Cooperation among liquefied natural gas suppliers: Is rationalization the sole objective? ☆

Olivier MASSOL [a,b,*]

[a] Center for Economics and Management, IFP School, 228-232 av. Napoléon Bonaparte, F-92852 Rueil-Malmaison, France

[b] Department of Economics, City University, Northampton Square, London EC1V 0HB, UK

Stéphane TCHUNG-MING [c,d]

[c] Economic Studies Division, IFP, 1-4 av. de Bois-Préau, F-92852 Rueil Malmaison, France.

[d] CREDEN, Université Montpellier I, Av. de la mer, BP 9606, F-34054 Montpellier, France

February 12, 2010

JEL Classification codes: L71, C71

Keywords: Liquefied Natural gas; Cooperative game theory; Linear programming problem.

☆ Preliminary versions of this paper were presented at the City University CCRP Workshop (London, 2009), EURO (Bonn, 2009) and at the conference "The Economics of Energy Markets" (Toulouse, 2010).

* Corresponding author. Tel.: +33 1 47 52 68 26; fax: +33 1 47 52 70 66.
E-mail address: olivier.massol@ifp.fr

Abstract

This paper examines the development of cooperative strategies between countries exporting Liquefied Natural Gas (LNG) and members of the Gas Exporting Countries Forum (GECF). This economic study focuses specifically on an often-raised scenario: the emergence of a cooperative approach designed with the sole aim of logistic rationalization, and which would not have any effect on LNG prices. We first assess the annual gains that may result from this market-power-free cooperative approach using a simple static transportation model. The numerical results obtained suggest that, in the absence of a gain redistribution policy, this cooperative strategy will probably not be adopted because cooperation would not be a rational move for some exporters. The problem of gain sharing is then formulated using cooperative game theory concepts. Several gain-sharing methods have been studied, including the Shapley value and various nucleolus-inspired concepts. Our results suggest that the choice of a redistribution policy appears relatively restricted. Out of the methods studied, only one – per capita nucleolus – satisfies two key requirements: core belonging and monotonicity (in the aggregate). Lastly, we look at how cooperation may give rise to a coordination cost and try to determine the maximum amount of this cost. In view of the low level of this amount and the relative complexity of the sharing method implemented, we consider that the credibility of a logistic cooperation scenario exempt from market power should be reappraised.

Introduction

In the gas industry, the establishment of the Gas Exporting Countries Forum (GECF), founded in 2001 in Tehran, is undoubtedly one of the key events of the last few years. For the first time in history, the main gas exporting states, existing or emerging, got over the first steps to implement a cooperative approach. All the meetings of this informal inter-ministerial assembly (Hallouche, 2006) have given rise to plenty of comments. Indeed, the concentration of reserves[1], the precedent constituted by the OPEC (to which several GECF member states also belong) and the similarities between oil and natural gas (comparable technologies used in the exploration and production phases, analogies in terms of concentration of reserves) are all familiar topics when examining the long-term future of this industry.

Concerning the GECF, one of the major questions is how this group of exporters might behave. According to the dichotomy proposed by C. Mandil[2], two possibilities can be envisaged, depending on whether the GECF will seek to exercise market power or not. In the first case, the GECF would behave like a cartel, while in the second, it would concentrate on promoting regional cooperation as *"a think tank for gas exporting countries, enabling them to consider the best possible conditions for the exercise of their mission"* (Mandil, 2008). In the first scenario, economic theory provides models for analyzing the GECF profitability. For example, Jaffe and Soligo (2006) model the gas-OPEC as a dominant firm facing a competitive fringe to illustrate the collective market power that could be exerted by that organization[3]. However, as yet, there has been no examination of the other alternative: a cooperation that would be conducted without exerting any collective market power, i.e. without any effect on the prices paid by importing countries. This is the aim of this paper.

It is no surprise to note a revival of an early literature dedicated to international trade in natural gas and more specifically the theme of cooperation between exporters (Percebois, 1989 pp. 559-582). Some recent publications (e.g.: Hallouche, 2006; Finon, 2007; Wagbara, 2007; Tönjes and de Jong, 2007, Percebois, 2008) offer an in-depth description of the GECF and provide the basics required for more detailed analyses, such as those concerning (i) the attitude of each of the GECF member countries in relation to cooperation or (ii) the effect that cartelization would have on the importing countries. These contributions examine the subject in the broad perspective of geopolitics.

Besides, it can be judicious to implement an analytical approach grounded in economic theory. Hopefully, the literature dedicated to the gas industry provides numerous examples of insightful contributions obtained thanks to comprehensive quantitative models. Examples include the numerical market equilibrium models inspired by Mathiesen et al. (1987) either in a competitive perspective

[1] Three countries – Russia, Iran and Qatar – alone hold 55% of the planet's proven reserves of natural gas (BP, 2008). According to Hallouche (2006), the countries represented at the 2004 GECF assembly collectively held 87% of global gas reserves.
[2] Former Executive Director of the International Energy Agency.
[3] Following Cremer and Weitzman (1976), that "dominant firm" approach has been used in many models of OPEC.

(Hartley and Medlock, 2006) or in a Cournot oligopoly one (Golombek et al., 1995; Boots et al., 2004; Holz et al., 2008; Egging et al., 2008)[4]. Occasionally, these model-based contributions have proven to be helpful in dismissing conventional wisdom expectations[5]. This article aims at building on that analytical literature.

We focus on Liquefied Natural Gas (LNG), since GECF countries have a privileged position in this respect: they collectively hold almost 90% of the world's liquefaction capacities (Hallouche, 2006, p. 25), an impressive figure that has raised concerns about the possible emergence of *"an association of some kind among LNG exporters"* (Yergin and Stoppard, 2003). During the last 10-15 years, LNG trade has undergone an average growth of +7.44% a year since 2000 and represents almost 30% of today's international trade in gas (BP, 2008). Simultaneously, significant cost reductions – including economies of scale in the design of liquefaction plants (Jensen, 2003), an increased competition among liquefaction technology suppliers (Greaker and Sagen, 2008) and a drop in the unit cost of LNG shipping (Brito and Hartley, 2007; Rosendahl and Sagen, 2009) – have been experienced in that industry. These trends have resulted in the development of remote, and previously unexploited, resources and the expansion of transoceanic exchanges between previously isolated markets (Jensen, 2003).

The current organization of the LNG industry remains largely shaped by its history. Heavy investments are required to cover the financial needs of LNG projects. Because of the conditions imposed by fund lenders, most of the existing liquefaction terminals have been designed as part of integrated supply projects that also included cryogenic vessels and regasification facilities. The commercial arrangements attached to these projects usually involve complex long-term (typically 20 years) sale and purchase agreements that commonly link specific buyers' and sellers' facilities in a bidding inflexible pairing. According to these contracts, LNG tankers are usually committed to shuttle between a specific liquefaction plant and a specific destination (Jensen, 2004). As a result, current LNG flows are clearly dependent on past contractual decisions. On a global level, the aggregation of these contractual flows offers many opportunities for cross-shipping savings (Jensen, 2003). For example (GIIGNL, 2008), Trinidad and Tobago has a contract to supply 1.19 million tons of LNG per year (mt/y) to Cartagena (Spain). Simultaneously, Algeria is committed to shipping 3.2 mt/y of LNG to Lake Charles (USA). In both cases, under the provisions of the Delivered Ex Ship (DES) contract, the supplier is responsible for transportation[6]. In view of the respective geographical positions, these two LNG exporters could consider a profitable shipping coordination.

[4] In this vein, we can also mention the collection of models prepared for the 23rd edition of the Energy Modeling Forum. See EMF (2007) and the individual papers collected and edited by Huntington in a special issue of the Energy Journal (Huntington, 2009).

[5] A recent example is given by Rosendahl and Sagen (2009) who show how, in a competitive environment, a reduced gas transportation cost does not necessarily lead to lower prices in the importing regions.

[6] These DES provisions stipulate that the buyer agrees to purchase, receive and pay the Seller for LNG at a unique and predefined delivery point.

Recently, flexible destination cargo trading has emerged and has induced new market opportunities (cf. Yepes Rodríguez (2008) for an appropriate valuation of destination flexibility). Recent empirical evidence suggests that these arbitrages could prop up a regional price convergence across the Atlantic basin (Neumann, 2009). However, Brown and Yücel (2009) also note that variations in crude oil prices could also explain those apparent coordinated movements in natural gas prices. Further empirical analysis would certainly benefit from reliable and detailed information on cargo redirections and contractual structures. Unfortunately, the current opacity of the LNG industry impedes those further investigations. Morever, it must be reaffirmed that this move is limited to the Atlantic Basin (the USA and some Western European countries). In the rest of the world, LNG redirections remain largely motivated by importers balancing needs and price differences are not necessarily predominant in these decisions[7]. Besides, even if the market creates the conditions for cargo diversion, it can not be effective unless contractual clauses allow it. In many cases, the persistence of binding contractual limitations (either DES arrangements or rigid destination clauses in FOB arrangements) makes arbitrage almost impossible, with only rare exceptions (outages or other exceptional cases)[8]. As a result, it seems reasonable to assume that there are still considerable contractual rigidities in the LNG industry.

In this context, some observers have suggested that the GECF could play an intermediation role by identifying opportunities for logistic rationalization between GECF members (Wagbara, 2007). Taking that perspective, we aim at providing an ex-post evaluation of the gains that could have been obtained if such an optimization had been implemented during a given year, for example: 2006, 2007 or 2008. In terms of the GECF countries as a group, determining an optimal shipping rationalization is similar to resolving a standard transportation problem. This transportation problem has fuelled a rich literature in both economic theory (Koopmans, 1949; Kantorovich, 1960) and operations research with a famous formulation proposed by Dantzig (1951). Note that this logistic optimization has no impact on the price paid by the importing countries[9].

Several questions now arise. Firstly, what collective gain is likely to be achieved by such a coordination of exports within the GECF? Can we expect the spontaneous adoption of a coordinated policy without implementing a redistribution mechanism designed to create an incentive compatible cooperation? In other words, is such a collective gain attainable without worsening any member's profit? If no, the coordination wouldn't be possible unless a money transfer among participants could be implemented. But in that case, is it possible to identify a redistribution policy likely to encourage all the stakeholders to cooperate within the GECF? Is the current composition of the GECF the best

[7] Zhuravleva (2009) enumerates several barriers that hamper the commoditization of LNG markets, including: inappropriate market regulations, technical and market restrictions, the high transaction costs imposed by an illiquid and opaque market...

[8] For the future, we could envisage that future renegotiation of existing long-term contracts will somehow phase out these restrictions (Zhuravleva, 2009). But this is obviously a long-run process that can not be reasonably taken into consideration in a study focusing on the current LNG industry.

suited to this coordination, or would it be in the interest of certain participants to cooperate within the framework of a restricted coalition? All these questions refer to the concepts of cooperative game theory, which analyzes the distribution of gains resulting from cooperation between economic players. This theory has been used in a wide variety of contexts. Applications linked to energy include such diverse examples as the regional cooperation in planning an electricity supply system between three states in India (Gately, 1974); the measurement of market power in the Western American coal industry (Wolak and Kolstad, 1988); the sharing of joint costs in a distribution planning situation at Norsk Hydro (Engevall et al., 1998); the allocation of electricity transmission cost (Kattuman et al., 2004) and the allocation of a refinery's CO_2 emissions (Pierru, 2007)… In this paper, we analyze the credibility of the so-called "rationalization" argument by studying the feasibility of a cooperation which focuses solely on the logistic optimization of LNG supply chains, without trying to exert any upward pressure on prices. Finally, we aim to discuss the credibility of such a "market-power-neutral" cooperation.

The next section details and discusses the assumptions used in this study. Section 3 justifies the formulation of the GECF's problem in the form of a linear program. It also provides an evaluation of the transportation gains that could have been earned either in 2006, 2007 or 2008, if such a logistic cooperation had been implemented. According to these results, such a cooperation would be collectively profitable. However, some countries would not spontaneously adhere to this collectively optimal export policy. As a gain-sharing rule is needed, section 4 discusses this issue with the help of cooperative game theory concepts. It sets achievable gain-sharing schemes using basic solutions as well as more advanced ones such as the Shapley value, the nucleolus and some of its derivatives. The last section concludes the paper.

1. Assumptions

This first section presents the notations and discusses the assumptions used in this article.

1.1 Notations

- t, a given year, either 2006, 2007 or 2008;
- N_t, the set of GECF members that exported LNG in year t;
- i, an LNG exporting country;
- j, an LNG importing country;
- n_t, the number of GECF countries that exported LNG in year t;
- d_t, the number of destinations that received some LNG from GECF countries in year t;

[9] This is compatible with the medium-term price rigidity resulting from long-term contracts. In these contracts, prices and indexing formulas are negotiated and fixed for periods of approximately 3 years.

- q_{ij}^t, the (non-negative) annual quantity of LNG shipped from i to j during year t;
- Q_{ij}^t, the annual quantity of LNG that has been effectively shipped from i to j in year t;
- P_j^t, the annual average import price of LNG in j during year t. It gives the value of LNG at the gate of j's regasification plants;
- C_i, the unit cost of natural gas extracted and liquefied in i;
- T_{ij}, the unit cost of transporting a given quantity of LNG from i to j.

For the sake of clarity, it must be underlined that the approach considered here is static and relates only to an annual time horizon. Each year t is considered as a different instance and is thus modeled independently. As no ambiguity arises, the subscript t has thus been dropped to simplify the notations. For the same reason, we also define $q_i = \left(q_{ij}\right)_{j\in\{1,\dots,d\}}$, the vector of i's annual deliveries to the different destinations during a given year and $Q_i = \left(Q_{ij}\right)_{j\in\{1,\dots,d\}}$ those effectively observed.

1.2 Framework and numerical assumptions

<u>LNG exporting countries</u>

In this study, the list of countries likely to adopt coordination includes all the non-OECD exporting countries[10] that have participated in a GECF meeting (Hallouche, 2006): Algeria, Brunei, Egypt, Equatorial Guinea (only after the opening of its first liquefaction plant in 2007), Indonesia, Libya, Malaysia, Nigeria, Oman, Qatar, Trinidad & Tobago and the United Arab Emirates. Hence, n is equal to 11 in 2006 and to 12 in 2007 and 2008.

<u>LNG importing countries</u>

The following list of importing countries has been considered: Belgium, China (only after the start of its imports from GECF countries in 2007), Dominican Republic, France, Greece, India, Italy, Japan, Mexico, Portugal, Puerto Rico, South Korea, Spain, Taiwan, Turkey, the UK and the USA.

<u>Production and liquefaction costs</u>

The unit costs C_i are displayed in Table 9 in Appendix A. These costs include two components: extraction and liquefaction. A common technology has been assumed for all the liquefaction plants

[10] Australia, Norway (which holds an observer status at the GECF) and the United States (Alaska) also export LNG. However, it is very unlikely that these countries would agree to join the GECF (Tönjes and de Jong, 2007). Similarly, the modest Belgian re-exportations observed in 2008 have also been neglected.

resulting in a uniform cost of \$1.00 per MMBtu these operations (DTI, 2005). Extraction costs[11] exhibit some variations due to differences in geological endowments.

