

Théorie des jeux coopératifs, un exemple de mise en oeuvre dans le secteur de l'énergie

Olivier MASSOL

Based on joint work with S. Tchung-Ming:
Massol & Tchung-Ming (2010). Energy Economics, 32(4) 933-947.



Outline

■ I - Some stylized facts on the LNG industry

The GECF: content, objectives, interpretations

Research question

■ II - Research Outline

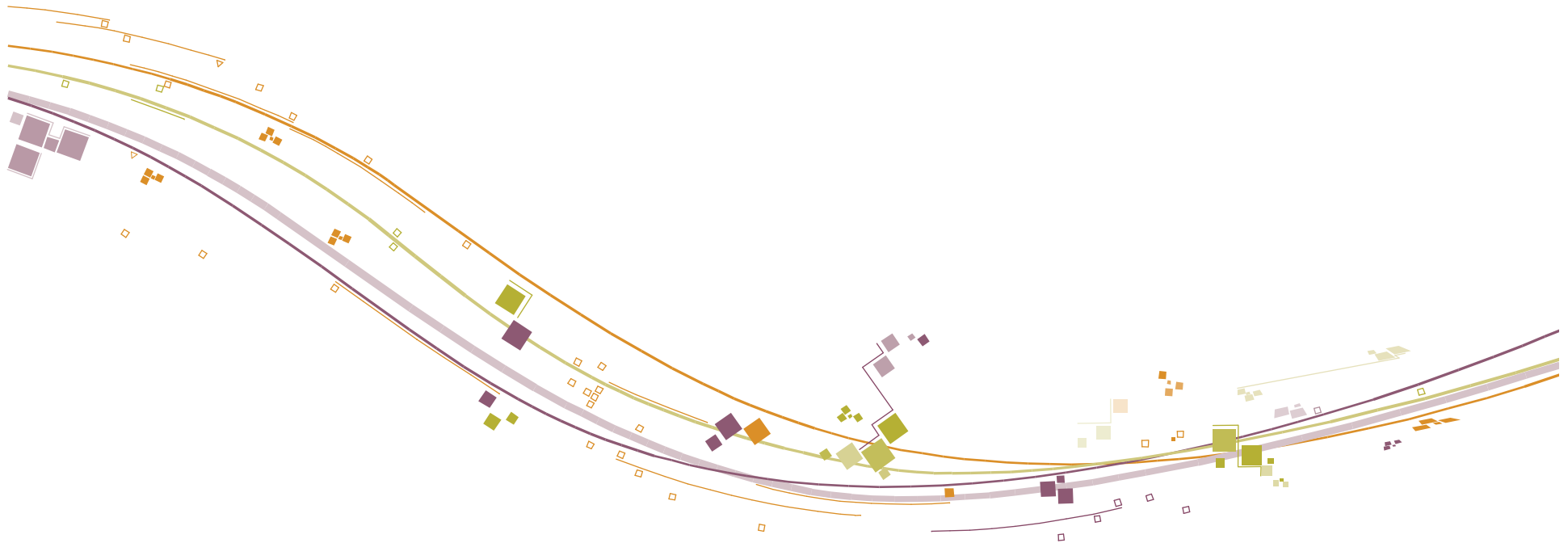
Modeling the gains derived from a *logistic cooperation*

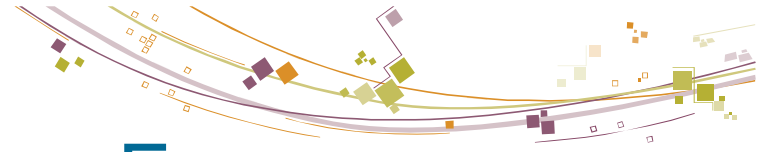
A gain sharing approach

A possibly costly coordination: what consequences?

■ III – Conclusions, discussions and possible extensions

Some stylized facts





The Gas Exporting Countries Forum

■ Tehran – 2001: birth of the GECF

■ An informal and rather chaotic organization

- unstable membership and mandate
- A Liaison Office has been established in Qatar

■ A potentially powerful organization

- 79% of world reserves,
- 56% of world production,
- 63% of exports.
- Seven OPEC members are also members of the GECF

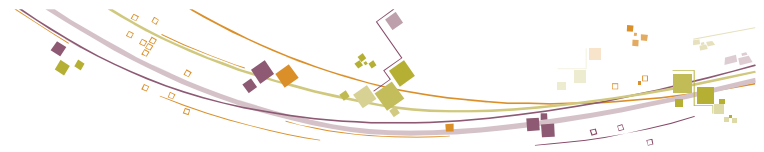
=> Question: **Are we facing an infant GASPEC?**

■ The GECF in the academic literature

■ Before 2010: mainly holistic treatments

- e.g. Soligo and Jaffe (2004), Hallouche (2006), Wagbara (2007)
- An institutional description + a geopolitical perspective

■ Egging et al. (2009): first large scale model



Some conventional wisdoms

■ A GASPEC for gas or for LNG ?

■ Yergin and Stoppard (2003)

- *"An association of some kind among LNG exporters is likely."*

■ J. Stern, *CESSA Conference, Cambridge, Dec. 14, 2007*

- *"Prime movers are LNG exporters: Algeria, Qatar, Trinidad, therefore an organization for LNG exporters is more likely than gas exporters"*

■ An inoffensive organization?

