refinery goods become more popular and more easily produced over time. Thus, the difference in the endowment ratio becomes less effective on imports.

4. CONCLUSIONS

The H-O model explains trade with different factor endowment ratio but still cannot explain some findings of Leontief (1953), Bowen *et al*. (1987), and Grubel and Lloyd (1975). In this paper, we contribute to the literature with an explanation for the poor empirical performance of the H-O model using the network theory explaining why trade occurs. The panel trade data for petroleum refineries from the Trade and Production Database of the CEPII covers 110 countries and Korea for the period from 1980 to 2003.

This paper finds the consistent with the predictions of the gravity model (trade flows based on the size of the economy and the distance between two countries in gravity model) and the H-O model through interactions of the network variable (the difference of factor endowment ratio between countries is positively associated with trade in H-O model). Because the gravity model and the H-O model work well for the petroleum-based refinery goods including the network variable, we confirm that the model including network structure has greater power in explaining why petroleum refinery products are imported.

In conclusion, we confirmed that gravity theory and H-O theory are both more effective for assessing the imports of South Korea after including network structure. Nevertheless, the effects of difference between the endowment ratio are not strong. Thus, it could be said that the network structures of the petroleum refineries support both the gravity model and the H-O model but the effect of difference of factor endowment ration between two countries is still negligible.

APPENDIX

Table A1 Network Index

Year	Network Index
1980	1.350
1981	1.370
1982	1.362
1983	1.362
1984	1.360
1985	1.369
1986	1.360
1987	1.355
1988	1.371
1989	1.373
1990	1.366
1991	1.347
1992	1.354
1993	1.371
1994	1.349
1995	1.341
1996	1.334
1997	1.318
1998	1.324
1999	1.324
2000	1.320
2001	1.316
2002	1.315
2003	1.311

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