LNG ships transport costs

For each ij route, the unit cost values T_{ij} are presented in Table 9 in Appendix A. Obviously, T_{ij} is monotonically increasing with the maritime distance. Theses values have been calculated in accordance with a usual methodology (Flood, 1954), assuming a fleet of standardized cryogenic vessels committed to shuttle on a given route ij and include the main LNG specificities like evaporation losses during transport.

LNG prices in importing regions

The annual average LNG import prices P_j have been obtained by subtracting a regasification service fee[12] to the local gas prices. A standardized fee of \$0.50 per MMBtu has been uniformly assumed for all the importing countries (DTI, 2005). Concerning the natural gas prices observed in importing regions, we follow Mazighi (2003, p. 319) and assume that three macro regions can be distinguished – Asia, Europe and America – and that those prices are uniform within each area. This assumption is consistent with industrial reality as spatial price variations observed within these macro-zones are usually limited compared to those observed when considering these macro-zones. The gas price data used in this study are those labeled *“Japan CIF”*, *“European Union CIF”* and *“US Henry Hub”* in the BP Statistical Review (see Table 1).

Table 1: key figures on LNG trade from GECF members

Final Destination		2006	2007	2008
Asia	Volumes shipped from GECF members (Bcm)	115.44	126.56	134.34
	Reference Price (Japan CIF) (\$/MMBtu)	*7.14*	*7.73*	*12.55*
Europe	Volumes shipped from GECF members (Bcm)	57.42	53.20	54.08
	Reference Price (EU CIF) (\$/MMBtu)	*8.69*	*8.93*	*12.61*
North America	Volumes shipped from GECF members (Bcm)	18.47	25.09	14.27
	Reference Price (US Henry Hub) (\$/MMBtu)	*6.76*	*6.95*	*8.85*
Total	Volumes shipped from GECF countries (Bcm)	191.33	204.85	202.69

Reported trade flows

The annual flows Q_{ij} are those reported by the consecutive editions of the BP Statistical Review.

1.3 Preliminary remarks

These assumptions prompt some remarks. Firstly, these assumptions allow us to present an aggregated vision of LNG trade originating from non-OECD exporters. Taking year 2007 as an example, Table 2 provides an overall vision of the LNG value chain. That year, LNG trade generated a \$57 billion

[11] These extraction costs correspond solely to technical operations and include neither the effects of oil and gas taxation nor the opportunity cost related to the exhaustible nature of gas resources.
[12] Such a uniform rate insures that this cost element plays no role in the transportation model’s outcome.

revenue and the total costs amounted to $21 billion (enabling a nearly $35 billion rent). Shipping alone accounted for nearly one-third of these annual costs. Such a significant share justifies the attention paid to transportation issues in that industry.

Table 2: The LNG value chain for GECF exporting countries (year 2007)

		$ billion	%
E&P costs	Production	3.588	*16.6%*
LNG costs	Liquefaction	7.234	*33.4%*
	Shipping	8.167	*33.3%*
	Re-gas	3.617	*16.7%*
Total costs		21.638	*100.0%*
Rent		34.870	
TOTAL revenue		57.476	

Secondly, only two factors motivate the differences in the unit costs of supplying LNG to a given destination: extraction cost variations and differences in the localizations. Because of the uniform rates used for both liquefaction and regasification, these activities do not in any way contribute to these unit cost differences and are thus assumed to play no direct role in the exporting decisions. An illustration of these points is given by *### Figure 1 to be inserted ###*

Figure 1 that presents a least-cost merit order for each of the main importing countries in North America, Europe and Asia. As expected, there are significant cost differences and the bulk of these variations is related to the distance factor. Moreover, no country has an absolute global cost advantage, which emphasizes that localization matters in the LNG industry.

Figure 1 to be inserted

Figure 1 : Unit costs of imports of natural gas from GECF members ($/MMBtu) for three destinations: (A) the USA, (B) Spain, (C) Japan.

2. Cooperation between LNG exporters

In this section, the GECF's shipping rationalization decision to be taken for year t is formulated as a simple static linear programming model.

2.1 Formulation of the problem

We focus on a given year t and assume that exporting countries have total control over their LNG shipments. During that year, a homogeneous product, LNG, is to be shipped from n shipping origins to d destinations. The cost of shipping a unit amount from the i^{th} origin to the j^{th} destination is known for all combinations (i, j). For that particular year, the problem is to determine the quantities q_{ij} to be shipped over all routes so as to maximize the GECF's collective profit.

In addition, GECF's shipment decisions are submitted to some constraints. As liquefaction projects require considerable investments, fund lenders usually submit their financial commitment to the presence of binding agreements for the supply of a predefined quantity of LNG. Therefore, we assume that a cooperative shipment policy must comply with those agreements, so that the overall volumes exported from any exporting country remain unchanged: $\forall i, \ \sum_{j=1}^{d} q_{ij} = \sum_{j=1}^{d} Q_{ij}$.

The GECF aims at implementing a logistic rationalization without attempting to exert any collective market power, i.e. without any modification in prices P_j . Hence, the GECF's decisions are supposed to leave unchanged the total volume of LNG received in each destination, i.e.: $\forall j, \ \sum_{i=1}^{n} q_{ij} = \sum_{i=1}^{n} Q_{ij}$.

So, the annual profit obtained by i is a linear function of q_i : $\pi_i\left(q_i\right) = \sum_{j=1}^{d}\left(P_j - C_i - T_{ij}\right) q_{ij}$. For that particular year t , the GECF’s problem turns out to be a familiar transportation problem (Dantzig, 1951) whose solution is denoted q^* :

<u>Program 1:</u>

$$\max_{q_{ij}} \ \sum_{i=1}^{n} \pi_i\left(q_i\right)$$

$$\text{s.t.} \quad \sum_{j=1}^{d} q_{ij} = \sum_{j=1}^{d} Q_{ij} \qquad \left(i = 1, 2, ..., n\right) \qquad (1)$$

$$\sum_{i=1}^{n} q_{ij} = \sum_{i=1}^{n} Q_{ij} \qquad \left(j = 1, 2, ..., d\right) \qquad (2)$$

$$q_{ij} \geq 0$$

This program corresponds to a shipping cost minimization problem. It contains nd non-negative variables q_{ij} and $n+d$ equality constraints of type (1) and (2). This problem is obviously feasible as, for any given year, the observed LNG flows Q_{ij} satisfy all the constraints. Moreover, the optimal solution requires at most $n+d-1$ routes with positive shipments (Dantzig, 1951). Whatever the year, a simple enumeration of the positive flows reported by the BP Statistical Review indicates a number of used routes always larger than $n+d-1$. Therefore, the observed LNG flows Q_{ij} were suboptimal which leaves some room for a logistic optimization.

At this stage, it may be important to underline that an annual perspective is used in this model. Obviously, this methodology could be extended to a different time frame. For example, an infra-annual perspective might be considered to capture possible seasonal variations in trade patterns (in terms of either LNG volumes or relative regional prices). Unfortunately, the lack of a consistent and exhaustive infra-annual data set at the world scale precluded that infra-annual analysis. As a result, we have to rely on the annual data reported by publicly available sources such as the BP Statistical Review. This situation means that we are implicitly assuming that the trade patterns remain constant throughout the year[13].

2.2 Results

General comments

Three optimal policies q^* have been independently computed for the years 2006, 2007 and 2008. According to the results displayed in Table 3, significant shipping cost savings could have been achieved thanks to a logistic cooperation.

Table 3: Collective gain resulting from an annual shipping coordination (in M$)

	2006	2007	2008
Annual collective profit obtained with past flows (a)	30 676.45	34 869.82	65 170.67
Annual collective profit attained with an optimal shipping policy (b)	31 422.65	35 838.12	66 157.88
Shipping gains obtained from cooperation (b)-(a)	746.20	968.31	987.21
(as a % reduction in that year's shipping costs)	*10.5%*	*11.9%*	*12.9%*

At the GECF level, this cooperation seems profitable. But, at an individual level, the annual gains $\pi_i\left(q_i^*\right)-\pi_i\left(Q_i\right)$ displayed in Table 4 clearly show that cooperation could lead to a lowered profitability for Brunei, Indonesia, Qatar and Trinidad & Tobago. It will be shown below that implementing q^* induces significant variations in the individual's costs and revenues.

Table 4: Impact of the optimal GECF shipping policies on the individual annual profits (in M$)

	2006	2007	2008
Trinidad & Tobago	-182.29	-110.94	-539.85
Oman	118.74	120.70	139.07
Qatar	-587.25	-624.88	-317.30
UAE	319.28	341.05	337.98
Algeria	273.71	511.31	226.87
Egypt	743.44	704.03	320.21
Equatorial Guinea	-	138.98	317.10
Libya	0.71	0.75	0.53
Nigeria	64.77	-115.04	477.26
Brunei	-3.86	-2.60	-3.26
Indonesia	-38.25	-37.88	-32.64
Malaysia	37.20	42.82	61.24
TOTAL	**746.20**	**968.31**	**987.21**

[13] In fact, infra-annual variations in the relative market conditions of the various importing countries (quantities demanded, price levels) could possibly provide a justification for some of the seemingly irrational cross-shipments observed in the annual LNG trade data. Nevertheless, the inclusion of these infra-annual considerations in the GECF's problem would further narrow the shipping optimization possibilities, and, hence, the collective shipping gain that may be obtained by the GECF. In other words, this annual perspective provides an upper bound of the gains derived from a logistic coordination between LNG exporters.

Detailed comments

A detailed analysis of the results obtained for a specific year also gives an interesting perspective. For the sake of brevity, that discussion is exclusively focused on 2007 but similar observations could also be presented for the other years.

An optimal shipping policy for 2007 is displayed in Table 10 (See Appendix B). It comprises only $n_{2007} + d_{2007} - 1$=28 positive flows (compared to 77 in the observed flows Q_{ij}^{2007}). Figure 2 illustrates the shipment reallocations associated with that optimal policy: Mediterranean exporters reallocate most of their LNG to Europe, and Trinidad & Tobago readjusts its exports to neighboring North American markets, and the volumes liquefied in South East Asia remain dedicated to Asian destinations. For Asian exporters, the GECF's optimization only fine-tunes exports at an intra-regional level.

Figure 2 to be inserted

Figure 2: Variations in the LNG destinations induced by the adoption of the GECF's optimal policy for the year 2007 (a positive value signals a shipment increase)

Figure 3 to be inserted

Figure 3 : Gains in cost and revenues derived from the adoption of the optimal solution in 2007 (in M$)

As that solution might be non-unique, it is unnecessary to comment extensively on these flows. Nevertheless, for an exporter i, implementing the optimal shipping policy induces two effects: a variation in its revenues and a variation in its shipping costs. For 2007, that point is illustrated in Figure 3. For example, the shipping cost gains obtained by Trinidad & Tobago with q^* would not cover the associated revenue losses. For other countries (Qatar, Brunei and Indonesia), the situation would be even worse: with adverse variations in both costs and revenues. For these last three countries, participation in the GECF would not be rationale even if that group was to be organized so as to (i) keep individual revenues unchanged and (ii) minimize the shipping costs[14]...

A first conclusion emerges from these results: a shipping rationalization may look desirable at a collective level but not at an individual one. This feature could seriously impede the spontaneous implementation of an optimized shipment policy as participation would not constitute a rational move for some countries. As it seems that substantial collective gains might be obtained from cooperation, cooperative game theory concepts could possibly pave the way to an incentive-compatible participation. This issue is studied in the next section.

[14] In that case, q^* would still correspond to an optimal policy. Hence, these countries would still face adverse shipping cost variations...

3. An 'incentive compatible' gain sharing

Supposing that the exporters agree to work together, we assume that the annual gain earned through the cooperation can be divided among the members of the coalition. To implement this reallocation of the benefits, we have to suppose that money has the properties of a "transferable utility" so that the problem at hand can be analyzed as a transferable utility game. This is a strong hypothesis, but looking at the industrial reality suggests the existence of side-payments among participants in a logistic cooperation[15]. The case where players cannot transfer the collective gains amongst themselves is discussed in section 4.4.

3.1 A game theory background

<u>Context</u>

It is now time to introduce some notations. A cooperative game with transferable utility (TU-game) is a pair (N,v), where $N:=\{1,...,n\}$ is a finite set of *players* and $v:2^N \to \mathbf{R}$ is a function assigning to each coalition $S \subseteq N$, its worth $v(S)$. By convention, $v(\varnothing)=0$. Let $|S|$ be the number of elements of coalition S. To simplify the notations, when no ambiguity arises, we use i to denote $\{i\}$ a particular element in N.

In our particular case, we are considering the implementation of a logistic cooperation among GECF members during a given year: either 2006, 2007 or 2008. Here, three different (and independent) TU-games are going to be successively studied: (N_t, v_t), where N_t is the group of n_t potential participants in the GECF and the worth function v_t gives the maximum gain in annual profits that can collectively be attained by any coalition in year t. As these three TU-games are going to be studied independently, the subscript t has been dropped to simplify the notations.

For each coalition S, the gains $v(S)$ to be apportioned among its members are measured by the difference between the maximum annual profits of its members when they all cooperate and when they don't. Such a coordination policy is strictly limited to S and thus has no impact on the shipments decided by the others $|N \setminus S|$ countries. In other words, $v(S)$ is simply the gain obtained from the creation of a smaller GECF-like organization that implements an optimal shipment policy specifically computed for coalition S. A simple adaptation of the previous linear programming model is sufficient to compute the value $v(S)$ of each of the 2^n coalitions that can be formed in N. If we denote

[15] In the 1990s, the Italian ENEL and the French GDF signed a swap deal under which Nigerian LNG is delivered in France and GDF diverts an equivalent volume of its imports to Italy. In fact, this swap agreement generated a logistic optimization and transfer prices were used as side-payments to create an incentive-compatible gain allocation.

$\delta_i(S)$, the function whose value is equal to 1 if $i \in S$ and to 0 otherwise, these values $v(S)$ can be obtained by solving the following problem:

Program 2

$$v(S) = \underset{q_{ij}}{Max} \quad \sum_{i=1}^{n} \delta_i(S).\left[\pi_i(q_i) - \pi_i(Q_i)\right]$$

$$\text{s.t.} \quad \sum_{j=1}^{d} q_{ij} = \sum_{j=1}^{d} Q_{ij} \qquad (i = 1, 2, \ldots, n)$$

$$\sum_{i=1}^{n} q_{ij} = \sum_{i=1}^{n} Q_{ij} \qquad (j = 1, 2, \ldots, d)$$

$$(1\text{-}\delta_i(S)) q_{ij} = Q_{ij} \qquad ((i, j) \in \{1, 2, \ldots, n\} \times \{1, 2, \ldots, d\})$$

$$q_{ij} \geq 0$$

Obviously, the gains from cooperation are always positive. Moreover, this function is 0-normalized: $v(i) = 0$, $\forall i$. On top of that, v has a nice property: by construction, v is super-additive since for all coalitions A, B with $A \cap B = \varnothing$, we clearly have $v(A \cup B) \geq v(A) + v(B)$. This feature suggests that countries have real incentives to cooperate since the union of any two disjoint groups of players can only improve their total gains. Thus, it should pay to cooperate in the largest coalition, and the problem may turn out to be the sharing of the overall annual gain among the n countries.