■ J. Stern, *CESSA Conference, Cambridge, Dec. 14, 2007*

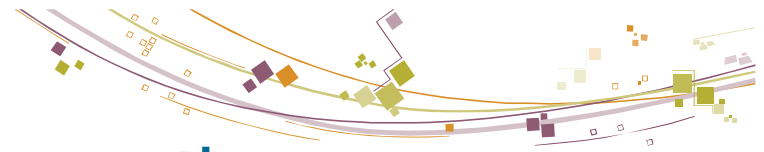
- A gas "price setting" organization/cartel is not an immediate concern

■ C. de Margerie (CEO Total), *Interview to Times, February, 2007*

- *"The cartel of world gas exporters is capable to play a positive role in conditions of a prompt rise in prices on this fuel. A gas OPEC would help to avoid inefficient investments, that works in interests of the consumers."*

■ Mr. Mandil (former Director of the International Energy Agency)

- There is a possibility for the GECF to remain *"a think tank for gas exporting countries, enabling them to consider the best possible conditions for the exercise of their mission"*



Formulation of a research question

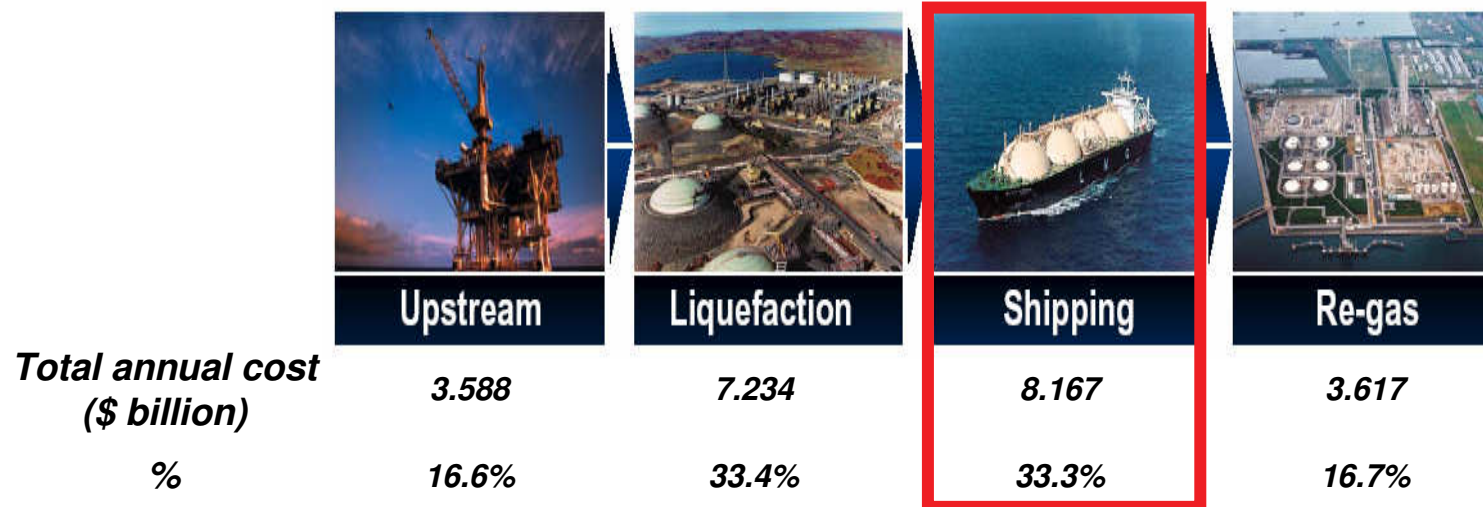
=> Research question:

What is the underlying economic goal?

- Hypothesis 1: an inoffensive cooperation?
 - **QUESTION: IS IT REALISTIC ?**

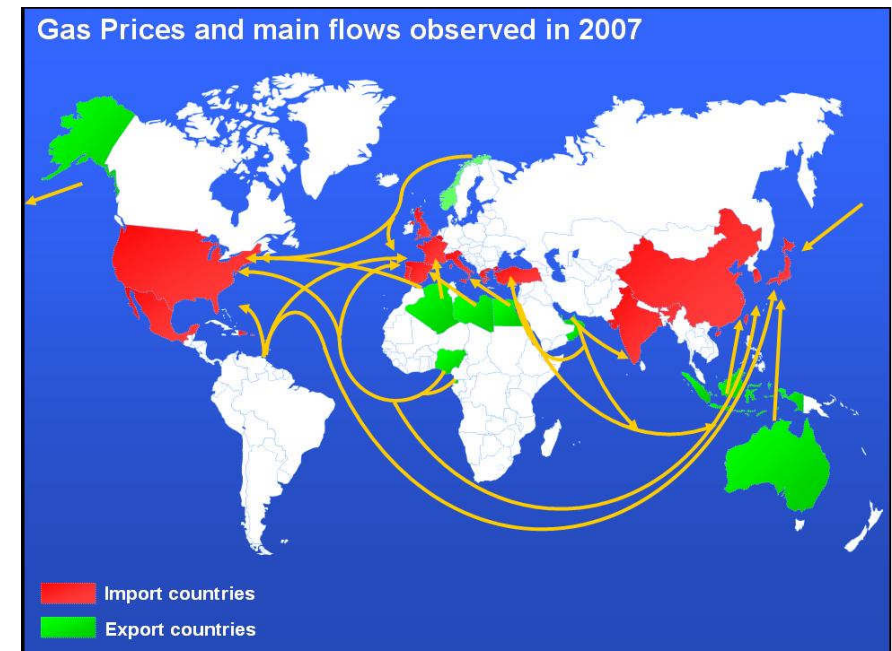
- Hypothesis 2: a cartel that seeks some market power?
 - Cf. Egging et al. (2009)...

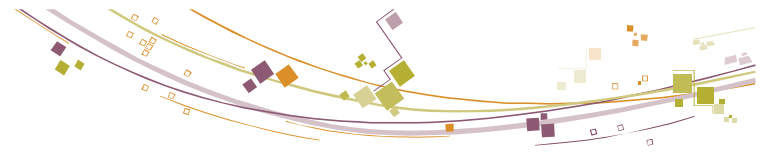
The LNG Chain in 2007



Shipping:

- On a given route, shipping cost is a growing function of distance
 - Observed trade flows are obviously suboptimal
 - The easiest way to organize a cooperation





Research objectives

Questions

1 – Is there a collective gain attached to a shipping rationalization?

