Export diversification and resource-based industrialization: the case of natural gas

Olivier MASSOL
Albert BANAL-ESTAÑOL

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Context:
The "resource curse"

- **A well established fact**

- **What transmission mechanism?**
  - **A – Political mismanagement**
    - cf. Ross (1999); Isham et al. (2005)
  - **B – Economic explanations**
    - 1950's: a secular decline in the Terms of Trade?
    - 1960's: the lack of "linkages" (Hirschman, 1958)
    - 1980's: the Dutch Disease explanation (Corden & Neary, 1982)
      - (1) an appreciation of the state's real exchange
      - (2) a tendency of the booming sector to draw resources away from manufactures
    - 1990's: Export revenue volatility harms growth
      - Easterly et al. (1993); Mendoza (1997); Hausmann and Rigobon (2003)
Natural Gas Flaring

Europe: 3 bcm
Central and South America: 10 bcm
North America: 12-17 bcm
Middle East: 30 bcm
Africa: > 45 bcm
CIS: 15-60 bcm
Asia: 7-20 bcm

Source: World Bank
Gas Resources Monetization for a small economy

Gas allows multiple export-oriented strategies:

- **Raw exports (pipelines, LNG vessels)**
- **Processed Primary Products**
  - Chemical commodities: Methanol, Olefins
  - Fertilizers: Urea
  - Liquid fuel (GTL technologies): Diesel Oil
  - Iron & Steel industry: DRI
  - Energy Intensive activities: Aluminum

- **Owens and Wood (1997):** resource-rich countries can have a comparative advantage in processed primary goods.

**RESEARCH QUESTIONS:**

A - Is an export-oriented RBI strategy suitable or not?

B - Which primary products should be given priority over others?
Part I - Methodology
A critical review of existing studies

- Practitioners:
  - basic comparisons based on the E(NPV) criteria (ESMAP)
- In the academic literature
  - Brainard and Cooper (1968) – an MVP approach
    - Love (1979), Labys & Lord (1990), Strobl et al. (2009)…

Typical MVP formulation:

\[
\begin{align*}
\max \quad & U(q) = \bar{P}^T q - \frac{\lambda}{2} q^T \Sigma q \\
\text{s.t.} \quad & A^T q = 1 \\
& q \in \mathbb{R}^m
\end{align*}
\]

Applicability to the gas sector

1 – Can volume instability be neglected? \hspace{1cm} \text{OK}

2 – Can costs be neglected? \hspace{1cm} \text{NO!}
The technologies at hand: a standard engineering representation

Remarks:

- **Gas processing technologies: the main features**
  - modular technologies with LR scale economies at the module's level ...
  - lumpiness + a large range of size for the modules

<table>
<thead>
<tr>
<th>Gas use</th>
<th>Gas input (Mcf/ton)</th>
<th>Range of implementable processing capacities (ktpa - 10^3 tons per annum)</th>
<th>Investment cost function $C_i(x_i) = \alpha_i x_i^{\beta_i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium (line pot)</td>
<td>91.13</td>
<td>Minimum: 50.00, Maximum: 386.00</td>
<td>$\alpha_i = 12,424.33, \beta_i = 0.941$</td>
</tr>
<tr>
<td>Gas-to-Liquid (Fischer-Tropsch reactor)</td>
<td>71.82</td>
<td>Minimum: 110.99, Maximum: 838.61</td>
<td>$\alpha_i = 3,517.74, \beta_i = 1.000$</td>
</tr>
<tr>
<td>Direct Reduced Iron (shaft furnace)</td>
<td>12.17</td>
<td>Minimum: 310.00, Maximum: 1,950.00</td>
<td>$\alpha_i = 2,276.56, \beta_i = 0.840$</td>
</tr>
<tr>
<td>LNG (liquefaction train)</td>
<td>55.35</td>
<td>Minimum: 2,500.00, Maximum: 7,100.00</td>
<td>$\alpha_i = 3,843.43, \beta_i = 0.853$</td>
</tr>
<tr>
<td>Methanol (methanol reactor)</td>
<td>31.76</td>
<td>Minimum: 204.00, Maximum: 3,400.00</td>
<td>$\alpha_i = 3,023.30, \beta_i = 0.875$</td>
</tr>
<tr>
<td>Urea (urea reactor)</td>
<td>21.61</td>
<td>Minimum: 170.00, Maximum: 1,500.00</td>
<td>$\alpha_i = 4,161.45, \beta_i = 0.832$</td>
</tr>
</tbody>
</table>