Formulation of a gain-sharing problem

In this TU-game (N, v), the redistribution problem faced by the GECF can be formulated as finding a vector $x \in \mathbf{R}^n$ where the i^{th} coordinate named x_i is simply equal to the benefit allocated to country i. Here again, to simplify the notations, when no ambiguity arises, we use x to denote $x(v)$. It seems natural to expect that x allows a full distribution of the gains created by the GECF. Equivalently, x is expected to be *efficient,* that is to satisfy $\sum_{i=1}^{n} x_i = v(N)$.

For the GECF, the goal of a redistribution policy is to encourage the cooperation of the twelve countries. Thus a reasonable test of the method is to check whether the participants agree in principle to the proposed allocation of benefits. A natural requirement for x is to be *individually rational;* that is, for each $i \in N$, $x_i \geq v(i)$. This individual rationality condition basically states that no country should receive less in the joint operation proposed by the GECF than it would receive on its own. Finding an allocation which satisfies this property is fundamental since it constitutes the minimum incentive for an individual country to join the GECF. The set of all efficient and individually rational allocations is named the *imputation set* $I(v)$. Choosing an allocation in $I(v)$ can be viewed as a minimal requirement for the GECF.

A similar analysis can be extended to coalitions of countries as well as to individual exporters. The condition that no group receives less than the value it could generate on its own is the principle of *group rationality*. An allocation x satisfies group rationality if there is no coalition $S \subseteq N$ such that $\sum_{i \in S} x_i < v(S)$. Group rationality obviously implies individual rationality. Now, the notion of the core (Gillies, 1953) can be introduced. Denote $C(v)$ the core of a game (N,v); it is defined as the set of all efficient and group rational allocations, i.e.,

$C(v) := \left\{ x \in \mathbf{R}^n : \sum_{i=1}^{n} x_i = v(N) \text{ and, for each } S \subset N, \sum_{i \in S} x_i \geq v(S) \right\}$. In this GECF case, selecting an allocation within the core constitutes an appealing requirement since it ensures that no participant, or subgroup of participants, can complain about the proposed distribution. In fact, each coalition prefers to cooperate within the grand coalition N – and earns its share of the total gain – rather than choosing a 'stand alone' attitude that yields a lower gain.

However, there is always the adverse possibility that there may be no core imputations: that is, no gain allocations that are group rational. Thus, we have to check whether the core of this gain-sharing game is void or not. In some cases, it can be relatively easy to show that the core is non-void. For example, in a convex game[16], the core is always non-void. Unfortunately, the gain-sharing games that are under consideration here are generally not convex. An illustration of that non-convexity is given in Table 5.

Table 5: An illustration of the non-convexity of the game (N,v) for the year 2007 (in M$)

S	$v(S)$
A := {Brunei, Indonesia}	9.445
B := {Oman, UAE, Equatorial Guinea, Indonesia}	50.100
$A \cup B$:= {Oman, UAE, Equatorial Guinea, Brunei, Indonesia}	50.366
$A \cap B$:= {Indonesia}	0

Thus:

$$v(A) - v(A \cap B) \ > \ v(A \cup B) - v(B)$$
$$9.445 \ > \ 0.266$$

However, the super-additive nature of v suggests that a large cooperation can be appealing. Thus, the existence of a non-void core has to be checked using a linear program as follows:

<u>Program 3</u>

[16] A TU-game (N,v) is convex if for all coalitions A and B in N: $v(A \cup B) - v(B) \geq v(A) - v(A \cap B)$. Roughly speaking, a game is convex if we have increasing returns to cooperation. In the TU-game framework this means that *"the larger the coalition that an individual agent joins, the larger his marginal contribution."* (Moulin, 1991, p. 112).

$$
\begin{aligned}
&\underset{x_i\ ,\varepsilon}{Max} \quad \varepsilon \\
&\text{s.t.} \quad \sum_{i=1}^{n} x_i = v(N) && (3)\\
&\qquad \sum_{i\in S} x_i - \varepsilon \geq v(S) \qquad \forall S \subset N,\ (S \neq \emptyset, N) && (4)\\
&\qquad x_i \geq 0 \qquad (i = 1, 2, \ldots, n)\\
&\qquad \varepsilon \geq 0
\end{aligned}
$$

A non-empty solution to this problem basically shows that a non-empty core exists since a positive value for ε guarantees that it is possible to find at least one allocation $x \in \mathbf{R}^n$ that satisfies all the constraints attached to the definition of the core. Fortunately for the GECF, we found ε equal to $536,082, $360,469 and $452,994 for the year 2006, 2007 and 2008 respectively). Moreover, the core is not reduced to a unique vector since we found that several $x \in \mathbf{R}^n$ provide this value for ε.

The core provides a preliminary criterion of a satisfactory allocation. Given that it is neither void nor reduced to a singleton, the core offers an attractive guideline for choosing an allocation since it narrows down the set of acceptable imputations. So, it is now time to verify whether some classic gain-sharing rules verify this requirement.

3.2 Presentation of some gain-sharing methods

Many gain-sharing methods can be envisaged for the GECF. In this article, we limit ourselves to a limited sample that includes most of the most popular ones. The first three rules propose to share the collective gain in proportion to the total of a given quantitative criteria. Those naïve rules could typically be inspired by some accounting considerations. A second type of rule is then presented; those two methods explicitly take into account the marginal contribution of each participant. Last but not least, four methods developed in game theory are presented.

Method 1: Equal repartition of the total gain

The annual shipping gain is basically divided into n equal shares: $x_i = \frac{v(N)}{|N|}, \quad \forall i \in N$.

Method 2: Proportional to non-cooperative profits

Here, the total annual gain $v(N)$ is shared in proportion to the profits observed for that year: $x_i = \frac{\pi_i(Q_i)}{\sum_{i=1}^{n} \pi_i(Q_i)} v(N), \quad \forall i \in N$.

Method 3: Proportional to shipments

Information on LNG shipped quantities is presented in numerous publicly available sources. In this third proportional rule, the total gain $v(N)$ is simply shared in proportion to the total quantities shipped by each exporter during the year: $x_i = \frac{\sum_{j=1}^{d} Q_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{d} Q_{ij}} v(N), \quad \forall i \in N$.

Method 4: A marginal contribution scheme

By definition, the *marginal contribution* m_i of a participant i is the gain created by i when joining the coalition of the $(n-1)$ other participants, $v(N)-v(N \setminus i)$. It will be shown below that this method is not necessarily efficient (and thus does not belong to $I(v)$). In the present case, it clearly overestimates the total gain to be shared $\sum_{i=1}^{n} m_i > v(N)$.

Method 5: A scheme inspired by the Alternative Cost Avoided method (ACA-method)

This method is inspired by a technique developed during the 1930s to allocate the joint costs of multipurpose water development projects (Tijs and Driessen, 1986). In this adaptation to a gain-sharing problem, it can simply be viewed as a two-step procedure. In the first step, each player i receives a payment based on its marginal contribution m_i. But, for many value functions, the sum of these marginal contributions is greater than the total value created by the grand coalition. Therefore, a second step is needed to readjust the difference $\sum_{i=1}^{n} m_i - v(N)$. In the ACA-method, this surplus is simply subtracted in proportion to $(m_i - v(i))$, the differences between the i's marginal value and its value in a stand alone case:

$$x_i = m_i - \left(\sum_{i=1}^{n} m_i - v(N)\right) \frac{m_i - v(i)}{\sum_{l=1}^{n}\left(m_l - v(l)\right)}, \quad \forall i \in N .$$

As v is a 0-normalized function, the surplus $\sum_{i=1}^{n} m_i - v(N)$ is simply shared in proportion to the marginal values.

Method 6: The Shapley value

The Shapley value is a well-known game theoretic allocation that has been defined as the unique allocation that satisfies a consistent set of three axioms (Shapley, 1953). An intuitive interpretation of the Shapley value can be presented as follows: as the grand coalition is formed by the sequential addition of exporters, each participant i receives a benefit equal to the entire value $\left(v(S)-v(S\setminus i)\right)$ he offers to the coalition $S\setminus i$ formed just before him. But the order in which the various exporters will join the grand coalition can be uncertain. The Shapley value is i's expected benefit if all orders of formation of N – the permutations of the grand coalition – are considered and intervene with the same probability $1/|N|!$ in the computation. It is defined as:

$$x_i = \sum_{\substack{S\subseteq N\\ i\in S}} \frac{|S\setminus i|!\times|N\setminus S|!}{|N|!}\left(v(S)-v(S\setminus i)\right),\quad \forall i\in N\,.$$

The Shapley value has an attractive property since this allocation always belongs to the core of a convex game. Unfortunately, the results are not so clear-cut for super-additive games. For our particular instances of our GECF game, we will thus have to test if it belongs to the core.

Method 7: The nucleolus

Another game theoretical concept is the nucleolus proposed by Schmeidler (1969). He defined the unhappiness of a coalition S with respect to a proposed allocation x and proposed to measure it with $e(S,x)=v(S)-\sum_{i\in S}x_i$, the *excess* of the non-trivial coalitions $S\subset N\quad(S\neq\varnothing,N)$ with respect to an allocation x. This excess can simply be viewed as an index of that coalition's objections to the payoffs its members are receiving in the grand coalition. The coalition which objects most strongly to the proposed allocation x is the one with the greatest excess. If this excess is positive, the proposed allocation is outside the core; if it is negative, the allocation is acceptable, but the coalition nevertheless has an interest in obtaining the smallest possible excess. Thus, it is appealing to look for an allocation that minimizes the maximum unhappiness. Schmeidler (1969) went one step ahead and proposed a new solution concept: the nucleolus of the game.

Let $e(x)=\left\{e_1(x),\ldots,e_{2^n-2}(x)\right\}$ be a vector in $\mathbf{R}^{2^n-2}$ the components of which are the excess listed in a decreasing order, where S runs over the subset of $N\ (S\neq\varnothing,N)$. Thus, $e_1(x)$ is the maximum unhappiness created by the proposed allocation x. Thanks to these vectors, two allocations

$x, y \in I(v)$ can be compared: x is preferred to y if $e(x)$ is lexicographically smaller[17] than $e(y)$, this is noted $e(x) \leq_L e(y)$. Schmeidler (1969) named the nucleolus of the game the set $Nu(v) := \{x \in I(v); e(x) \leq_L e(y) \text{ for all } y \in I(v)\}$ and he proved that the nucleolus is a unique allocation. By construction, the nucleolus satisfies an appealing property: it always belongs to the core when it is non-empty. From a computational perspective, Kopelowitz (1967) proposed an algorithm for calculating the nucleolus by means of a sequence of linear programs. The computational procedure used here relies on Granot et al. (1998) and Boyer et al. (2006).

Method 8: The "per capita" nucleolus

The nucleolus is entirely based on a measure of the unhappiness of a coalition with respect to a proposed allocation. But there is some arbitrariness in the definition of the metric. This led Grotte (1970) to define a variant, named the per capita nucleolus (also named normalized nucleolus), which is based on a per capita measure of the excesses. In this allocation, the unhappiness of a coalition S with respect to a proposed allocation x is simply measured with $e(S,x) = \frac{v(S) - \sum_{i \in S} x_i}{|S|}$.

Method 9: The disruption nucleolus

This other variant of the nucleolus is due to Gately (1974) who, in a 3-person game, proposed an additional concept named "propensity to disrupt" a given allocation that was later extended to n-person games by Littlechild and Vaidya (1976). For a given allocation vector x, the propensity to disrupt, denoted $PD(x,S)$, of any coalition $S \subset N \quad (S \neq \emptyset, N)$, is defined as the ratio of the total amount which the complementary coalition $N \setminus S$ would lose if the grand coalition broke up, to the loss incurred by the coalition S itself if that coalition refused to cooperate, i.e.:

$$PD(x,S) = \frac{\sum_{l \in N \setminus S} x_l - v(N \setminus S)}{\sum_{i \in S} x_i - v(S)}$$

Suppose that only strict core[18] allocations are proposed to the members of the grand coalition N. It is clear that the propensity of a given subgroup S to disrupt this grand coalition becomes larger when its payment becomes smaller (in such a case, the payment received by $|N \setminus S|$ increases). It can even rise

[17] It means that there are no index $u \in \{1,...,2^n - 2\}$ so that $e_u(x) \geq e_u(y)$ and $e_t(x) = e_t(y)$ for all $t < u$.

to infinity, reflecting an aspiration to quit the agreement, as the gain share of S approaches its minimum $v(S)$. Littlechild and Vaidya (1976) proposed using this ratio as a dissatisfaction measure to be minimized in a lexicographic sense. The resulting unique allocation is named disruption nucleolus. By construction, it also belongs to the strict core if it is non-empty. To compute that allocation, we rely on the computational procedure described in Littlechild and Vaidya (1976).

4. Results

In this section, we comment on the results obtained with these gain-sharing methods on three different TU-games: (N_{2006}, v_{2006}), (N_{2007}, v_{2007}) and (N_{2008}, v_{2008}) for which the collective annual gain to be shared is equal to \$746.20 million, \$968.31 million and \$987.21 million respectively.

4.1 Preliminary comments

The results obtained with these nine allocation methods are reported in Table 11 in Appendix C. To begin with, the marginal contribution scheme cannot be considered as a workable allocation mechanism as it is not an efficient rule for the GECF. Yet, this method provides an indication of the relative importance of the different actors. And there are large differences among them. Taking year 2007 as an example, these marginal contributions vary from a limited \$0.7 million for Brunei to \$459 million for Qatar – more than 47% of the total annual gains. Those differences obviously depend on factors such as pre-cooperation export policies or costs differences. Anyway, these results suggest that Qatar's participation is very important for the whole cooperation and should thus be appropriately rewarded.

Whatever the year considered, proportional methods differ significantly from the others. These differences are noteworthy for Qatar and South East Asian exporters (Brunei, Indonesia and Malaysia). With proportional methods, Qatar's share is not that different from those received by other exporters, which is somehow astonishing given the presupposed importance of Qatar for the grand coalition (because of its marginal contributions). By contrast, these allocations provide large gains to South East Asian exporters. The three "lexicography inspired" methods all provide equivalent rankings of the shares to be earned in a given year. In the 2007 example, Qatar would have received the largest share, followed by Egypt, Algeria, Nigeria, Trinidad & Tobago, Indonesia, Malaysia, Oman, UAE, Equatorial Guinea, Libya and Brunei. Moreover, the nucleolus and the per capita nucleolus schemes provide similar numerical results.

[18] The strict core is defined as $\left\{ x \in C(v) : \sum_{i \in S} x_i > v(S), S \subset N, S \neq \varnothing \text{ and } \sum_{i \in N} x_i = v(N) \right\}$.