2 – If YES, is there an incentive to cooperate?

- **Can the GECF find an "adequate" rule to share this collective gain?**
 - **Can that rule be "coalitionaly" preferred to "asset swaps" organized outside the GECF?**

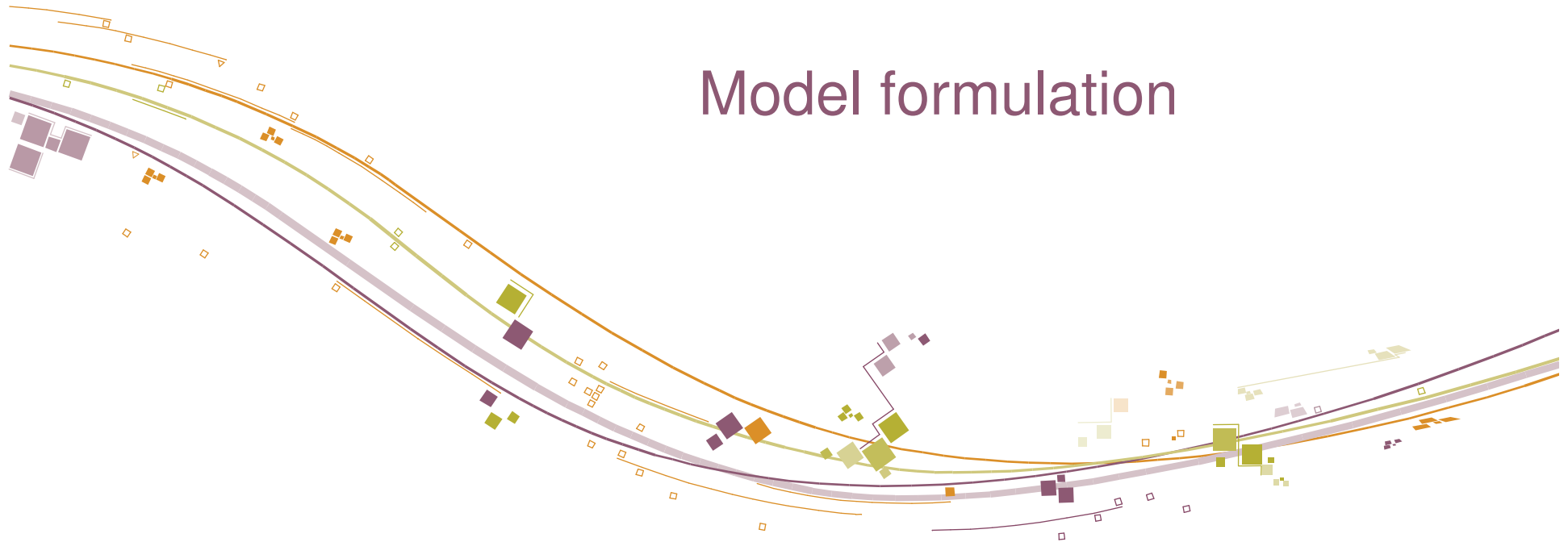
Suppose now that export coordination is costly,

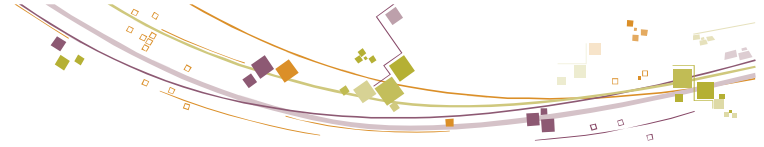
3 – Is there still an incentive to cooperate ? What is the maximum admissible coordination cost for this cooperation?

**PROPOSE QUANTITATIVE INSIGHTS
TO ANALYZE THE FEASIBILITY OF SUCH A GECF**

Cooperation in LNG trade

Model formulation





Assumptions and notations

Index

n - the number of LNG exporters involved in the GECF

Here $n=12$ (all the non-OECD exporters)

i - one of these exporters

d - the number of countries importing LNG $d=17$

j - one of these importers

Variables

q_{ij} - the volume of gas shipped from i to j

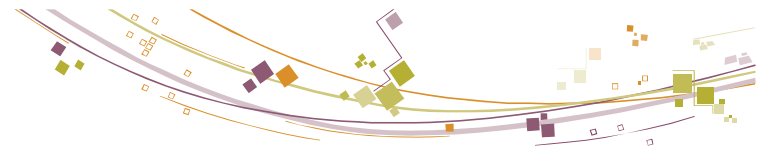
Exogenous data (for the specific year 2007)

Q_{ij} - the volume of LNG that was shipped from i to j

P_j - the price of LNG in j

C_i - the unit cost of LNG in i

T_{ij} - the unit shipping cost from i to j



A simple LP model

- An exporter's i profit:

$$\pi_i (q_i) = \sum_{j=1}^d (P_j - C_i - T_{ij}) q_{ij}$$

- The GECF objective:

A familiar transportation problem (Dantzig, 1951)

$$\text{Max}_{q_{ij}} \sum_{i=1}^n \pi_i (q_i)$$

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

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

$$q_{ij} \geq 0$$

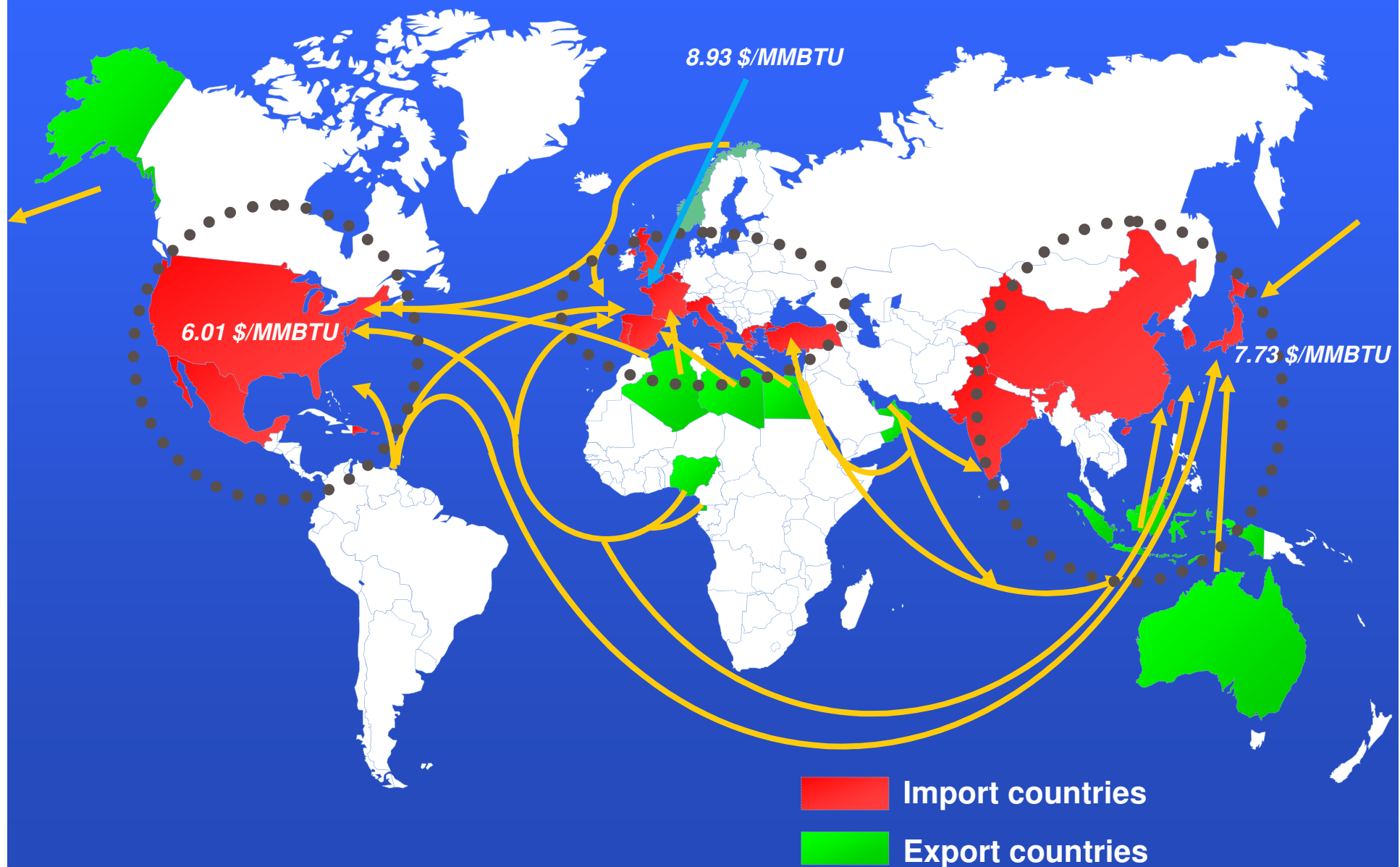
Unchanged utilization of
liquefaction plants

(1)

Unchanged volumes
deliveries for each
importing country

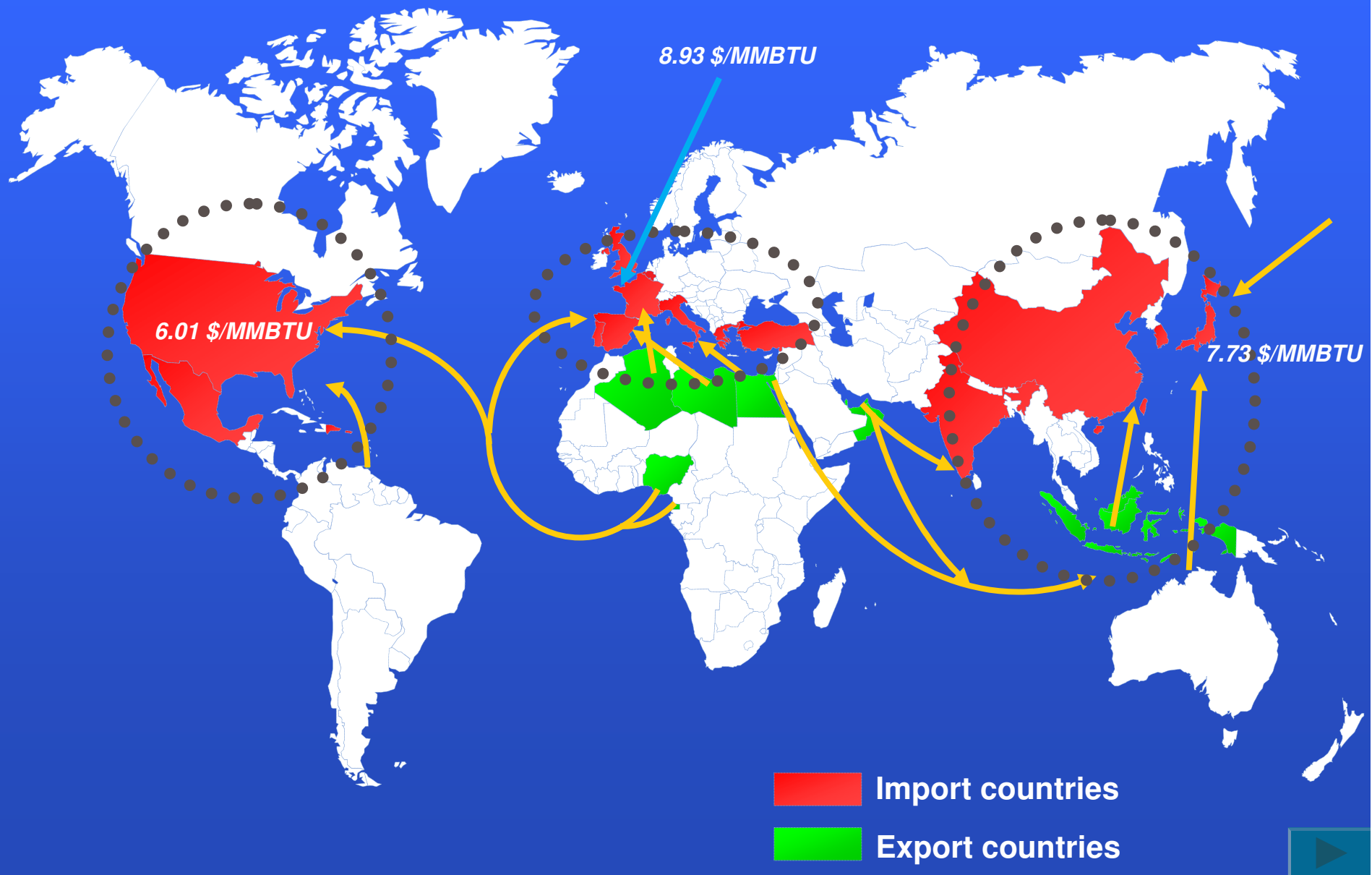
(2)

