The Effect of Transportation on Global Petroleum Trade Trend

by

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Abstract

The objective of the study was to determine possible relations between international petroleum trade and transportation trends. The trend of global petroleum trade distribution was analyzed and the sensitivity of global petroleum trade with respect to distance was investigated. The study covered the petroleum trade activity among 173 countries over a time period extending from year 1965 to 2005. The examined database consists of 13 time-series variables, grouped in four categories: petroleum commodity trade, geographical, socio-economic and political characteristics. After collecting the pertinent data and creating the database for the study time span, gravity and linear programming models were developed. Preliminary statistical analyses revealed that distance between countries and Gross Domestic Product, GDP, were the major contributing factors impacting petroleum trade. Modeling petroleum spatial distribution and flow was based on cross-sectional analyses. The elasticity of bilateral trade with respect to distance showed increasing time trend for distance coefficients in gravity models. The Linear Programming modeling was applied to facilitate identifying possible relations between trade and transportation distance, optimizing the possible distributions during different years, and comparing the total cost of petroleum transportation for the observed distribution and the optimal one. Comparison of the results for multimodal network revealed that the percentages of possible improvements increased over time and the observed petroleum distributions diverged from the possible optimal solutions. Future petroleum trade strategies and business decision makings are suggested to more directly incorporate distance and transportation aspects by utilizing the study methodology and results.

Keywords: Transportation, Petroleum, Trade Distribution

1. Introduction

Petroleum trade is one of the most strategic worldwide trades. The cost of transportation of petroleum has a significant effect on its net price. To reduce transportation cost, trade partners are expected to make business decisions accordant to selection of nearest demand and supply hubs. Limited research attempts were made to examine the role of transportation impedance in the petroleum trade (Disdier and Head, 2008; Vaziri and Tabatabi, 2009). Indeed the effect of the distance on the trade is ambiguous because there are many different mechanisms that might be at work. By taking a direct approach and carrying out a number of econometrics tests that examine the role of distance, the study reported herein tried to fill the existing gap in the literature.

The objective of the study was to determine possible relations between international petroleum trade and transportation trends. Many factors affect international petroleum trade. In this research four categories of variables were considered as relevant: trade, geographical, socio-economic and political. The study covered the petroleum trade activities among 173 countries over a time period extending from year 1965 to 2005. The relevant information was extracted from centralized databases of international agencies. The examined database consists of 13 time-series variables grouped in the four categories. After preliminary and correlation statistical analyses, the status quo of cross-sectional petroleum distribution was deployed in gravity models. As for elasticity of bilateral trade with respect to distance, the gravity model results suggested an increasing time trend for distance coefficient based on sensitivity analysis concept. The Linear Programming modeling was applied to facilitate identifying possible relations between trade and transportation distance, optimizing the possible distributions during different years, and comparing the total cost of petroleum transportation for the observed distribution and the optimal one. Comparison of the results for multimodal network revealed that the percentages of possible improvements increased over time and the observed petroleum distributions diverged from the possible optimal solutions. Future petroleum trade strategies between Asia-Pacific and Europe are suggested to more directly incorporate distance and transportation aspects by utilizing the study methodology and results.

2. Database Development

The appraisal of global petroleum trade required establishing a conceptual framework for analysis and a corresponding set of pertinent data. The relevant times-series information, covering 173 countries for 9 years during 1965 to 2005, was classified into four categories.

Trade category consisted of bilateral petroleum trades, extracted from the United Nations Commodity Trade Statistics Division's web pages. The complex nature of the basic customs and statistical needs makes it necessary to have a rather detailed commodity classification. There are several commodity classifications widely used including Harmonized System, HS, Standard International Trade Classification, SITC, and Broad Economic Categories, BEC. The SITC covers a broad database worldwide comparing to others and is often the preferred UN commodity classification. Considering missing data for countries and calendar years, commodity code 33 at the 5 digit SITC Rev.3 level over the period 1965-2005 in the 5 year intervals for 173 countries was selected. The selected commodity code represents petroleum and petroleum products. This resulted in 9 time intervals 1965, 1970… to 2005.