4.2 *Checking the method's properties*

Group rationality

Excepted for the marginal contribution, all these allocation methods are elements of the imputation set $I(v)$ and individual exporters thus have an incentive to join the cooperation. But do those allocations provide an incentive to cooperate for each of the other $(2^n - 2 - n)$ non-trivial and non individual subgroups that could be formed in N ? By construction, this verification is obviously not required for the nucleolus-inspired allocations since the cores of these three games are non-empty.

For some other methods, a simple observation of the allocation results listed in Table 11 can be sufficient to prove that some methods do not belong to the core. With proportional schemes, the share allocated to some individual participants i like Oman, Libya, Brunei, Indonesia and Malaysia would be too large since it would exceed i's marginal contributions m_i. Reframed in a cross-subsidy's context (Faulhaber, 1975), it simply means that those allocations would "unduly" favor these individual exporters i at the expense of those involved in the complementary coalitions $N \setminus i$. Each of those complementary coalitions $N \setminus i$ could thus rightly prefer to stay away from any GECF agreement based on these proportional schemes.

According to the results of a complete enumeration presented in Table 6, a similar line of arguments could also be proposed for numerous non-trivial coalitions. Compared to the proportional methods, both the Shapley value and the ACA method appear somewhat more appropriate since the number of "unhappy" coalitions is reduced. For 2006, we even found that an ACA allocation belongs to the core of a year's game. But, these two gain-sharing schemes can not provide a mechanism that would be unanimously accepted whatever the year considered.

Table 6: Results of core belonging tests. 'Yes' indicates core belonging.
The numbers of coalitions likely to refuse the GECF agreement, if any, are given in italics.

	Equal Repartition	Proportional to profits	Proportional to quantities	« ACA » method	Shapley Value
2006	No *358*	No *332*	No *351*	Yes *0*	No *18*
2007	No *981*	No *756*	No *748*	No *2*	No *52*
2008	No *1354*	No *1095*	No *1079*	No *37*	No *105*

Therefore, among the methods studied in this article, only three: the nucleolus, the per capita nucleolus and the disruption nucleolus, systematically provide an incentive-compatible gain allocation. But can we go further and find a criterion that could be used to discriminate one method among the three remaining ones?

Aggregate-monotonicity

Following Young et al. (1980), we can note that the allocation method is usually chosen before the cooperation has been started, at a time when the total gains obtained from cooperation are yet to be earned and can only be estimated. As a consequence, it is not unrealistic to imagine that each potential participant in the GECF will actively consider various gain scenarios and check allocation outcomes before committing to the GECF. As a result, it would not be surprising to observe that participants collectively require the allocation method to satisfy an elementary monotony property named *aggregate-monotonicity* property (Megiddo, 1974). Denote $x(v)$ - respectively $x(\bar{v})$ - the outcome of a given allocation method computed for the game (N,v) - respectively $(N,\bar{v})$. An allocation $x \in \mathbf{R}^n$ is monotonic in the aggregate if (Young, 1985, p.17) for all v, $\bar{v}$ and N :

$$v(N) \geq \bar{v}(N) \text{ and } v(S) = \bar{v}(S) \text{ for all } S \underset{\neq}{\subset} N$$
$$\text{implies } x_i(v) \geq x_i(\bar{v}) \text{ for all } i \in N$$

For the GECF case, aggregate-monotonicity is desirable since it basically assures the participants, after committing themselves to an allocation, that if the total gain was to decrease then no participant would receive more; conversely, if total gain increases, no individual payments will decrease.

Unfortunately, this desirable property is not always satisfied. For the nucleolus, this is a well-known result that was formally established by Megiddo (1974). On the contrary, the per capita nucleolus rule is always monotonic in the aggregate (Young et al., 1980). Regarding the disruption nucleolus, a simple numerical test provides some valuable information. For example, we consider the year 2008[19] and assume that the total gain of the grand coalition N is slightly decreased by \$0.5 million, a figure that is compatible with a non-empty core for the game $(N,\bar{v})$. The three nucleolus methods have been successively computed for that game and the results are reported in Table 7. A simple comparison with previous results presented in Table 11 confirms that the disruption nucleolus is not monotonic in the aggregate (cf. Qatar's allocations).

As a result, considering both core belonging and monotonicity in the aggregate significantly narrows the set of possible allocations for the GECF. Among the methods considered in this article, the per capita nucleolus is the only one that verifies both requirements... In the next subsection, we thus assume that the per capita nucleolus is selected and implemented.

[19] As similar results have also been obtained with the years 2006 and 2007, we have chosen to report only 2008 figures for the sake of brevity.

Table 7: Allocation results for the year 2008 with a $0.5 million reduction in the total gain (in M$).

	Nucleolus	Per Capita Nucleolus	Disruption Nucleolus
Trinidad & Tobago	131.529	128.551	129.176
Oman	17.206	16.775	18.749
Qatar	439.122	447.762	401.588
UAE	5.441	4.343	7.113
Algeria	101.306	97.619	108.507
Egypt	159.117	168.460	167.875
Equatorial Guinea	24.708	21.265	30.788
Libya	0.807	0.220	1.358
Nigeria	66.212	63.643	77.806
Brunei	0.203	0.034	0.342
Indonesia	20.327	19.229	20.813
Malaysia	20.729	18.809	22.594
TOTAL	*986.708*	*986.708*	*986.708*

4.3 Dealing with a costly coordination

In the previous subsection, we have assumed that coordination can be organized at a zero cost so that there is a complete redistribution of the gains earned thanks to the GECF. However, it is highly likely that such a cooperation will induce a coordination cost. In the oil industry, OPEC's coordination requires a General Secretariat based in Vienna whose cost is possibly limited but obviously not equal to zero. As far as the GECF is concerned, the creation of a dedicated Liaison Office to be located in Qatar is considered (Hallouche, 2006). Moreover the formulation of a logistic model, the gathering of the data, and the numerical analysis are time-consuming and possibly expensive activities. If the coordination becomes a costly activity, two questions arise. Firstly, how does the existence of an annual coordination cost denoted $\omega > 0$ influence the gain-sharing outcome? Secondly, what is the maximum amount, denoted $\bar{\omega}$, that can be tolerated by the participants without calling into question the advantages of cooperation via the GECF?

Incidence on the gain-sharing outcome

Regarding the impact on the per capita nucleolus outcome, the demonstration in Young et al. (1980) provides a nice answer. If we assume that a costly GECF can be described by the game $(N,\bar{v})$ with a reference to the zero-cost case (N,v) so that $\bar{v}$ is defined as: $\bar{v}(N) = v(N) - \omega$ and $v(S) = \bar{v}(S)$ for all $S \underset{\neq}{\subset} N$, the per capita nucleolus $x(\bar{v})$ of the game $(N,\bar{v})$ can also be described from those of game (N,v). In the costly case, each country i receives $x_i(\bar{v}) = x_i(v) - \frac{\omega}{n}$, which corresponds to an equal repartition of the coordination costs. In passing, we can note that applying an OPEC-inspired institutional organization to the GECF is an issue frequently raised by GECF observers and it is interesting to see that this coordination cost sharing rule is precisely the one used by the OPEC (OPEC Statute, 2008, art. 37, p.21).

The maximum coordination cost

The second question can be reframed as finding the maximum $\overline{\omega}$ compatible with a non-empty core for the game $\left(N,\overline{v}\right)$. Again, solving a simple linear programming problem provides the answer:

Program n°4

$$\overline{\omega} = \underset{x_i,\omega}{Max} \quad \omega$$

$$\text{s.t.} \quad \omega + \sum_{i=1}^{n} x_i = v(N)$$

$$\sum_{i \in S} x_i \geq v(S) \qquad (S \subset N, S \neq N)$$

$$\omega \geq 0 \ , \ \ x_i \geq 0 \ , \qquad (i = 1,2,...,n)$$

With previous assumptions, we found some particularly low values for $\overline{\omega}$: \$1.072 million for the year 2006, \$0.721 million for the year 2007 and \$0.905 million for 2008. Any greater amount can be considered as unsustainable because it corresponds to an empty core situation.

By construction, with $\omega = \overline{\omega}$, there is at least one coalition $S' \subset N$ for which any allocation x in the core of $\left(N,\overline{v}\right)$ satisfies $\sum_{i \in S'} x_i = v(S')$. Such a coalition S' has thus an infinite propensity to disrupt and is perfectly indifferent between (1) cooperating within the GECF (and hence contributing to $\overline{\omega}$) or (2) staying on its own. Obviously, this remark suggests that a zero coordination cost has been implicitly assumed for any subgroup $S \subset N, S \neq N$. Hence, we are supposing that S' is able to earn $v(S')$ without incurring any coordination costs even if the cardinality $|S'|$ is large. It means that the coordination cost $Cc(S)$ of a given subgroup $S \subseteq N$ is equal to $\overline{\omega}$ if $S = N$ and to zero when $S \subset N \ \ (S \neq \emptyset, N)$. An assumption of the amount of coordination costs incurred by S as a function of $|S|$ could certainly be needed to get a more realistic representation. As a result, we have tested various functional forms for these coordination costs but our results remain consistent with the conclusion that the GECF cannot afford large coordination costs[20].

Obviously, the coordination of these exportation policies can be a complex task. Given the very low figures found for $\overline{\omega}$, it is clear that even a limited coordination cost can be enough to lead to an empty core situation. In this unfortunate situation, whatever the proposed gain-sharing method, there is always at least one coalition that can rightly protest against the allocation outcome.

[20] For example, in the 2007 game, the maximum cost $\overline{\omega}$ remains as low as \$4.153 million with a quadratic cost like $Cc(S) = \rho.(|S|-1)^2$ where $\rho = \overline{\omega}/(n-1)^2$ for $S \subseteq N \ \ (S \neq \emptyset)$.

4.4 *Further discussion: a cooperation without money transfers?*

Given that a gain redistribution policy may be difficult to agree upon, it may be worthwhile to consider a case where players cannot transfer these gains amongst themselves[21]. That subsection offers some preliminary insights in that direction.

In fact, a simple adaptation of the previous framework is sufficient to assess the maximum collective gain that could be achieved by an incentive-compatible cooperation without any money transfers. That assessment has been obtained by adding n participation constraints to "Program 1": $\pi_i\left(q_i\right) \geq \pi_i\left(Q_i\right),\ \forall i$. As expected, the inclusion of these additional constraints further reduces the annual collective gain: -33% in 2006, -25% in 2007 and -16% in 2008 (cf. Table 8). Moreover, some countries (e.g.: Trinidad & Tobago, Qatar, Nigeria...) derive no individual gain from their participation to N and thus remain indifferent between a stand alone attitude and a cooperation within the grand coalition.

Table 8: Impact of the optimal GECF shipping policies on the individual annual profits (in M$)

	2006	2007	2008
Trinidad & Tobago	0	0	0
Oman	0	16.91	21.07
Qatar	0	0	0
UAE	0	0	95.09
Algeria	28.55	322.44	226.87
Egypt	443.75	344.88	320.21
Equatorial Guinea	-	14.31	118.79
Libya	0.71	0.75	0.53
Nigeria	0	0	0
Brunei	0	0	0
Indonesia	0	0	0
Malaysia	24.42	26.75	44.66
TOTAL	**497.43**	**726.05**	**827.22**

At this stage, it may be worthwhile analyzing whether some exporters may be willing to block, or not, the creation of that large cooperation. For a given coalition $S \subset N$, comparing the individual gain improvements proposed by S with those proposed in Table 8 provides a useful indication on the attitude of S toward the grand cooperation. Any coalition S able to provide individual gains $v_i\left(S\right)$ to its members i that are all strictly larger than their counterpart $v_i\left(N\right)$ proposed by the grand coalition is said to block N. Evidently, all the exporters involved in such a coalition S would unanimously prefer to cooperate within S than within N.

Using Program 2, it is easy to compute the optimal shipping policy for each of the non-trivial subgroups in N. Among them, we have identified numerous coalitions whose optimal shipment policy would both (i) provide strictly positive individual gains to each member (i.e. the individual

[21] We thank an anonymous referee for having drawn our attention on the questions discussed in this subsection.

rationality constraints are not binding and no money transfer are required to obtain the individual participation of the members) and (ii) involve countries who all obtain a strictly larger individual gain than those proposed by the grand coalition (hence, members unanimously prefer to organize themselves into groups rather than cooperate within a group). Among these coalitions, there are obvious ones. For example in 2008, a simple bilateral cooperation between Trinidad & Tobago and Qatar could have provided them with $76.85 million and $57.74 million respectively. Comparing these figures with the zero individual gains proposed in Table 8 clearly demonstrates that blocking the creation of the grand coalition would be a rational decision for these two countries.

Furthermore, we have also tried alternative arrangements for the grand coalition and have still found that implementing a large cooperation within N without side payments is a difficult task. For example, we have considered the case of a cooperation designed to maximize, in a lexicographic order, the individual gain of each member. Our goal was to provide strictly positive gains for every member without implementing any side payment. Of course, such a compromise also leads to a further reduction in the total collective gain to $311.71 million, $427.89 million and $528.62 million for 2006, 2007 and 2008 respectively. Unfortunately, we found that this compromise remains insufficient to prevent some subgroups from blocking the creation of the large coalition. Again, our 2008 example provides a clear illustration as Qatar and Trinidad & Tobago would continue to unanimously prefer their bilateral agreement to the grand cooperation (as that latter cooperation would only provide them an individual $49.70 million gain in profit).

Further research involving the formulation of a cooperative game with non-transferable utility (NTU-game) could be required to discuss the feasibility of a large shipping cooperation that involves no money transfers. This is beyond the scope of this article. Nevertheless, these preliminary insights suggest that the creation of such an organization would face large complexities.

Conclusions

Since the mid-2000s we are seeing heightened concern about the future of the GECF and the possible emergence of a cartel in the gas industry. As a consequence, many authors have proposed a detailed description of the GECF. Apart from rare exceptions, most of those contributions present a strict geopolitical approach and lack a clear economic analysis. This paper attempts to illustrate how some quantitative techniques can be used to address an important issue: What behavior will the GECF adopt in the future?

Many industrial observers share an idealized view of how cooperation among LNG exporters could be entirely devoted to the promotion of a purely logistic cooperation. In most cases, there is no room for market power issues in those mental constructions. This paper investigates the rationale of that argument. We thus adopted this strong behavioral assumption and supposed that the GECF’s objective can be reframed as the identification of optimum routes and schedules for a fleet of vessels carrying participants' LNG throughout the world by means of a simple transportation model. In this particular instance of a transportation problem, cooperation is found to be collectively profitable since there is a potential for a reduction of the lengths of actual supply chains. But, results also indicate that some countries could rationally prefer to stay away from the GECF unless a redistribution mechanism could be implemented. Thanks to a cooperative game theory framework, we show that the logistic cooperation at hand corresponds to a super-additive TU-game whose core is non-empty. Several classic allocation concepts (basic sharing methods, the Shapley value and nucleolus-inspired methods) have been implemented and analyzed in the light of two desirable axiomatic properties. Firstly, core belonging is considered as an imperative prerequisite since it eliminates possible contestation to the proposed redistribution scheme. Then, aggregate-monotonicity is checked in order to promote the methods that are able to adapt to changing conditions of the total value to be shared. Out of the methods studied, only one - the per capita nucleolus – satisfies both criterions. Thus, the range of conceivable methods appears significantly narrower than expected. Moreover, this nucleolus-inspired method is somehow complicated and requires detailed information on costs, distances... From a strict practical perspective, some doubts can be raised on the capability of the GECF to implement such a non-trivial allocation. Lastly, coordination costs were considered. Our results indicate that a limited amount of coordination costs could be sufficient to deny the possibility of finding a core-belonging allocation of the gains, thus creating some incentive for a split up of the grand coalition. According to these results, it seems that a *reductio ad absurdum* has been reached which makes us think that the assumption of a rationalization-motivated cooperation must be reconsidered.