- **E&P costs can be excluded**
**Assumption**

**Lemma: on cost minimizing industrial configurations**

Assume:  
- the concave specification above,
- \( q_i \geq K_i \) and denote \( n_i = \left\lfloor \frac{q_i}{K_i} \right\rfloor \)

Then, the cost minimizing industrial configuration for \( i \) is:

<table>
<thead>
<tr>
<th>Case</th>
<th>Cost-minimizing industrial configuration</th>
<th>Total Cost ( C_i(q_i, n_i, \delta_i) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_i \bar{K}_i + K_i \leq q_i \leq (n_i + 1) \bar{K}_i ) ( \delta_i = 1 )</td>
<td>( n_i ) modules with a size ( \bar{K}_i ) plus a residual one of size ( q_i - n_i \bar{K}_i )</td>
<td>( n_i c_i(\bar{K}_i) + c_i(q_i - n_i \bar{K}_i) )</td>
</tr>
<tr>
<td>( n_i \bar{K}_i \leq q_i \leq n_i \bar{K}_i + K_i ) ( \delta_i = 0 )</td>
<td>( n_i - 1 ) modules with a maximum size ( \bar{K}_i ) a module of minimum size ( \bar{K}_i ) plus the residual one: ( q_i - (n_i - 1) \bar{K}_i - \bar{K}_i )</td>
<td>( (n_i - 1)c_i(\bar{K}_i) + c_i(\bar{K}_i) + c_i(q_i - (n_i - 1) \bar{K}_i - \bar{K}_i) )</td>
</tr>
</tbody>
</table>
A modified MVP Model

This is a "well behaved" MINLP
- feasible
- Computationally friendly

A disjunctive choice:
"export at least a certain amount, or not at all".

\[
\begin{align*}
\max \quad & U(q, n, \delta, \zeta) = \overline{P}^T \cdot q - C(q, n, \delta, \zeta) - \frac{\lambda}{2} q^T \Sigma q \\
\text{s.t.} \quad & 1^T \cdot q = \text{PROD} \\
\quad & \text{diag}(\overline{K}) \cdot n \leq q \leq \text{diag}(\overline{K}) \cdot (n+1) \\
\quad & \text{diag}(\overline{K}) \cdot n + \text{diag}(\overline{K}) \cdot \delta \leq q \\
\quad & \text{diag}(1 - \delta) \cdot q \leq \text{diag}(\overline{K}) \cdot n + \text{diag}(\overline{K}) \\
\quad & q \leq \text{PROD} \cdot \zeta \\
\quad & \text{diag}(\overline{K}) \cdot \zeta \leq q \\
\end{align*}
\]

\[q \in \mathbb{R}^m_+, \quad n \in \mathbb{N}^m, \quad \delta \in \{0,1\}^m, \quad \zeta \in \{0,1\}^m\]
Part II - Application

a) Assessing revenues: an empirical price model
The route to an application

- Estimation of a time series model
  Simulation: 100,000 price paths are generated

- The unit discounted revenues net of linear variable costs are then computed...
  Hypotheses are based on publicly available data:
  - construction delays, lifetimes, rate of return, unit O&M costs, freight...

Empirical Model

DCF Model
(CAPEX excluded)

MVP Model
(CAPEX included)

Efficient frontier
Data:
242 monthly prices from Jan90 to Feb10 (in 2010 USD)

Preliminary tests:

- stationarity? All series are I(1) => use of first differences
- Cointegration? Yes => a VECM

Sources: World Bank, Platts, USGS.
Methodology

A data-driven model of the DGP

- A - Conditional mean equations: a VECM

\[ \Delta P_t = \mathbf{A}_0 + \Pi P_{t-1} + \Gamma_1 \Delta P_{t-1} + \ldots + \Gamma_{k-1} \Delta P_{t-p+1} + \mathbf{\epsilon}_t \]

- B - The conditional variance equation: a MV-GARCH model

\[ \mathbf{\epsilon}_t = \mathbf{H}_t^{1/2} \mathbf{\eta}_t \]

- the family of correlation multivariate GARCH models:  \[ \mathbf{H}_t = \mathbf{D}_t \mathbf{R}_t \mathbf{D}_t \]

- where  \[ \mathbf{D}_t = \text{diag}\{\sqrt{h_{i,t}}\} \] and  \[ h_{i,t} = \omega_i + \sum_{p=1}^{R} \alpha_{i,p} \mathbf{\epsilon}_{i,t-p}^2 + \sum_{q=1}^{Q} \beta_{i,q} h_{i,t-q} \]