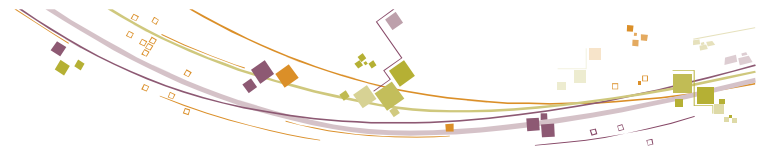
Observed LNG flows in 2007



Optimized 2007 LNG flows

Collective gain: +M\$ 968
for 12 countries



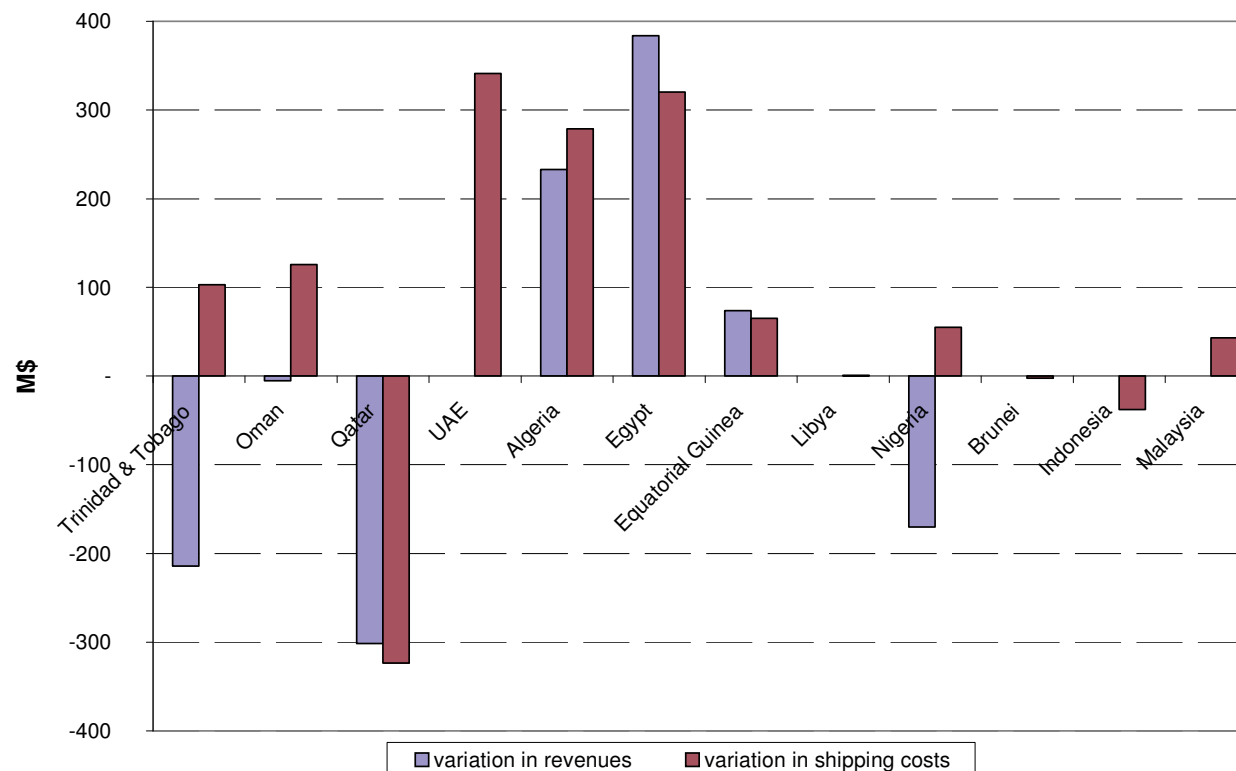


First conclusions

=> **CONCLUSION #1: a profitable coordination could be organized**

- **An overall collective gain: +M\$ 968 for the 12 countries in 2007**
 - an 11.9% reduction in the GECF's shipping cost
 - it represents a +2.8% rise of 2007 profits

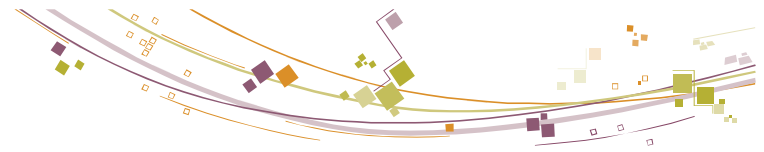
■ **But some countries do not individually benefit from this collective rationalization....**