Further research is thus needed to analyze the GECF. Regarding the perspective used in this article, several improvements could be considered to strengthen the validity of that result (e.g. a dynamic framework, the probable upcoming entry of large LNG exporters such as Russia, Iran and Venezuela...). Of course, upcoming research should also consider an alternative behavioral assumption for the GECF: that of a cartel that collectively seeks to exert some market power.

Acknowledgement

The first author is heavily indebted to Michel Le Breton for his brilliant presentation of cooperative game theory. Many people have provided helpful comments and suggestions on the analysis, and we are pleased to take this opportunity to thank them. We are especially grateful to Albert Banal-Estanol, Aymeric Lardon, Michel Le Breton, Jacques Percebois and one anonymous referee for helpful comments and suggestions. Thanks are also due to Gaelle Barrot, Laurent David, Joanne Evans, Dermot Gately, Axel Pierru, and Philippe Solal. All remaining errors are ours. The views expressed herein are strictly those of the authors and are not to be construed as representing those of the IFP.

References

Boots, M.G., Rijkers, F.A.M., Hobbs, B.F., 2004. Trading in the downstream European gas market: a successive oligopoly approach. The Energy Journal 25 (3), 73–102.

BP, 2008. BP Statistical Review of World Energy. BP, London.

Boyer, M., Moreaux, M., Truchon, M., Partage des coûts et tarification des infrastructures, Monographie CIRANO 2006MO-01, Mars 2006, CIRANO, Montréal.

Brito D.L, Hartley P.R., 2007. Expectations and the Evolving World Gas Market, The Energy Journal 28 (1), 1–24.

Brown S., Yücel M., 2009. Market Arbitrage: European and North American Natural Gas Prices. The Energy Journal Special issue: World Natural Gas Markets and Trade: A Multi-Modelling Perspective, 167-185.

Cremer J., Weitzman M., 1976. OPEC and the Monopoly Price of World Oil. European Economic Review 8 (2), 155-164.

Dantzig, G. B. 1951. Application of the simplex method to a transportation problem. In Koopmans, T. C. (ed.), Activity Analysis of Production and Allocation, John Wiley& Sons: NY; 1951. 359-373.

DTI, 2005. UK Capability in the LNG Global Market. Department of Trade and Industry, Energy Technologies and Industries Unit. London.

Egging R., Gabriel S.A., Holz F., Zhuang J., 2008. A complementarity model for the European natural gas market. Energy Policy 36 (7), 2385-2414.

EMF (Energy Modeling Forum), 2007. Prices and Trade in a Globalizing Natural Gas Market, EMF Report 23, July 2007. Stanford University. Stanford.

Engevall S., Göthe-Lundgren M., Värbrand P., 1998. The traveling salesman game: An application of cost allocation in a gas and oil company. Annals of Operations Research 82 (1), 453-472.

Faulhaber G.R., 1975. Cross-subsidization: pricing in public enterprises. American Economic Review 65 (5), 966-977.

Finon D., 2007. Russia and the "Gas-OPEC". Real or Perceived Threat? IFRI Russia/NIS Center, Paris.

Flood M. M., 1954. Application of Transportation Theory to Scheduling a Military Tanker Fleet. Journal of the Operations Research Society of America (2), 150-162.

Gately D., 1974. Sharing the games from regional cooperation: a game theoretic application to planning investment in electric power. International Economic Review 15 (1), 195-208.

GIIGNL, 2008. The LNG Industry. GIIGNL, Paris.

Gillies, D.B., 1953. Some theorems on n-Person games. Ph.D. Thesis, Princeton.

Golombek R., Gjelsvik E., Rosendahl K.E., 1995. Effects of liberalizing the natural gas markets in Western Europe. The Energy Journal 16 (1), 85–111.

Granot, D., F. Granot, Zhu W.R., 1998. On Characterization Sets for the Nucleolus, International Journal of Game Theory 27, 359-374.

Greaker M, Sagen E., 2008. Explaining experience curves for new energy technologies: A case study of liquefied natural gas. Energy Economics 30, 2899–2911

Grotte, J.H., 1970. Computation of and Observations on the Nucleolus, and the Central Games. M.Sc. Thesis, Cornell University.

Hallouche H., 2006. The Gas Exporting Countries Forum: Is it really a Gas OPEC in the Making, Oxford Institute for Energy Studies, NG 13, Oxford.

Hartley P., Medlock. K.B., 2006. Political and economic influences on the future world market for natural gas. In Victor, D.G., Jaffe, A.M., Hayes, M. H. (Eds), Natural Gas and Geopolitics: From 1970 to 2040, chapter 12, Cambridge University Press; 2006.

Holz F., Hirschhausen C.v., Kemfert C., 2008. A Strategic Model of European Gas Supply (GASMOD), Energy Economics 30 (3), 766–788.

Huntington H. G. (ed.), 2009. World Natural Gas Markets and Trade: A Multi-Modelling Perspective, The Energy Journal, Special issue.

Jaffe A.M., Soligo R. 2006. Market Structure in the New Gas Economy: Is Cartelization Possible? In Victor, D.G., Jaffe, A.M., Hayes, M. H. (Eds), Natural Gas and Geopolitics: From 1970 to 2040, chapter 11, Cambridge University Press; 2006.

Jensen J.T., 2003. The LNG revolution. The Energy Journal 24 (2), 14-58.

Jensen, J.T. The Development of a Global LNG Market. Is it Likely? If so When?, Oxford Institute for Energy Studies, London; 2004.

Kantorovich L. V., 1960. Mathematical Methods of Organizing and Planning Production. Management Science 6 (4), 366-422.

Kattuman P.A., Green R.J., Bialek J.W., 2004. Allocating electricity transmission costs through tracing: a game-theoretic rationale. Operations Research Letters 32 (2), 114-120.

Koopmans T., 1949. Optimum Utilization of the Transportation System. Econometrica 17, 136-145.

Kopelowitz A., 1967. Computation of the kernels of simple games and the nucleolus of n-person games. RM-131, Mathematics Department, The Hebrew University of Jerusalem, Israel.

Littlechild S.C., Vaidya K.G., 1976. The propensity to disrupt and the disruption nucleolus of a characteristic function game. International Journal of Game Theory 5 (2-3), pp. 151–161.

Mandil C., 2008. "Bientôt une OPEP du gaz" Interview by Challenges magazine 22nd September 2008; http://www.challenges.fr/actualites/finance_et_marches/20080922.CHA6616/bientot_une_opep_du_gaz_.html

Mathiesen L., Roland K., Thonstad K., 1987. The European Natural Gas Market. Degrees of Market Power on the Selling Side. In Golombek and Hoel (eds.), Natural Gas Markets and Contracts, North Holland Publ. Co., Amsterdam, 1987.

Mazighi A. E. H., 2003. An examination of the international natural gas trade, OPEC Review 27 (4), 313-329.

Moulin H. Axioms of Cooperative Decision Making: Monograph of the Econometric Society, Cambridge University Press: Cambridge; 1991.

Megiddo N., 1974. On the nonmonotonicity of the bargaining set, the kernel, and the nucleolus of a game. SIAM Journal of Applied Mathematics 27 (2), 355-358.

Neumann A., 2009. Linking Natural Gas Markets – Is LNG Doing its Job? The Energy Journal Special issue: World Natural Gas Markets and Trade: A Multi-Modelling Perspective, 187-199.

OME. Assessment of Internal and External Gas Supply Options for the EU - Evaluation of the Supply Costs of New Natural Gas Supply Projects to the EU and an Investigation of Related Financial Requirements and Tools. Observatoire Méditerranéen de l'Energie: Sophia-Antipolis; 2001.

OPEC (Organization of Petroleum Exporting Countries). OPEC Statute 2008, OPEC Secretariat: Vienna; 2008.

Percebois J. L'économie de l'énergie, Editions Economica: Paris; 1989.

Percebois J., 2008. The supply of natural gas in the European Union—strategic issues, OPEC Energy Review 32 (1), 33-53

Pierru A., 2007. Allocating the CO_2 emissions of an oil refinery with Aumann–Shapley prices. Energy Economics 29 (3), 563-577.

Rosendahl K.E.and E. L. Sagen, 2009. The Global Natural Gas Market: Will Transport Cost Reductions Lead to Lower Prices? The Energy Journal 30 (2), 17-40.

Schmeidler D., 1969. The nucleolus of a characteristic function game. SIAM Journal on applied mathematics 17, 1163-1170.

Shapley, L.S., 1953. A Value for n-Person Games. In Kuhn, H.W. and Tucker, A.W. (eds.) Contributions to the Theory of Games, n. II, Annals of Math. Studies, 28. Princeton University Press; 1953. pp. 307-317.

Tijs S. H., Driessen T. S. H., 1986. Game Theory and Cost Allocation Problems, Management Science 32 (8), 1015-1028.

Tönjes C., de Jong J. Perspectives on security of supply in European natural gas markets, CIEP, Clingendael Institute: The Hague; 2007.

Wagbara O.N., 2007. How would the gas exporting countries forum influence gas trade? Energy Policy 35(2), 1224-1237.

Wolak F.A., Kolstad C.D., 1988. Measuring Relative Market Power in the Western U.S. Coal Market Using Shapley Values. Resources and Energy 10 (4), 293-314.

Yepes Rodríguez R., 2008. Real option valuation of free destination in long-term liquefied natural gas supplies. Energy Economics 30 (4), 1909-1932.

Yergin D., Stoppard M., 2003. The next prize. Foreign Affairs 82 (6), 103-114.

Young H.P., Okada N., Hashimoto T., 1980. Cost Allocation in Water Resources Development. A Case Study of Sweden. IIASA Research report, Laxenburg.

Young H.P., 1985. Methods and principles of cost allocation. In. H. Young. (Ed.) Cost Allocation: Method, principles, applications. North-Holland: Amsterdam; 1985.

Zhuravleva P., 2009. The Nature of LNG Arbitrage: an Analysis of the Main Barriers to the Growth of the Global LNG Arbitrage Market, Oxford Institute for Energy Studies, NG 31, Oxford.

Appendix A. Costs assumptions

Table 9: Unit costs used in that study ($/1000m^3)*

	Gas extraction and liquefaction costs C_i ($/1000m³) *	Unit shipping costs T_{ij} for LNG ($/1000m³) **																
		North America				Europe								Asia				
		US	Mexico	Dominican Republic	Puerto Rico	Belgium	France	Greece	Italy	Portugal	Spain	Turkey	United Kingdom	China	India	Japan	South Korea	Taiwan
Trinidad & Tobago	21.19	25.24	29.76	15.29	16.33	44.89	43.59	57.23	48.6	40.47	40.61	61.62	44.41	82.32	86.29	90.77	95.82	102.59
Oman	14.13	77.87	90.67	74.59	73.41	62.32	46.77	31.21	45.49	50.31	47.67	30.82	63.69	47.24	16.64	63.99	57.05	51.81
Qatar	10.59	95.4	108.36	92.08	90.89	65.65	50.34	35.88	49.07	56.86	51.47	35.49	67.02	53.11	20.61	64.78	62.96	54.63
UAE	12.36	94.88	107.84	91.56	90.37	65.54	49.95	35.35	48.67	56.75	50.94	34.97	66.92	54.21	20.29	65.91	64.08	55.73
Algeria	15.89	42.52	54.98	39.33	38.18	23.69	13.59	18.15	14.08	15.18	11.09	22.4	24.79	83.27	52.44	91.71	93.66	84.9
Egypt	21.19	56.92	69.54	53.68	52.52	38.47	22.99	15.11	22.32	29.84	23.48	15.67	38.95	68.02	39.32	81.2	78.31	71.49
Equatorial Guinea	17.66	58.48	67.52	52.72	50.9	49.69	46.04	59.46	47.83	41	40.48	60.19	50.18	95.95	73.84	108.04	104.25	97.42
Libya	17.66	52.72	65.33	49.57	48.35	33.8	19.57	19.79	18.55	25.21	19.55	20.27	34.91	74.89	43.92	88.51	85.22	77.59
Nigeria	17.66	56.59	65.63	51.38	49.92	49.06	45.41	54.4	47.2	40.37	39.85	55.14	49.55	94.35	73.3	106.28	103.95	95.39
Brunei	14.19	110.02	123.13	106.65	105.44	81	65.21	50.43	63.92	72.09	65.54	50.04	82.39	23.14	28.46	31	27.68	27.86
Indonesia	8.97	123.39	136.61	120	118.78	94.13	78.16	63.31	76.91	85.15	78.54	62.91	95.53	23.18	41.02	29.09	27.61	22.44
Malaysia	35.47	120.83	134.16	117.42	116.19	91.36	75.32	60.31	74.01	82.32	75.66	59.91	92.77	24.41	37.99	30.21	25.96	23.08

*Sources: * OME (2001) and calculations by the authors based on various sources (DTI, 2005; GIIGNL, 2008)*[22].

Appendix B. Numerical results for the year 2007

Table 10: Optimized LNG trade movements from GECF countries for year 2007 (Bcm)

to	North America				Europe								Asia					
From	US	Mexico	Dominican Republic	Puerto Rico	Belgium	France	Greece	Italy	Portugal	Spain	Turkey	United Kingdom	China	India	Japan	South Korea	Taiwan	Total Export
Trinidad & Tobago	14.88	2.17	0.36	0.74	-	-	-	-	-	-	-	-	-	-	-	-	-	**18.15**
Oman	-	-	-	-	-	-	-	-	-	-	-	-	.57	2.43	-	9.16	-	**12.16**
Qatar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.9	-	10.59	**38.49**
UAE	-	-	-	-	-	-	-	-	-	-	-	-	-	7.55	-	-	-	**7.55**
Algeria	-	-	-	-	-	9.26	-	-	-	15.41	-	-	-	-	-	-	-	**24.67**
Egypt	-	-	-	-	-	3.64	0.81	1.67	-	-	6.01	-	-	-	1.48	-	-	**13.61**
Equatorial Guinea	-	-	-	-	-	-	-	-	-	1.42	-	-	-	-	-	-	-	**1.42**
Libya	-	-	-	-	-	-	-	0.76	-	-	-	-	-	-	-	-	-	**0.76**
Nigeria	6.94	-	-	-	3.17	-	-	-	2.31	7.28	-	1.46	-	-	-	-	-	**21.16**
Brunei	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.35	-	-	**9.35**
Indonesia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.74	-	-	**27.74**
Malaysia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.12	24.67	-	**29.79**
Total imports	**21.82**	**2.17**	**0.36**	**0.74**	**3.17**	**12.9**	**0.81**	**2.43**	**2.31**	**24.11**	**6.01**	**1.46**	**0.57**	**9.98**	**71.59**	**33.83**	**10.59**	**204.85**

[22] A technical appendix, available from authors upon request, provides a complete presentation of the methodology and the numerical assumptions used in that study.