- Bollerslev (1990) Constant Conditional Correlation (CCC) model:

\[ \mathbf{R}_t = \mathbf{\bar{R}} \]
Estimation:
A - The conditional mean equation

Step 1: Selecting the lag order of the VECM
- Akaike’s FPE: a 9 lags specification

Step 2: Determining the cointegrating rank
- Test assumption: an intercept in both the CE & the VAR (Cf. the SBIC)
- Both, the Trace and the $\lambda_{\text{max}}$ test suggest $r = 2$ at the 5% level

Step 3: Reduction to a parsimonious model
- An iterative “general-to-specific” procedure (Brüggemann and Lütkepohl, 2001)
  - SER aimed at minimizing the HQ criterion. => 217 zero restrictions (not rejected by a LR test)
  - The resulting model has been estimated using a feasible GLS procedure.

<table>
<thead>
<tr>
<th>Equation</th>
<th>Adjusted $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \text{ALU}_t$</td>
<td>0.301</td>
</tr>
<tr>
<td>$\Delta \text{DIES}_t$</td>
<td>0.325</td>
</tr>
<tr>
<td>$\Delta \text{DRI}_t$</td>
<td>0.529</td>
</tr>
<tr>
<td>$\Delta \text{GAS}_t$</td>
<td>0.792</td>
</tr>
<tr>
<td>$\Delta \text{MET}_t$</td>
<td>0.583</td>
</tr>
<tr>
<td>$\Delta \text{UREA}_t$</td>
<td>0.653</td>
</tr>
</tbody>
</table>

**Table 9. Diagnostic checks of the conditional mean equations**

<table>
<thead>
<tr>
<th></th>
<th>Multivariate tests</th>
<th>Statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normality:</td>
<td>JB, $\chi^2(12)$</td>
<td>2222.58</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Autocorrelation:</td>
<td>LM(10), $\chi^2(360)$</td>
<td>377.26</td>
<td>(0.255)</td>
</tr>
<tr>
<td></td>
<td>LM(12), $\chi^2(432)$</td>
<td>462.70</td>
<td>(0.148)</td>
</tr>
<tr>
<td></td>
<td>LB(14), $\chi^2(382)$</td>
<td>378.15</td>
<td>(0.546)</td>
</tr>
<tr>
<td></td>
<td>LB(24), $\chi^2(742)$</td>
<td>742.46</td>
<td>(0.488)</td>
</tr>
<tr>
<td>Presence of ARCH:</td>
<td>ARCH(3), $\chi^2(1323)$</td>
<td>1911.86</td>
<td>(0.000)</td>
</tr>
</tbody>
</table>

Note: JB is Jarque-Bera multivariate statistic based on Doornik and Hansen (1994). All the other tests are those described in Lütkepohl (2006): LM(x) is the multivariate Breusch-Godfrey LM-test for the $x^{th}$ order autocorrelation, LB(y) is the multivariate portmanteau test for residual autocorrelation up to the order y, and ARCH(3) is the multivariate LM-test for ARCH effect with 3 lags.
Step 4:

- The sum < 1 => a mean reverting variance process.

The correlation matrix is significantly different from the Identity.

Standardized residuals:
- Normality? YES
- Absence of ARCH? YES
- i.i.d.? YES

Furthermore:
- Engle and Sheppard (2001)' test failed to reject the null hypothesis of

\[ R_t = \bar{R} \]