Cooperation in the LNG industry

Sharing the Gains from a Logistic
Cooperation:
A Game Theoretic Approach





Notations

N - a finite set of n exporters involved in the GECF

$S \subseteq N$ - a subcoalition of exporters ($2^{12} = 4096$ coalitions)

The **characteristic function** value for each coalition

It measures the logistic gain obtained by a coalition S (i.e. the difference between the total profits when they cooperate and when they don't.)

$$v: 2^N \rightarrow \mathbb{R}$$

$$S \mapsto v(S) = \underset{q_{ij}}{\text{Max}} \sum_{i=1}^n \delta_i(S) \cdot \left(\pi_i(q_{ij}) - \overline{\pi_i^{2007}} \right)$$

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

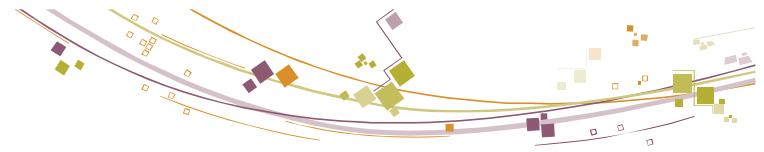
$$\sum_{i=1}^n q_{ij} = \sum_{i=1}^n Q_{ij} \quad (j = 1, 2, \dots, d)$$

$$(1 - \delta_i(S)) q_{ij} = (1 - \delta_i(S)) Q_{ij} \quad ((i, j) \in \{1, 2, \dots, n\} \times \{1, 2, \dots, s\})$$

$$q_{ij} \geq 0$$

We have just defined a TU-game (N, v)

v is a 0-normalized value



Some natural requirements

- An « acceptable » gain allocation rule $\mathbf{x}=(x_i)_{i \in N}$ satisfies:

- Efficiency

$$\sum_{i=1}^n x_i = v(N)$$

- Individual rationality:

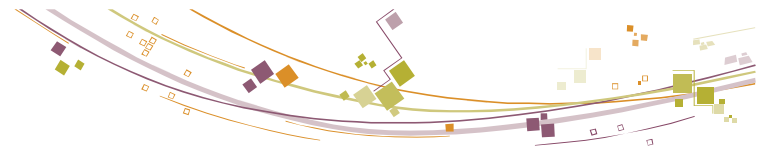
for each i $x_i \geq v(\{i\})$

- Coalitional rationality:

for each $S \subseteq N$ $\sum_{i \in S} x_i \geq v(S)$

Thus,

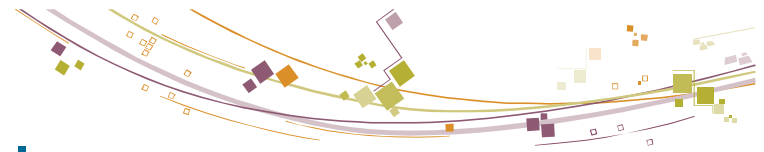
$\mathbf{x}$ must belong to the CORE of the game!



Some basic sharing rules

- **There exists a multitude of possible sharing rules**
 - Trivial examples include
 - **Equal shares**
 - 1/12 for each country
 - **Proportional to profit earned in 2007**
 - Profits variations: +2.78 % for each exporter
 - **Proportional to total quantity shipped in 2007**
 - A method inspired by cost sharing methods (Ransmeier, 1932)
 - **Each country i receives**
 - its marginal value contribution : $m_i = v(N) - v(N \setminus \{i\})$
 - corrected so as to recover exactly $v(N)$

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



Some advanced sharing rules

- A first cooperative game theoretical concept

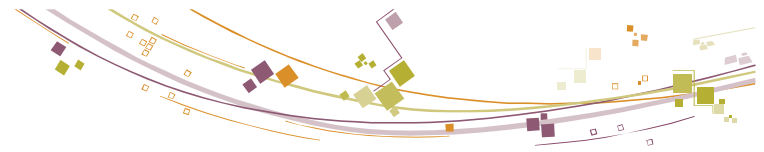
- Shapley Value

- One of the earliest method of allocation based on a set of postulates

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

intuitive explanation:

- Countries are assumed to “sign up” one by one in order to form the grand coalition of 12 countries, in some particular order.
 - Each of them receives the entire gain it offers to the coalition formed just before him.
 - If a subgroup **S** has already signed up, and *i* was the last country to arrive, it receives its **marginal value contribution** is to **S** is $v(S) - v(S \setminus \{i\})$
 - The Shapley Value is *i*’s average marginal value contribution if all orders for signing up are assumed to be equally likely.
 - All orders of formation intervene with the same weight $1/12!$.



Definition of Excess:

- The attitude of a coalition towards a proposed allocation:

$$e(S, x) = v(S) - \sum_{\{i\} \in S} x_i$$

measures the amount (the size of the inequity) by which coalition **S** falls short of its potential **v(S)** in the allocation **x**.

=> measures the "*unhappiness degree*" of each coalition **S**.

Remark:

- Since the core is defined as the set of imputations such that $\sum_{i \in S} x_i \geq v(S)$ for all coalitions **S**, we immediately have that:

x is in the core *iff* all its excesses are negative or zero.

The nucleolus (Schmeidler, 1969)

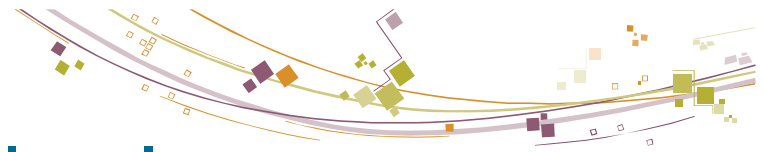


IDEA:

- On the principle that **the one who yells loudest gets served first**, we look first at those coalitions **S** whose excess, for a fixed allocation **x** , is the largest.
- Then we adjust **x** , if possible, to make this largest excess smaller. When the largest excess has been made as small as possible, we concentrate on the next largest excess, and adjust **x** to make it as small as possible, and so on. When we cannot improve further, the imputation we get is called the nucleolus.