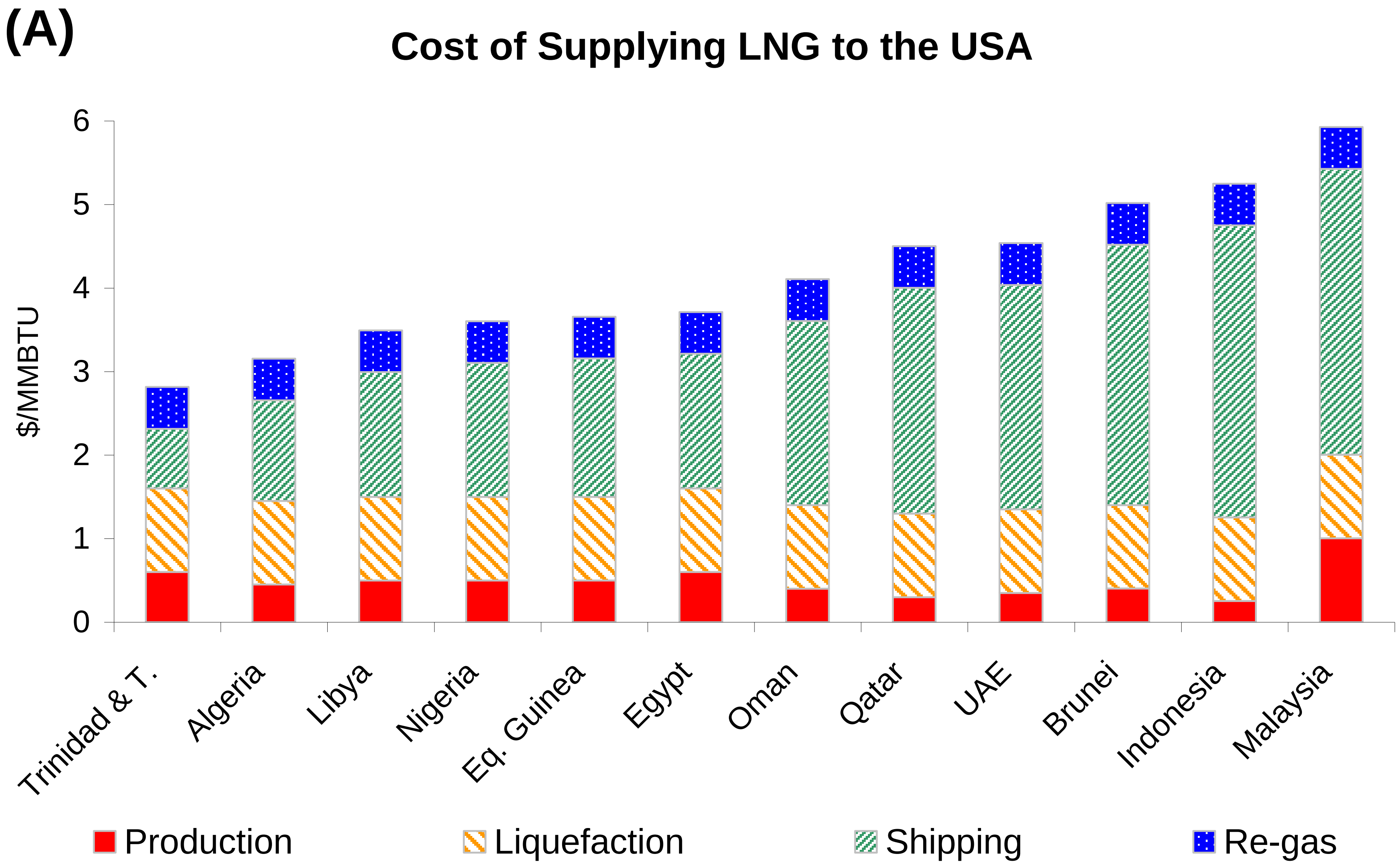
Appendix C. Results

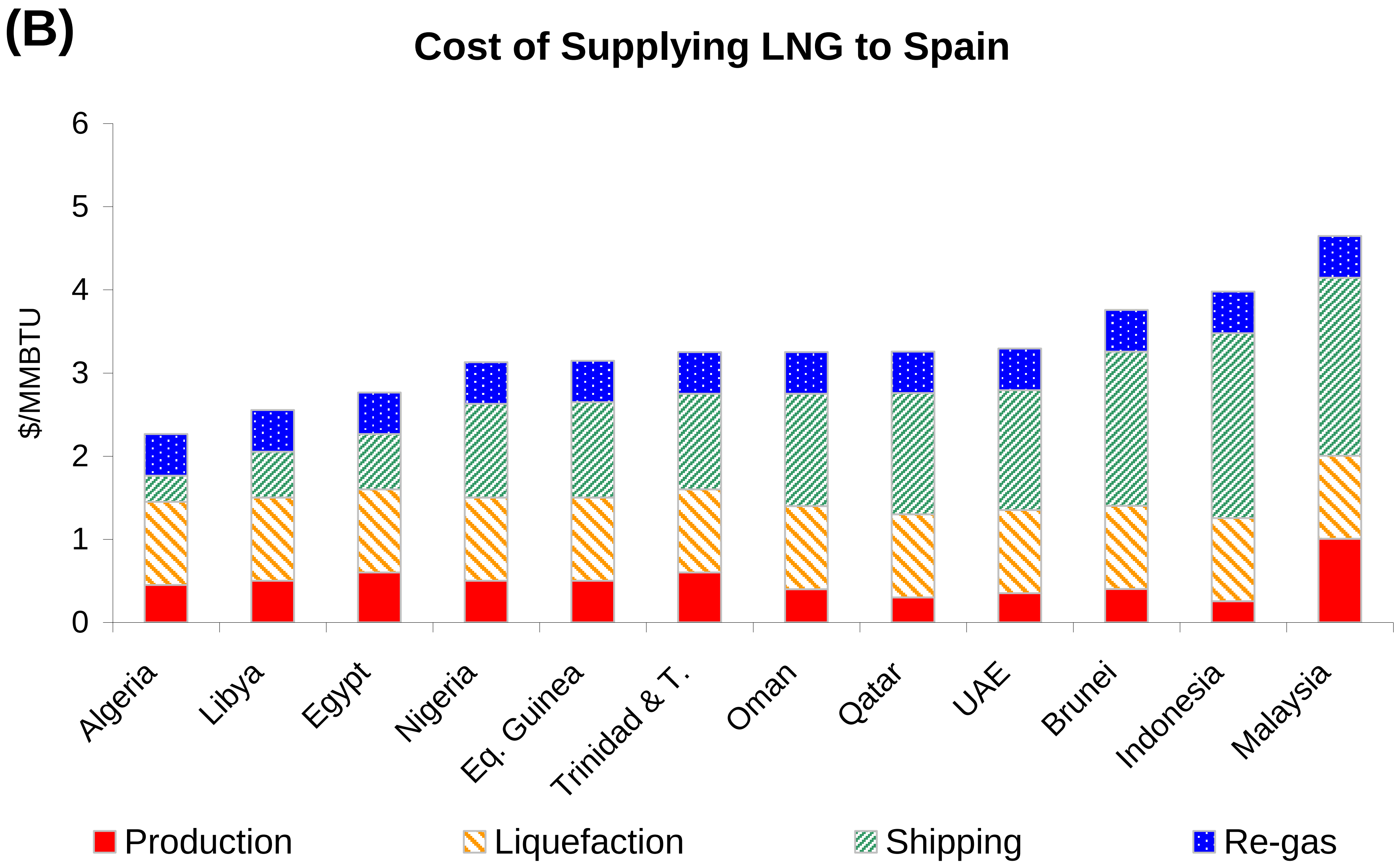
Table 11: Annual gain allocation by nine methods computed for each of the three annual games (M$)

		Marginal Contribution	Equal Repartition	Proportional to profits	Proportional to quantities	« ACA » method	Shapley Value	Nucleolus	Per Capita Nucleolus	Disruption Nucleolus
2006	Trinidad & Tobago	149.437	67.836	59.628	63.376	106.468	103.66	99.962	97.129	108.619
	Oman	21.29	67.836	37.285	45.007	15.168	31.027	14.922	14.755	15.964
	Qatar	235.713	67.836	110.288	121.253	167.937	148.864	166.697	175.454	163.237
	UAE	8.212	67.836	20.903	27.612	5.851	7.944	4.09	2.082	5.753
	Algeria	187.465	67.836	130.867	96.254	133.563	128.086	123.15	127.206	134.177
	Egypt	264.719	67.836	60.136	58.384	188.604	178.194	205.707	204.46	190.353
	Libya	2.036	67.836	3.843	2.808	1.451	2.491	1.018	0.258	1.068
	Nigeria	103.235	67.836	77.027	68.563	73.552	90.86	77.706	73.933	75.167
	Brunei	1.072	67.836	36.825	38.26	0.764	3.738	0.536	0.097	0.782
	Indonesia	33.493	67.836	116.78	115.325	23.863	22.662	28.108	27.363	25.041
	Malaysia	40.676	67.836	92.618	109.358	28.98	28.673	24.305	23.462	26.037
	TOTAL	*1047.348*	*746.2*	*746.2*	*746.2*	*746.2*	*746.2*	*746.2*	*746.2*	*746.2*
2007	Trinidad & Tobago	123.695	80.692	76.695	85.793	94.130	117.062	81.577	78.334	93.630
	Oman	20.253	80.692	49.784	57.479	15.413	20.445	17.195	16.868	16.541
	Qatar	459.779	80.692	174.921	181.938	349.885	289.67	386.845	398.619	351.103
	UAE	8.386	80.692	29.809	35.688	6.382	8.332	5.306	5.000	6.832
	Algeria	205.191	80.692	146.34	116.613	156.147	161.099	144.886	144.776	155.629
	Egypt	245.722	80.692	60.172	64.333	186.991	174.970	188.052	185.307	187.873
	Equatorial Guinea	6.663	80.692	4.190	6.712	5.071	20.568	3.604	3.277	5.442
	Libya	2.149	80.692	4.750	3.592	1.636	3.051	1.075	0.280	0.922
	Nigeria	134.774	80.692	105.591	100.021	102.561	121.775	92.220	89.413	102.845
	Brunei	0.721	80.692	45.461	44.197	0.549	3.221	0.360	0.060	0.313
	Indonesia	30.113	80.692	141.207	131.124	22.916	21.738	27.055	26.728	24.594
	Malaysia	34.99	80.692	129.387	140.814	26.627	26.377	20.132	19.643	22.581
	TOTAL	*1272.43*	*968.306*	*968.306*	*968.306*	*968.306*	*968.306*	*968.306*	*968.306*	*968.306*
2008	Trinidad & Tobago	179.086	82.267	65.813	82.933	140.349	125.942	131.423	128.592	129.209
	Oman	22.789	82.267	52.474	53.079	17.86	22.432	17.25	16.817	19.078
	Qatar	482.113	82.267	195.887	193.279	377.83	341.164	438.955	447.804	400.643
	UAE	10.356	82.267	35.721	36.723	8.116	8.755	5.506	4.384	6.975
	Algeria	143.709	82.267	117.065	106.494	112.625	114.976	101.136	97.661	108.382
	Egypt	230.727	82.267	62.517	68.088	180.82	170.038	159.348	168.501	168.066
	Equatorial Guinea	37.101	82.267	21.421	25.229	29.076	59.393	24.765	21.306	31.06
	Libya	2.114	82.267	2.851	2.581	1.657	2.562	1.057	0.261	1.77
	Nigeria	92.997	82.267	96.136	100.036	72.882	95.343	66.167	63.685	77.854
	Brunei	0.906	82.267	48.135	44.809	0.71	3.438	0.453	0.075	0.758
	Indonesia	25.242	82.267	143.711	130.754	19.782	18.782	20.419	19.27	21.132
	Malaysia	32.54	82.267	145.476	143.203	25.502	24.384	20.729	18.85	22.282
	TOTAL	1259.681	987.208	987.208	987.208	987.208	987.208	987.208	987.208	987.208

FIGURES

COLOUR VERSION


(A)
Cost of Supplying LNG to the USA
$/MMBTU
0
1
2
3
4
5
6
Trinidad & T.
Algeria
Libya
Nigeria
Eq. Guinea
Egypt
Oman
Qatar
UAE
Brunei
Indonesia
Malaysia
Production
Liquefaction
Shipping
Re-gas



(B)
Cost of Supplying LNG to Spain
$/MMBTU
0
1
2
3
4
5
6
Algeria
Libya
Egypt
Nigeria
Eq. Guinea
Trinidad & T.
Oman
Qatar
UAE
Brunei
Indonesia
Malaysia
Production
Liquefaction
Shipping
Re-gas

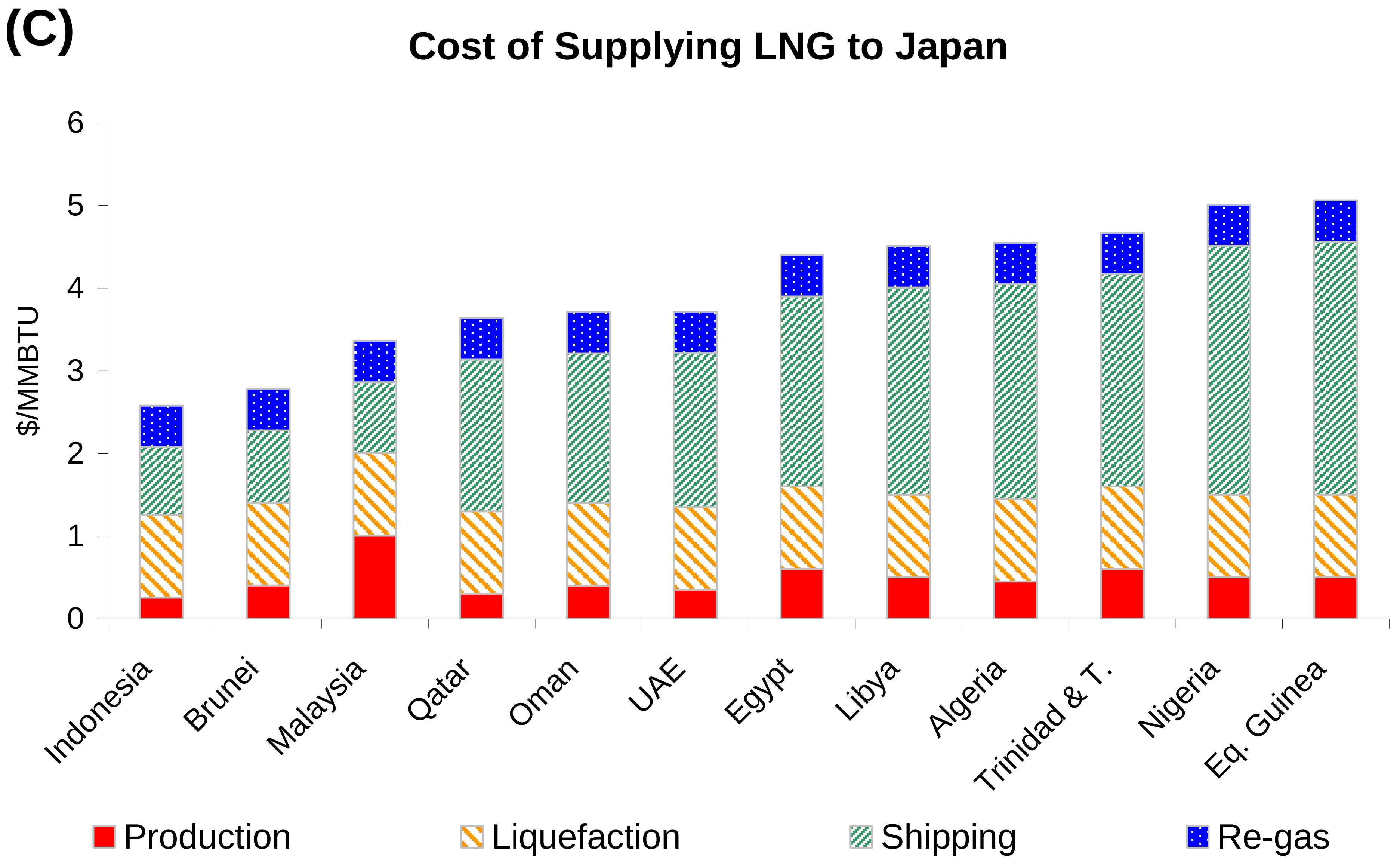


Figure 1 : Unit costs of imports of natural gas from GECF members ($/MMBtu) for three destinations: (A) the USA, (B) Spain, (C) Japan.