Table 11. CCC-GARCH model estimates and diagnostic test results

<table>
<thead>
<tr>
<th></th>
<th>( \Delta \mu )</th>
<th>( \Delta \sigma^2 )</th>
<th>( \Delta \rho )</th>
<th>( \Delta \rho )</th>
<th>( \Delta \rho )</th>
<th>( \Delta \rho )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( i = 1 )</td>
<td>( i = 2 )</td>
<td>( i = 3 )</td>
<td>( i = 4 )</td>
<td>( i = 5 )</td>
<td>( i = 6 )</td>
</tr>
<tr>
<td>Panel A – GARCH estimates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \omega_i )</td>
<td>1,624.3913***</td>
<td>13.3677</td>
<td>3.2444</td>
<td>0.0041*</td>
<td>41.5661***</td>
<td>30.9672***</td>
</tr>
<tr>
<td></td>
<td>(2,7007)</td>
<td>(0.7684)</td>
<td>(1.0310)</td>
<td>(1,6522)</td>
<td>(2,1023)</td>
<td>(2,0530)</td>
</tr>
<tr>
<td>( \alpha_i )</td>
<td>0.1690**</td>
<td>0.0604*</td>
<td>0.3756</td>
<td>0.1140**</td>
<td>0.2759**</td>
<td>0.2134***</td>
</tr>
<tr>
<td></td>
<td>(2,2745)</td>
<td>(1,8992)</td>
<td>(1,3137)</td>
<td>(2,0476)</td>
<td>(2,0321)</td>
<td>(2,7428)</td>
</tr>
<tr>
<td>( \beta_i )</td>
<td>0.6133***</td>
<td>0.9256***</td>
<td>0.5560*</td>
<td>0.7213***</td>
<td>0.6826***</td>
<td>0.6835***</td>
</tr>
<tr>
<td></td>
<td>[5,8337]</td>
<td>[18,7470]</td>
<td>[1,8542]</td>
<td>[5,9487]</td>
<td>[7,5427]</td>
<td>[6,8509]</td>
</tr>
</tbody>
</table>

Panel B – Correlation matrix estimates and related diagnostics

<table>
<thead>
<tr>
<th></th>
<th>( \rho_{2i} )</th>
<th>( \rho_{3i} )</th>
<th>( \rho_{4i} )</th>
<th>( \rho_{5i} )</th>
<th>( \rho_{6i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.2388***</td>
<td>0.0563</td>
<td>0.0635</td>
<td>0.1461**</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>[4.2246]</td>
<td>(0.8492)</td>
<td>(0.9905)</td>
<td>(2.4365)</td>
<td>(2.4324)</td>
</tr>
</tbody>
</table>

Associated test: \( \chi^2(15) = 48.3461 \) (0.000)

Panel C – Diagnostics tests conducted on the standardized residuals

- AD normality: 0.2465, 0.7803, 3.1324**
- LB(12): 10.538, 5.3915, 2.9349
- ARCH-LM(4): 2.5267, 1.0091, 0.6790
- i.i.d. ? YES
Part II - Application

b) Results
Portfolio performance appraisal:

Morey and Morey (1999), Briec et al. (2004)

<table>
<thead>
<tr>
<th>Region</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angola</td>
<td>5.1%</td>
</tr>
<tr>
<td>Bahrain</td>
<td>3275.2%</td>
</tr>
<tr>
<td>Brunei</td>
<td>1.0%</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>0.0%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>9.5%</td>
</tr>
<tr>
<td>Oman</td>
<td>6.2%</td>
</tr>
<tr>
<td>Qatar</td>
<td>13.5%</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>1.6%</td>
</tr>
<tr>
<td>U.A.E.</td>
<td>37.9%</td>
</tr>
</tbody>
</table>
Gauging the diversification policies of gas-based economies

<table>
<thead>
<tr>
<th></th>
<th>Initial portfolios:</th>
<th>Optimal portfolios:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas flow (MMCFD)</td>
<td>allocated Shares (%)</td>
</tr>
<tr>
<td></td>
<td>Aluminum smelters</td>
<td>GTL plants</td>
</tr>
<tr>
<td>Angola</td>
<td>938.4</td>
<td>16.0%</td>
</tr>
<tr>
<td>Bahrain</td>
<td>342.5</td>
<td>63.5%</td>
</tr>
<tr>
<td>Brunei</td>
<td>1,165.8</td>
<td>-</td>
</tr>
<tr>
<td>Equatorial Guinea</td>
<td>656.8</td>
<td>-</td>
</tr>
<tr>
<td>Nigeria</td>
<td>3,582.6</td>
<td>1.3%</td>
</tr>
<tr>
<td>Oman</td>
<td>2,016.2</td>
<td>4.5%</td>
</tr>
<tr>
<td>Qatar</td>
<td>12,722.6</td>
<td>1.1%</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>3,069.6</td>
<td>-</td>
</tr>
<tr>
<td>U.A.E.</td>
<td>1,454.0</td>
<td>29.0%</td>
</tr>
</tbody>
</table>

Source: own evaluations based on USGS and Global Insight.
Conclusions & future extensions

- Numerous LDCs are assessing a gas monetization policy
  Possible new gas exporting countries: PNG, Mauritania...

- A general framework:
  - could be applied to analyze other RBI/commodities
    - oil: refining and petrochemical activities
    - coal: steel and chemicals
    - iron ore: steel industry and further manufacturing...
Thank you for your attention!

Olivier MASSOL
Albert BANAL-ESTAÑOL