In other words:

**The nucleolus is the imputation that
maximizes (lexicographically)
the satisfaction obtained by the least well-off coalition.**



Computation of the Nucleolus I

Kopelowitz (1967), Granot and al. (1998): a sequence of LPs

Step $k=1$:

find $x = (x_1, \dots, x_n)$ **that min. the max. of** $e(S, x)$ **over all** S **s.t.** $\sum x_i = v(N)$

i.e. min. the max. of a collection of linear functions s.t. a linear constraint
it can easily be converted to a LP problem.

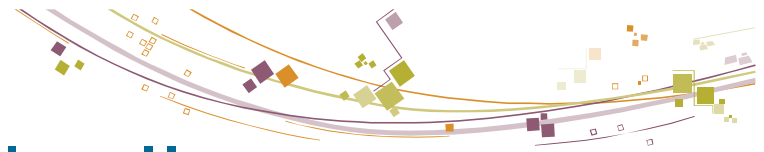
$$\begin{array}{ll} \text{Min} & \mathcal{E} \\ & x_i, \mathcal{E} \\ \text{s.t.} & \sum_{i=1}^n x_i = v(N) \end{array} \quad (1)$$

$$\mathcal{E} + \sum_{i \in S} x_i \geq v(S) \quad (S \in \Sigma^0) \quad (2)$$

$$x_i \geq 0 \quad (i = 1, 2, \dots, n)$$

where the set Σ^0 is $S \subset N$ ($S \neq \emptyset, N$)

- If the game has a non-void core, this problem has a non-void solution set and $\mathcal{E}$ has a negative value e_1 at the optimum.
- Then, we identify the coalitions for which (2) are saturated.



Computation of the Nucleolus II

Step $k=2$:
solve

Min $\mathcal{E}$
 $x_i, \mathcal{E}$

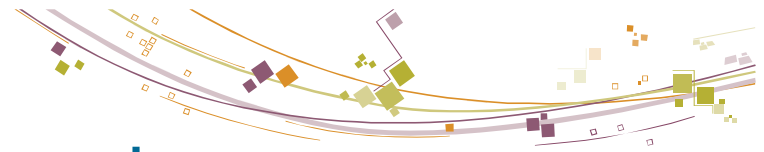
$$\text{s.c.} \quad \sum_{i=1}^n x_i = v(N) \quad (3)$$

$$\sum_{i \in S} x_i = v(S) - e_1 \quad (S \in \Sigma_1) \quad (4)$$

$$\mathcal{E} + \sum_{i \in S} x_i \geq v(S) \quad (S \in \Sigma^1) \quad (5)$$

$$x_i \geq 0 \quad (i = 1, 2, \dots, n)$$

and so on...



Some alternative nucleolus scheme

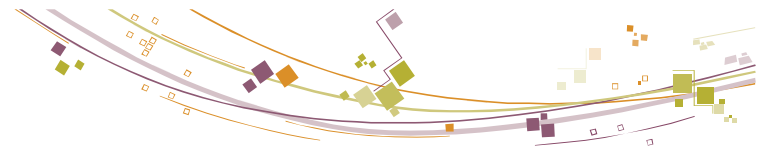
Other possible metrics to measure the unhappiness of a coalition:

- The Per Capita Nucleolus (Grotte, 1970)

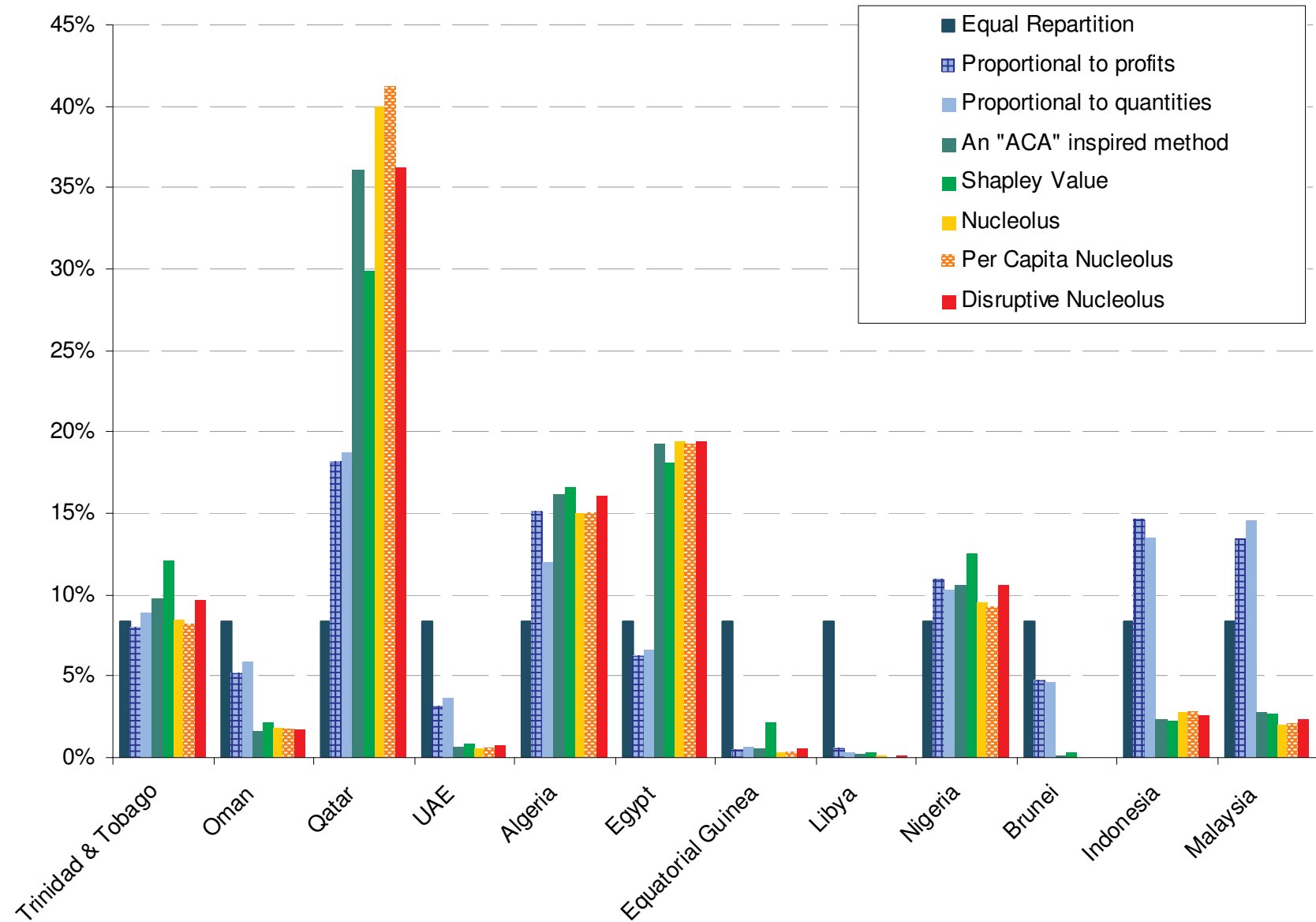
$$e(S, x) = \frac{v(S) - \sum_{i \in S} x_i}{|S|}$$