Geographic category consisted of the geographic transportation distance and the characteristic of the country whether it is land-lock or not. The geographic distance between trade partners was referred to as the impedance variable. Two petroleum trade networks were developed and compared: an integrated multimodal land and marine network and the conventional air distance network. Petroleum trade is mainly based on global networks consisting of a multimodal land and sea transportation networks. The sea transportation network is the most essential mode in international trade. Thus, in this study, an integrated marine and land transport network was developed. The multimodal network included road distances between origin country capitals and loading ports, marine distance between loading port in origin to unloading port and road distance between unloading port and capital in destination country. The sea network was built on the marine port distances. One port or in some cases, more than one port were chosen as representative node(s) of the specific country in the marine network. For land-lock countries, marine distance to the nearest port was measured and then was added to the road distance from that port to the capital of the land-lock country. Consequently, a multimodal transportation network was developed. The air distance network was the straight distance of trade centers of countries. Alongside of petroleum transportation networks, land-lock variable was defined as a dummy variable taking the value 1 for 43 landlocked countries and 0, otherwise.

Socio-economic category demonstrated characteristics that affect oil trade. The variables consisted of population, area, and Gross Domestic Product. The relevant data were extracted from the United Nation Statistic Division sources.

Political category consisted of dummy variables reflecting affiliations with international organizations. The selected organizations were: Organization of Petroleum Exporting Countries, OPEC, Organization of Arab Petroleum Exporting Countries, OAPEC, Organization of non OPEC countries, NON-OPEC, Organization for Economic Cooperation and Development, OECD, and North Atlantic Treaty Organization, NATO.

For the period of 1965 to 2005, the pertinent data of 13 variables representing the aforesaid 4 categories for 173 countries, were gathered. Totally 9 vectors and 4 matrixes were used for each of the 9 years covering 1965 to 2005. Dimension of vector variables was 173, equal with the number of selected countries. Dimension of matrixes of trades and distances between countries was 173x173. Database preliminary statistical analysis consisted of cross-sectional univariate and correlation analyses. The unvariate analysis determined statistics such as: maximum, minimum, mean, standard deviation and coefficient of variation for each of the 9 years. Correlation analysis between 2 trade variables and other variables showed that GDP and distance had the strongest significant correlations with trade during the 9 years. The distance variables showed negative correlations with trade variables. As an example, the results of preliminary univariate statistical analysis for the year 2000 are summarized in Table 1.

Table 1 Results of univariate statistical analysis for year 2000

No	Description	Symbol	Unit	No. of cases	Min	Max	Mean	St. Dev.	Coef. of var.
1	Population	P	Person	173	46×10^3	12.6×10^8	34.8×10^6	12.6×10^7	3.638
2	Area	A	Km^2	173	25	17.1×10^6	78.2×10^3	20.2×10^5	2.580
3	Landlocked	LL	-	173	0	1	0.179	0.384	2.146
4	Gross Domestic Product	GDP	$/Year	173	49×10^6	97.6×10^{11}	19.5×10^{10}	8.8×10^{11}	4.518
5	Air Distance	DijAir	Km	29929	60.8	19904	7947.3	4448.4	0.560
6	Multimodal Distance	DijMM	Km	29929	258.5	31820	12630.5	5359.7	0.424
7	Oil Import Data	TijIM	$/Year	29929	0	17.3×10^9	20.4×10^6	30.0×10^7	14.686
8	Oil Export Data	TijEX	$/Year	29929	0	17.1×10^9	17.3×10^6	28.9×10^7	16.752
9	OPEC members	OPEC	-	173	0	1	0.0956	0.295	3.085
10	Non-OPEC members	NOPEC	-	173	0	1	0.0608	0.240	3.947
11	OAPEC members	OAPEC	-	173	0	1	0.086	0.2401	2.791
12	OECD members	OECD	-	173	0	1	0.217	0.414	1.907
13	NATO members	NATO	-	173	0	1	0.252	0.431	1.710

3. Petroleum Trade Distribution Modeling

The database consisted of 2 dependent variables of trade category and 11 independent variables of the other three descriptive categories. The trade distribution modeling consisted of three major parts: distribution gravity modeling, distribution linear programming modeling, LP, and time series modeling based on sensitivity analysis and elasticity concept.