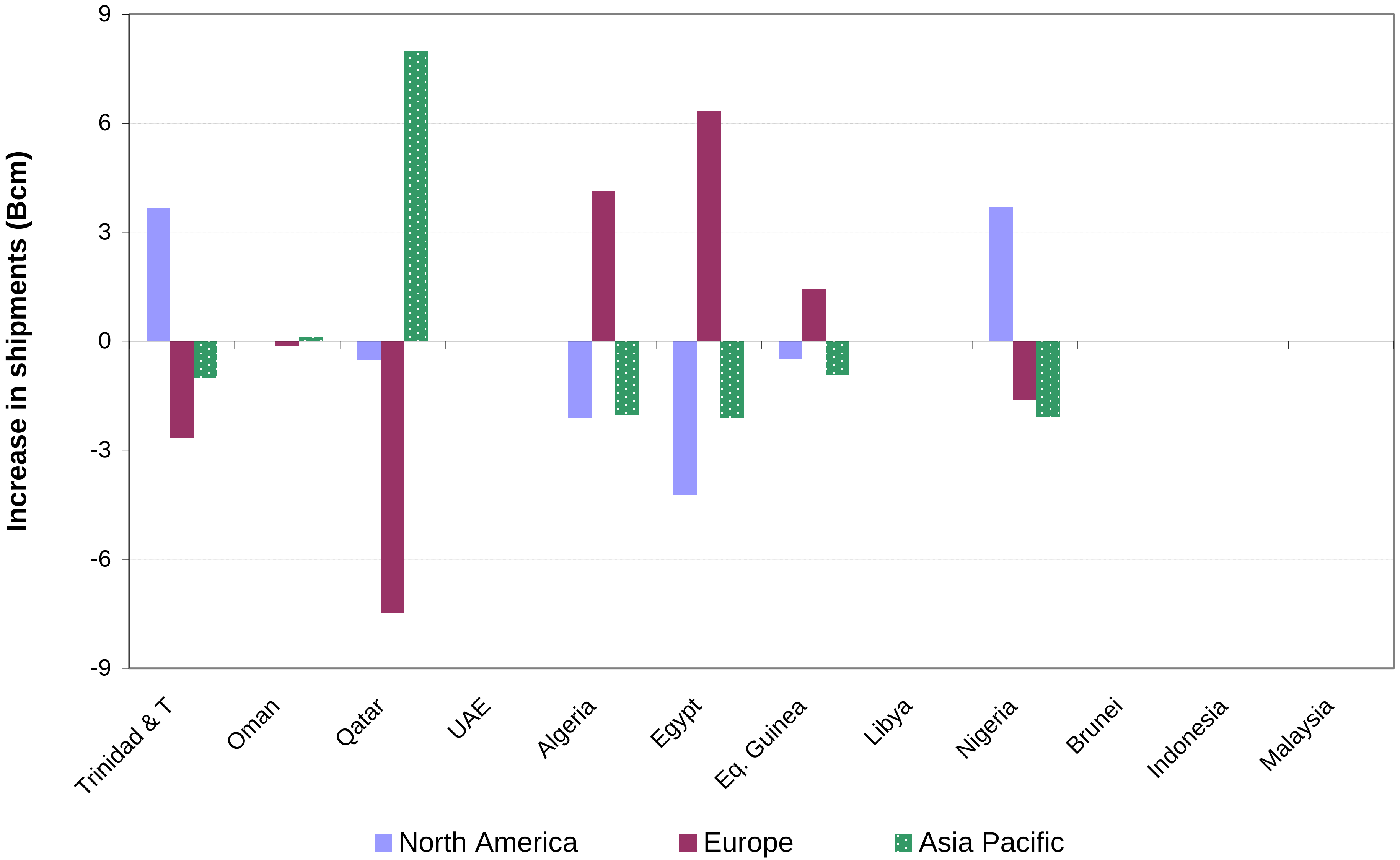


Figure 2: Variations in the LNG destinations induced by the adoption of the GECF's optimal policy for the year 2007 (a positive value signals a shipment increase)

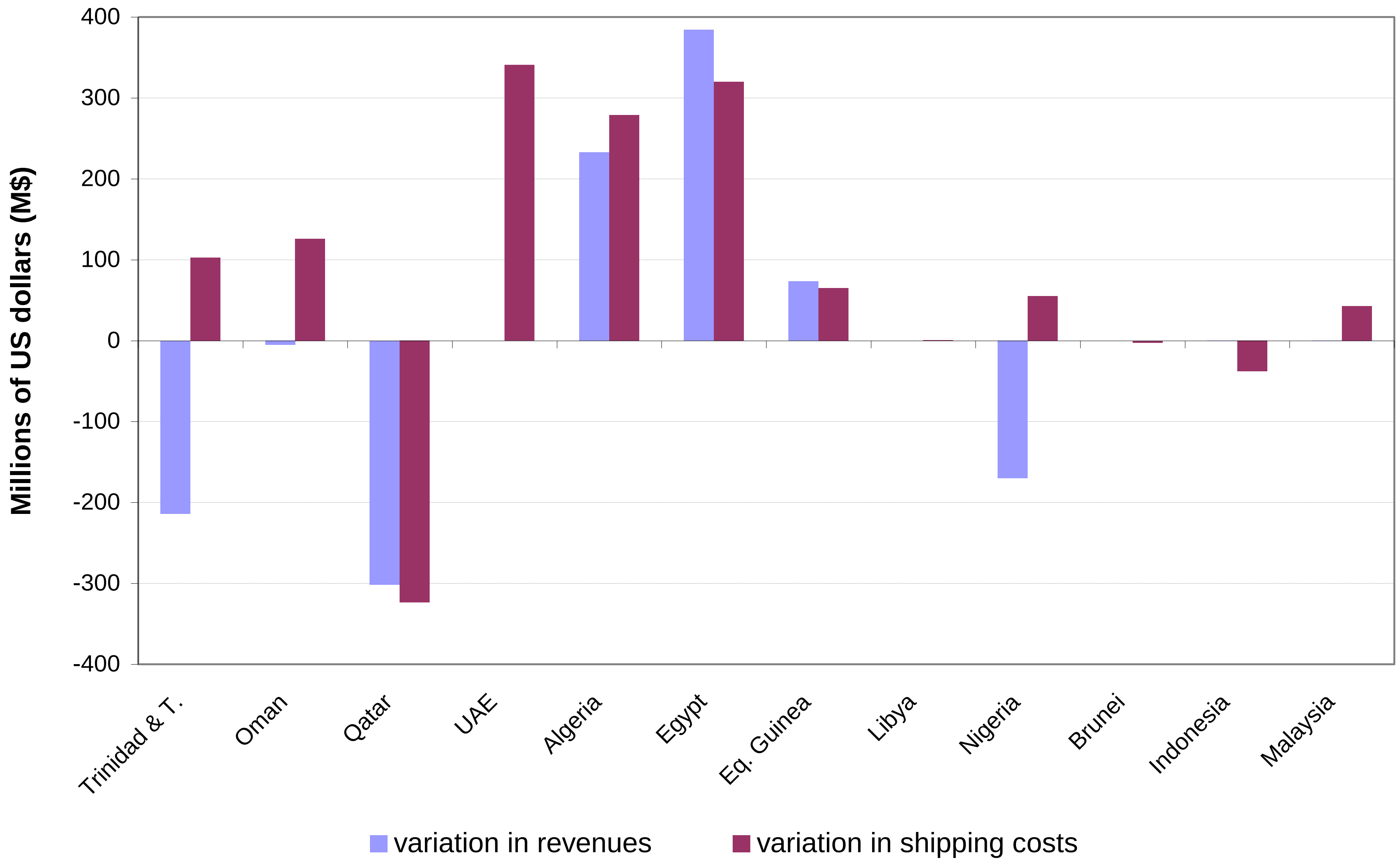
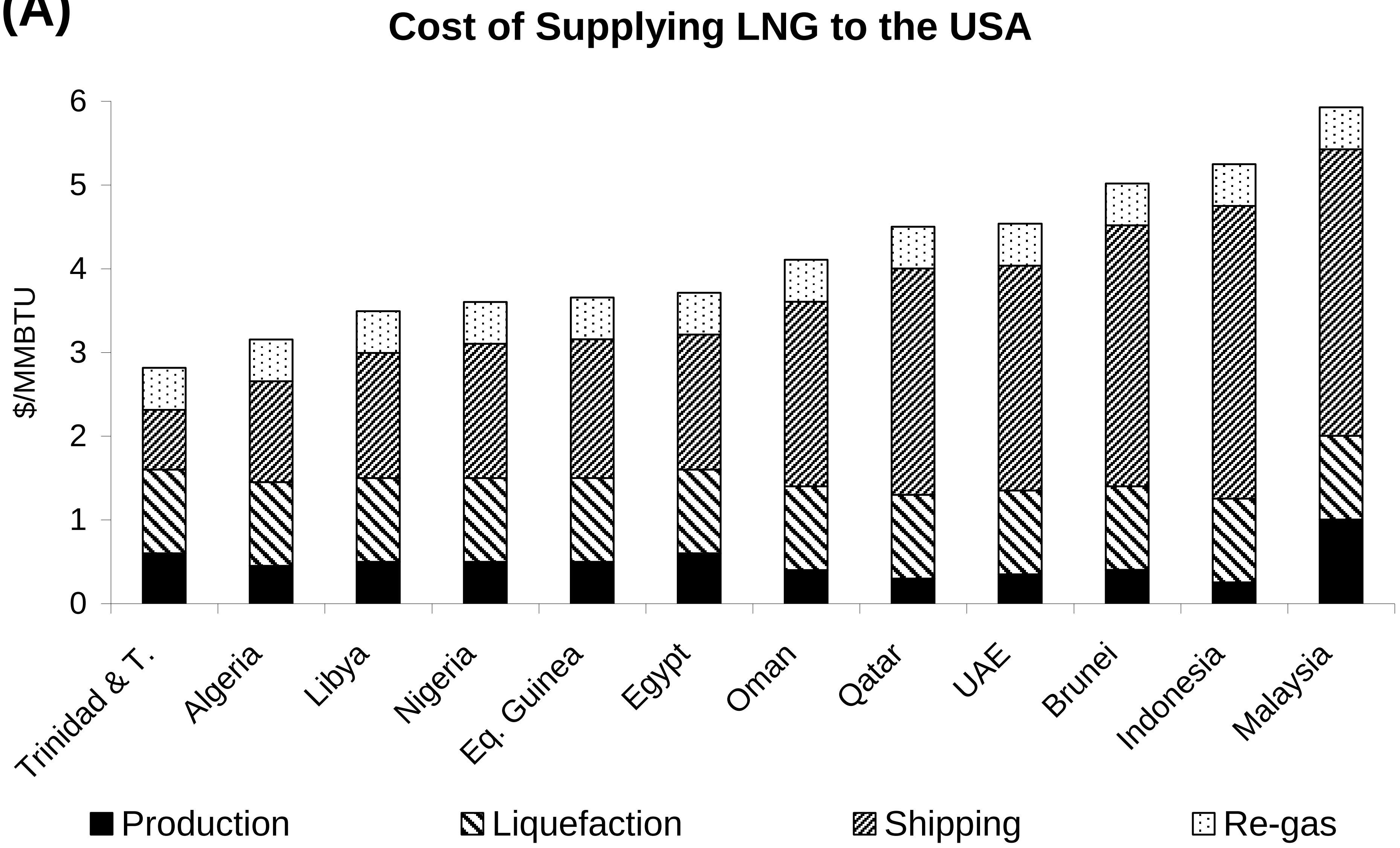


Figure 3 : Gains in cost and revenues derived from the adoption of the optimal solution in 2007 (in M$)