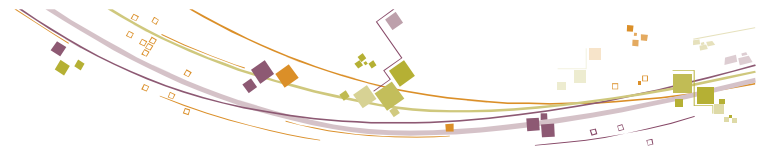
- The Disruption Nucleolus (Gately, 1974; Littlechild & Vaidya, 1976)

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



Results





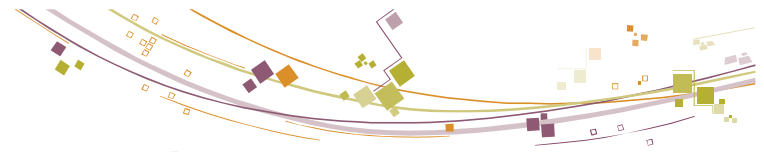
But are they in the CORE?

	Equal shares	Proportional to profit	Proportional to quantities	ACA	Shapley Value	Nucleolus	Per Capita Nucleolus	Disruptive Nucleolus
Does it belong to the CORE ?	No	No	No	No	No	YES	YES	YES
Number of coalitions that could quit the grand coalition ?	981	756	748	2	52	0	0	0

■ Core belonging

- Only complex methods (nucleolus-inspired methods) satisfy this minimal requirement
 - No individual earns less than in a stand alone case
 - No coalition of exporters earn less than in a stand alone asset swap

=> CONCLUSION #2: Selecting an allocation within the core is not so easy
 Only 3 methods satisfy this requirement



Another Desirable Requirement

- **Monotonicity in the aggregate**

- **After participants commit to an allocation, then**
 - No participant would receive more if the profit were to decrease
 - No participant would receive less if the profit were to increase
- **A "fair" requirement...**

=> CONCLUSION #3: Core & Monotonicity => a restricted choice

Only one method remains: the per capita nucleolus (Young et al., 1980)

THUS:

**IDENTIFYING AN ADMISSIBLE
SHARING METHOD IS NOT SO SIMPLE!**

Cooperation in the LNG industry

What about a costly coordination?





What about the cost of the coordination?

- Now, let's assume that all the 12 countries agree to use the per capita nucleolus as a profit sharing scheme.
- Suppose that a coordination cost is needed
e.g. to cover the cost of a General Secretariat
- What is the maximum coordination cost that can be sustained by that cooperation ?
 - i.e. those compatible with a non-empty core

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

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

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

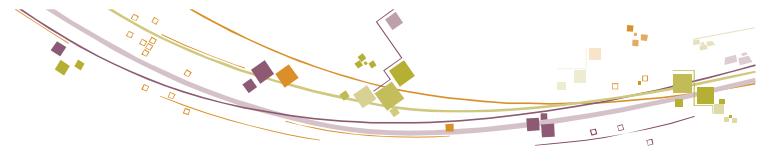
$$\omega \geq 0, \quad x_i \geq 0, \quad (i = 1, 2, \dots, n)$$

- If it exceeds 720,000 \$, the « market power free » cooperation can no longer be sustained

Cooperation in the LNG industry

CONCLUSIONS





Conclusions & insights

1. A logistic coordination could provide a collective profit gain.
2. But countries will not spontaneously cooperate
=> you need a profit sharing rule
3. Sharing these gains requires advanced cooperative game theory concepts
 - Not easy to negotiate...
4. The incentive to cooperate might not be so strong
5. Especially if the coordination costs are reasonable but significant

MAIN CONCLUSION:

IS THE "NO MARKET POWER" HYPOTHESIS REALLY CREDIBLE?

-> Elements likely to make things even trickier

1. Effect on market prices
2. Resource depletion

Thank you for your attention!

Some questions/comments?
Please do not hesitate to email:
[olivier \(dot\) massol \(at\) ifpen.fr](mailto:olivier(dot)massol(at)ifpen.fr)