The gravity model of international trade was developed more than 50 years ago (Vaziri and Khademi, 2010). The gravity model is presented by Equation 1. The logarithm of this function has a linear form, and can be easily used to calibrate the model.

$$T_{ij} = \alpha \frac{M_i^{\eta} M_j^{\theta}}{D_{ij}^{\rho}} \qquad (1)$$

Where T_{ij} is the trade between the two countries, M_i is a size measure of the country i, such as national income, GDP or population, D_{ij} is the distance between the two countries, others are coefficients to be calibrated. Based on the two transportation networks of air distance and multimodal for the 9 time intervals of import and export trade flows, totally 36 models were developed. As an example, Table 2 shows the results of petroleum export trade modeling, TijEX, by stepwise regression method for selected years based on multimodal and air distance networks.

Table 2 Petroleum Export Distribution Models for Multimodal and Air Distance Networks

Year	Network	R^2	F	Model
1965	Multimodal	0.366	36.26	$10^{5.616}\dfrac{GDP_i^{0.555}P_i^{0.368}10^{0.438\mathrm{OPECi}}}{D_{ij}MM^{0.773}10^{0.479LL_j}10^{1.174LLi}P_j^{0.272}10^{0.112\mathrm{OPECj}}10^{0.120\mathrm{OECDi}}}$
	Air distance	0.264	36.88	$10^{5.119}\dfrac{GDP_i^{0.541}P_i^{0.392}10^{0.365\mathrm{OPECi}}}{D_{ij}Air^{0.680}10^{0.594LL_j}10^{1.244LLi}P_j^{0.278}10^{0.044\mathrm{OPECj}}}$
1970	Multimodal	0.387	50.96	$10^{6.590}\dfrac{GDP_i^{0.293}GDP_j^{0.648}A_i^{0.107}10^{0.567\mathrm{OPECi}}10^{0.054\mathrm{NOPECi}}}{D_{ij}MM^{0.853}10^{1.358LLi}P_i^{0.285}P_j^{0.177}A_j^{0.108}10^{0.237\mathrm{OPECj}}10^{0.159\mathrm{OECDi}}}$
	Air distance	0.325	62.15	$10^{5.924}\dfrac{GDP_i^{0.156}GDP_j^{0.647}10^{0.568\mathrm{OPECi}}}{D_{ij}Air^{0.695}10^{1.419LLi}P_j^{0.191}A_j^{0.111}10^{0.034\mathrm{NATOj}}10^{0.187\mathrm{OPECj}}}$
1980	Multimodal	0.456	104.24	$10^{7.284}\dfrac{GDP_i^{0.408}GDP_j^{0.609}A_i^{0.218}P_j^{0.180}10^{0.954\mathrm{OPECi}}10^{0.221\mathrm{NOPECi}}}{D_{ij}MM^{1.287}10^{1.403LLi}A_j^{0.158}P_i^{0.518}10^{0.124\mathrm{OPECj}}10^{0.254\mathrm{OECDi}}}$
	Air distance	0.351	90.33	$10^{6.734}\dfrac{GDP_i^{0.366}GDP_j^{0.542}A_i^{0.227}P_j^{0.191}10^{0.745\mathrm{OPECi}}10^{0.098\mathrm{NOPECi}}}{D_{ij}Air^{1.113}10^{1.502LLi}10^{0.423LLj}A_j^{0.144}P_i^{0.504}10^{0.843\mathrm{OPECj}}10^{0.057\mathrm{OECDi}}}$
1985	Multimodal	0.521	221.01	$10^{6.286}\dfrac{GDP_j^{0.740}P_i^{0.693}10^{1.234\mathrm{OPECi}}10^{0.169\mathrm{NOPECi}}}{D_{ij}MM^{1.628}10^{0.787LLi}A_j^{0.101}10^{0.154\mathrm{OPECj}}10^{0.308\mathrm{OECDi}}}$
	Air distance	0.402	168.71	$10^{5.452}\dfrac{GDP_j^{0.664}P_i^{0.661}10^{0.876\mathrm{OPECi}}10^{0.112\mathrm{NOPECi}}}{D_{ij}Air^{1.362}10^{0.979LLi}10^{0.422LLj}A_j^{0.084}10^{0.942\mathrm{OPECj}}10^{0.076\mathrm{OECDi}}}$
2000	Multimodal	0.444	226.54	$10^{6.042}\dfrac{GDP_i^{0.283}GDP_j^{0.598}P_i^{0.253}P_j^{0.131}10^{1.456\mathrm{OPECi}}10^{0.326\mathrm{NOPECi}}}{D_{ij}MM^{1.448}10^{0.300LLi}A_j^{0.140}10^{0.257\mathrm{OPECj}}10^{0.410\mathrm{OECDi}}}$
	Air distance	0.342	224.90	$10^{5.413}\dfrac{GDP_i^{0.307}GDP_j^{0.610}P_i^{0.237}10^{1.045\mathrm{OPECi}}10^{0.198\mathrm{NOPECi}}}{D_{ij}Air^{1.317}10^{0.262LL_j}10^{0.489LLi}A_j^{0.077}10^{0.143\mathrm{OPECj}}10^{0.267\mathrm{OECDi}}}$
2005	Multimodal	0.424	232.30	$10^{4.256}\dfrac{GDP_i^{0.406}GDP_j^{0.637}P_i^{0.368}P_j^{0.173}10^{1.136\mathrm{OPECi}}10^{0.286\mathrm{NOPECi}}}{D_{ij}MM^{1.390}A_j^{0.151}10^{0.181LL_i}10^{0.33\mathrm{NATOj}}10^{0.38\mathrm{OPECj}}10^{0.328\mathrm{OECDi}}}$
	Air distance	0.375	305.76	$10^{4.726}\dfrac{GDP_i^{0.464}GDP_j^{0.619}A_i^{0.078}P_i^{0.299}10^{1.205\mathrm{OPECi}}10^{0.156\mathrm{NOPECi}}}{D_{ij}Air^{1.698}10^{0.411LL_i}10^{0.403LL_j}10^{0.24\mathrm{NATOj}}10^{0.54\mathrm{OPECj}}10^{0.286\mathrm{OECDi}}}$