FIGURES

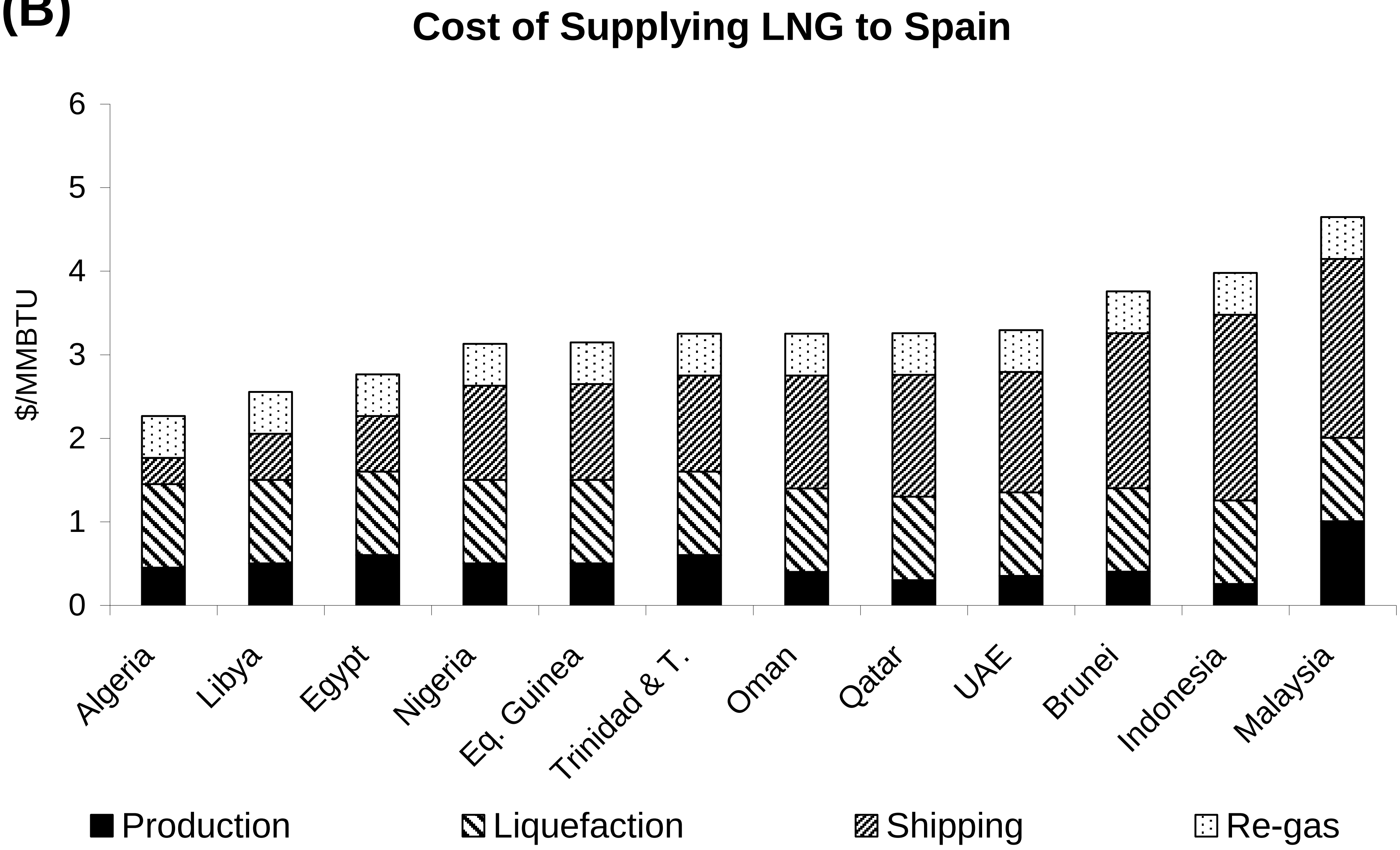
BLACK & WHITE VERSION

(A)



Cost of Supplying LNG to the USA
$/MMBTU
0
1
2
3
4
5
6
Trinidad & T.
Algeria
Libya
Nigeria
Eq. Guinea
Egypt
Oman
Qatar
UAE
Brunei
Indonesia
Malaysia
Production
Liquefaction
Shipping
Re-gas

(B)



Cost of Supplying LNG to Spain
$/MMBTU
0
1
2
3
4
5
6
Algeria
Libya
Egypt
Nigeria
Eq. Guinea
Trinidad & T.
Oman
Qatar
UAE
Brunei
Indonesia
Malaysia
Production
Liquefaction
Shipping
Re-gas

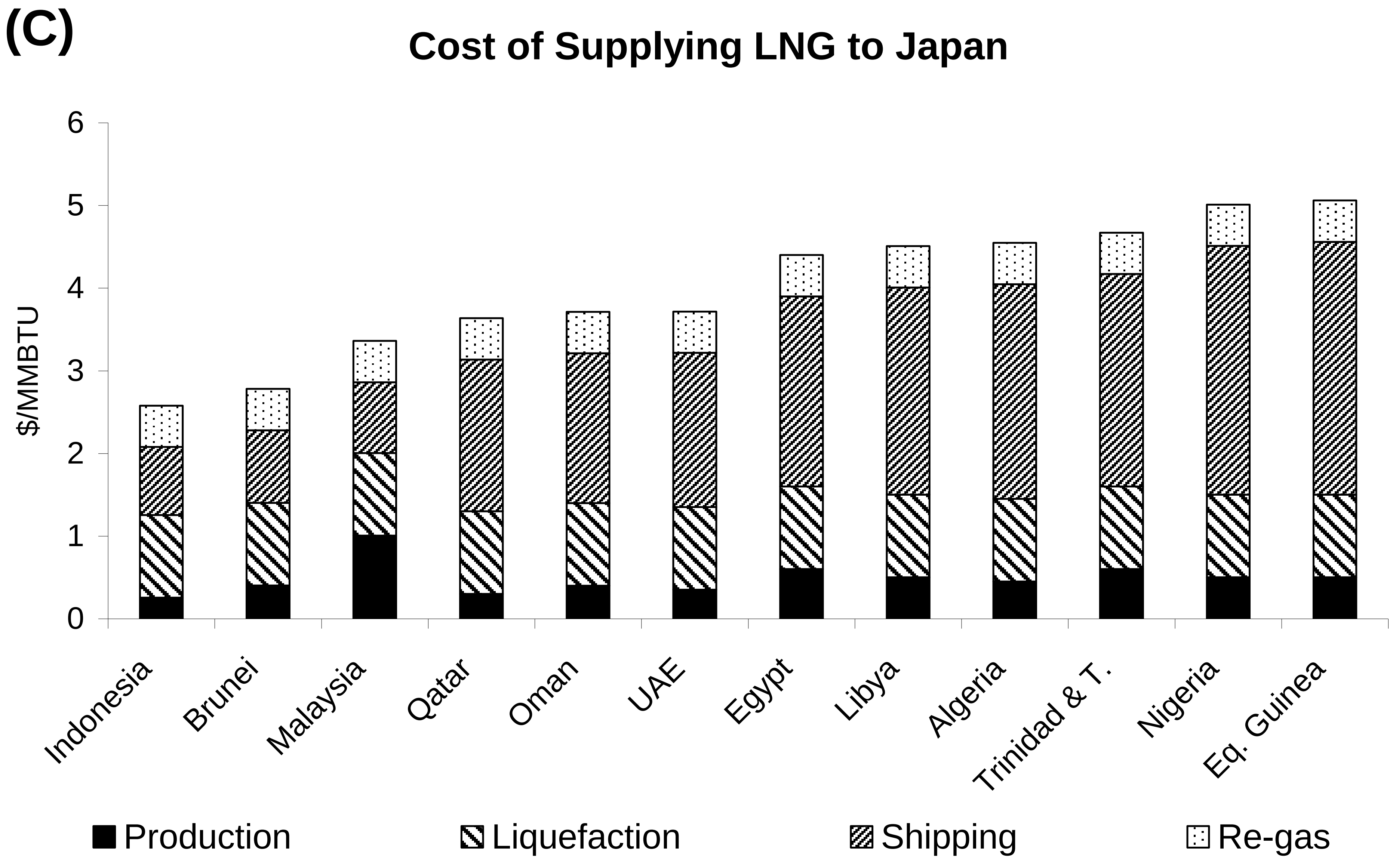


Figure 1 : Unit costs of imports of natural gas from GECF members ($/MMBtu) for three destinations: (A) the USA, (B) Spain, (C) Japan.

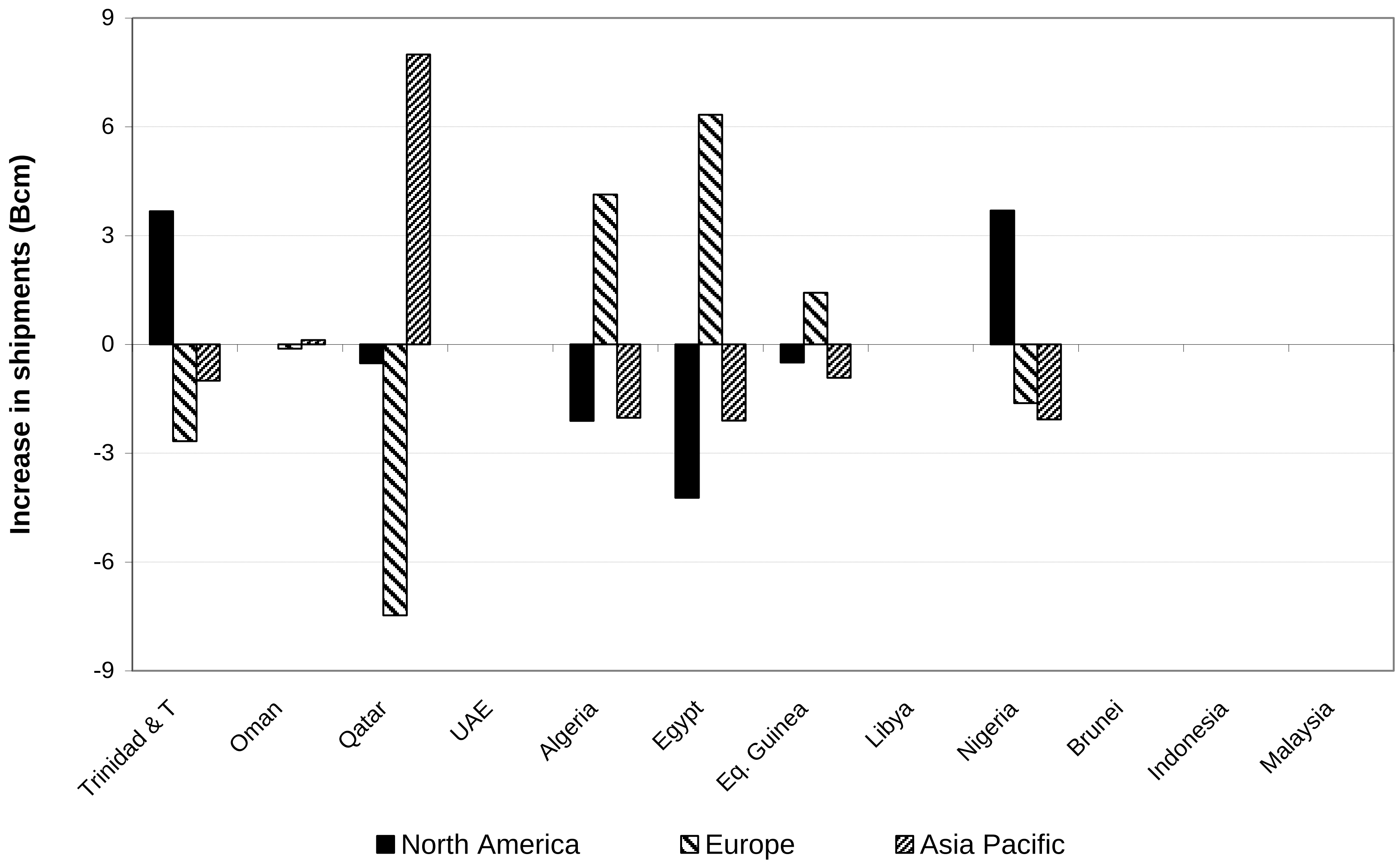


Figure 2: Variations in the LNG destinations induced by the adoption of the GECF's optimal policy for the year 2007 (a positive value signals a shipment increase)

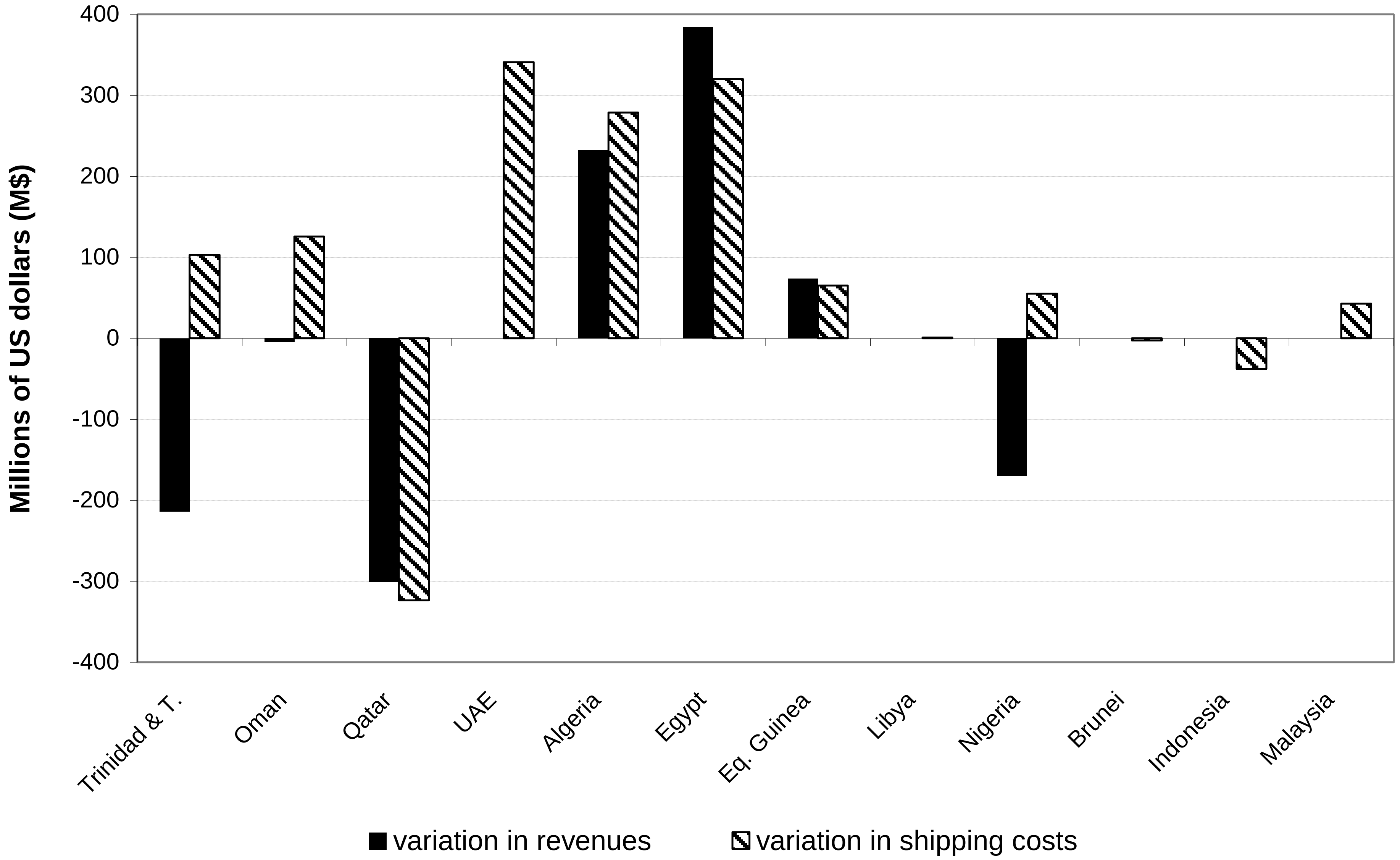


Figure 3 : Gains in cost and revenues derived from the adoption of the optimal solution in 2007 (in M$)