In general, the 36 models fitted the data fairly well with significant t and F statistics. Table 2 shows that some of independent variables such as GDP and distance were dominant variables in petroleum modeling. This reveals that on one hand, GDP as a measure of economic size increased petroleum consumption and trade, and on the other hand, distance and transportation costs reduced trade. The $D_{ij}MM$ and $D_{ij}Air$ appeared in the denominators. Based on t statistics and 95% confidence level, all of the descriptive variables using multimodal distance network were significant while $D_{ij}Air$ was marginally significant. The fact that the R^2 for multimodal network models were higher than air distance network models, suggested that multimodal network was more appropriate to describe petroleum trade modeling and the outcomes were closer to observed values comparing to air distance network used in most previous studies. Other social-economic and political variables also were entered in models reflecting their role in global petroleum trade. Table 2 shows that there was a strong reverse relation between LL land-lock variable, as a dummy one, and petroleum trade. This outcome revealed that access to open sea facilitated international trade, especially petroleum trade. Some political dummy variables, such as OPEC and OECD, were also entered the models.

4. Trend Analysis

The trade sensitivity with respect to distance was determined during 1965 to 2005. The elasticity, which is the ratio of the percent change in one variable to the percent change in another variable, was used for trade and distance relation appraisal. Since linear relationships between logarithms of variables results in power models such as Equation 1, the elasticity of global petroleum trade to other independent parameters would be the same as the power of variables in the model. As an example, from Equation 1, the elasticity of trade with respect to distance is:

$$E_{x,y} = \frac{\partial y / y}{\partial x / x} = \frac{\partial T_{ij} / T_{ij}}{\partial D_{ij} / D_{ij}} = \frac{\partial T_{ij}}{\partial D_{ij}} \times \frac{D_{ij}}{T_{ij}} = T_{ij}(-\frac{\rho}{D_{ij}}) \times \frac{D_{ij}}{T_{ij}} = -\rho \qquad (2)$$

The simple linear regression modeling was applied to appraise the trend of transportation coefficient with respect to time. Based on estimated coefficients of $D_{ij}MM$, and $D_{ij}Air$, as some are presented in Table 2, the results are presented in Figures 1 and 2. The figures confirmed upward trends of distance coefficients for multimodal and air distance networks.

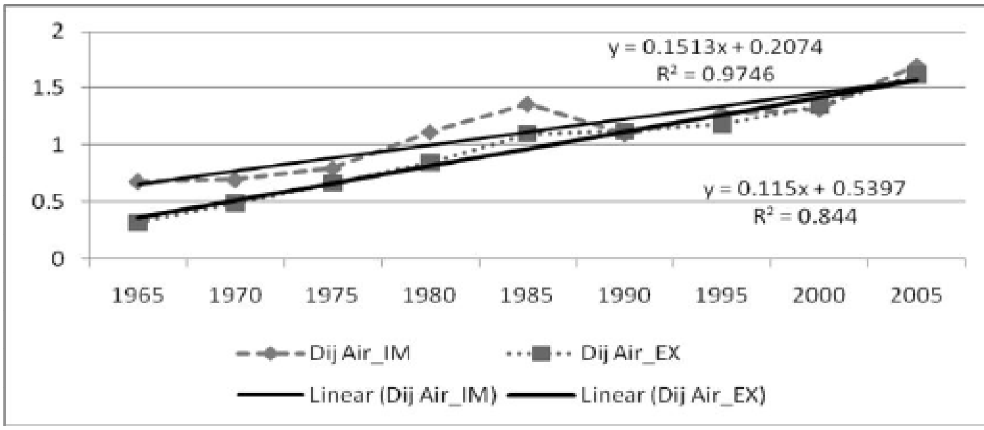

Figure 1 Trend of Distance Coefficient for Air Distance Network

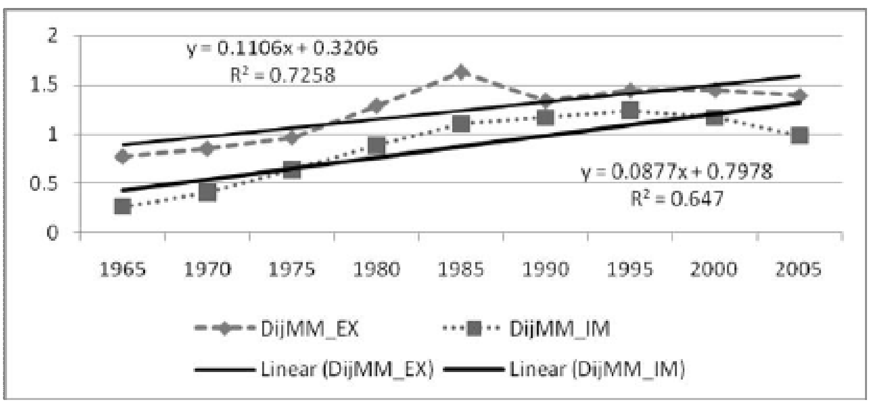

Figure 2 Trend of Distance Coefficient for Multimodal Distance Network

The results of linear modeling revealed that the relation between global petroleum trade and transportation parameters has intensified during the time. In fact, in spite of some proposed claims regarding the distance death, the upward trend of distance effect on trade values showed that this is not an accurate claim, at least in global petroleum trade. In contrast, countries tried to minimize petroleum transportation costs over time. It is expected that closer supplier of goods would be chosen rather than more distance ones, mainly because they have lower transaction costs as a result of being cheaper or easier to access.

5. Linear Programming

Transportation problem as a LP model to minimize Z, total transportation cost, is presented by following relations (Vaziri and Khademi, 2010):

$$\begin{aligned} &\text{Minimize } Z = \sum\sum C_{ij}\, T_{ij} \\ &\text{Subject to: } \sum T_{ij} \geq D_j \text{ for all } j\text{'s} \\ &\qquad \sum T_{ij} \leq S_i \text{ for all } i\text{'s} \\ &\qquad T_{ij} \geq 0 \text{ for all } i\text{'s and } j\text{'s} \end{aligned} \tag{3}$$

Where C_{ij} is the cost or distance between i's and j's, T_{ij} is the trade between i's and j's, D_j is the demand at j's and S_i is the supply at i's. Considering i's and j's as the 173 countries, optimized trade distribution was obtained by solving LP program and then optimized distribution was compared with observed distribution. Therefore, 36 LP were solved for 2 observed petroleum trade distribution of the petroleum export and import values for 2 transportation networks during the 9 time periods. Table 3 shows the result of LP model for global petroleum trade for multimodal and air distance network. Improvement percentage is the difference of observed and optimized total costs divided by observed total costs. Possible improvements for the multimodal network distributions were found in the range of 13% to 31%.

Table 3 Trade Distribution Linear Programming Results

Multimodal Network						
Year	Import			Export		
	Observed Z	Optimized Z	Improvement percentage	Observed Z	Optimized Z	Improvement percentage
1965	1.423E+08	1.216E+08	14.56%	6.205E+07	5.024E+07	19.04%
1970	2.231E+08	1.798E+08	19.42%	1.031E+08	8.512E+07	17.46%
1975	1.418E+09	1.230E+09	13.27%	8.428E+08	6.837E+08	18.87%
1980	3.439E+09	2.806E+09	18.41%	2.372E+09	1.976E+09	16.70%
1985	2.259E+09	1.679E+09	22.67%	1.010E+09	7.049E+08	30.20%
1990	2.451E+09	1.924E+09	21.50%	1.055E+09	7.585E+08	28.13%
1995	2.231E+09	1.737E+09	22.12%	1.145E+09	8.768E+08	23.41%
2000	4.254E+09	3.335E+09	21.61%	3.037E+09	2.277E+09	25.01%
2005	8.672E+09	6.656E+09	23.25%	6.281E+09	4.359E+09	30.59%
Air Distance Network						
Year	Import			Export		
	Observed Z	Optimized Z	Improvement percentage	Observed Z	Optimized Z	Improvement percentage
1965	6.691E+07	4.923E+07	26.42%	3.929E+07	2.844E+07	27.61%
1970	1.090E+08	7.139E+07	34.48%	4.816E+07	3.221E+07	33.11%
1975	7.356E+08	5.822E+08	20.86%	4.843E+08	3.700E+08	23.61%
1980	1.954E+09	1.520E+09	22.19%	1.445E+09	1.093E+09	24.37%
1985	1.237E+09	8.338E+08	32.60%	5.499E+08	3.074E+08	44.10%
1990	1.380E+09	1.036E+09	24.98%	6.249E+08	3.887E+08	37.80%
1995	1.250E+09	9.449E+08	24.42%	6.313E+08	4.295E+08	31.96%
2000	2.353E+09	1.835E+09	22.04%	1.683E+09	1.230E+09	26.88%
2005	4.864E+09	3.763E+09	22.65%	3.439E+09	2.484E+09	27.77%

Linear approximation model was also used to study the improvement percentage trend. Figures 3 and 4 show the improvement percentage trends for import and export values.

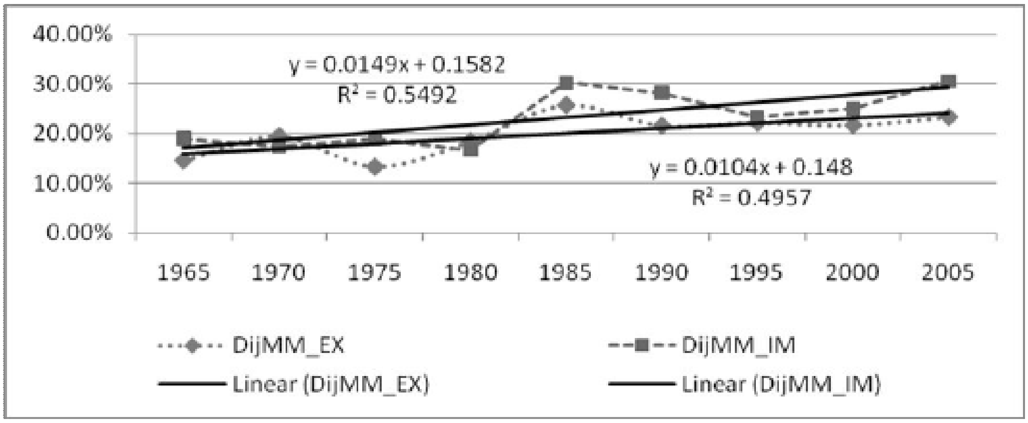

Figure 3 Improvement percentage trends for multimodal transportation network

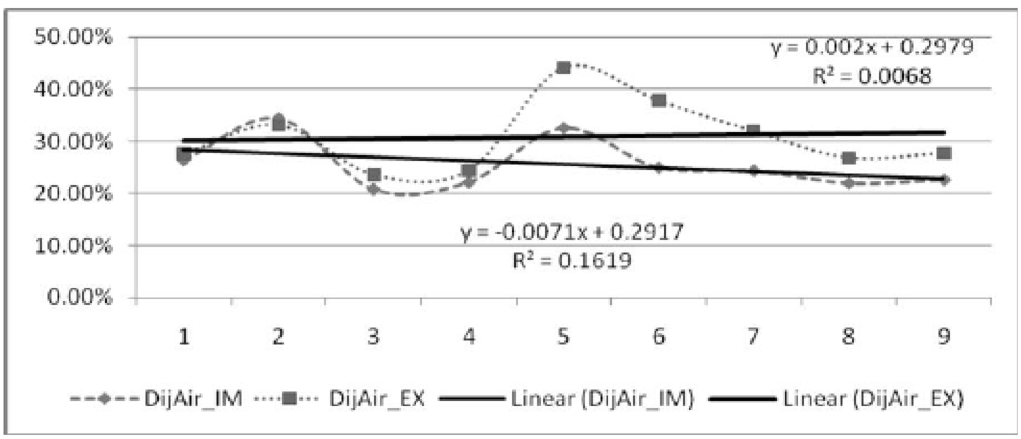

Figure 4 Improvement Percentage Trends for Air Distance Network

The models revealed that the coefficients of time variable were positive. The difference percentage for petroleum distributions increased during time periods and did not follow optimal distributions.

6. Conclusion

Using cross-sectional analyses, trends of international petroleum trade were studied. The study covered 173 countries, over the period of 1965-2005. To model trade distribution, gravity and linear programming were deployed. The models' descriptive variables included distance, GDP, political and land-lock variables.

A multimodal transportation network and an air distance network were developed and used as the most important factors in the gravity model. The other contributing factors included in this model were: GDP, population, area, country political attributes and land-lock variables. Thus, the major contributions of this paper are: 1) the development of a multimodal transportation network in commodity trade modeling and 2) and the development of a new gravity model based on four variable categories: commodity, geographical, economic and political characteristics. GDP, political factors, population and distance were all shown to be significant variables in this model. However, the developed calibrated gravity model based on the integrated sea-land network was shown to be more statistically significant than the traditional gravity model based on the air distance alone. In addition, modeling results revealed a robust negative relationship between the distance separating trade partners and the bilateral trade values which indicated that the geographic distance was still an important predominant factor in the international petroleum trade. The findings from the sensitivity analysis highlighted that the developed multimodal transportation network played an important role in explaining global petroleum trade and its effect was increasing over time. This effect was expected to be even more significant in the near future with the introduction of large ship size.

The LP modeling determined optimized petroleum trades and the results were compared with the observed global distributions. Comparison revealed that up to 30% of total transportation cost in multimodal network could have been reduced if the observed trades were replaced by the optimized distributions. Percentage possible improvements in multimodal transportation network increased during time, indicating that observed oil distribution did not follow the optimal one. That could have been attributed to the political and other variables that were not directly considered in the LP. Future strategies and business decision makings of petroleum trade partners are suggested to more directly incorporate distance and transportation aspects by utilizing the study methodology and results.

7. Acknowledgement

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