UNLOCKING NATURAL GAS PIPELINE DEPLOYMENT IN A LDC

A note on rate-of-return regulation

Olivier MASSOL

Florian PERROTTON

CITY UNIVERSITY OF LONDON EST 1894

IFP SCHOOL

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Background 1: Mozambique's Gas Bonanza

- **One of the poorest nations (WB, 2015)**

2013 population:	25.83 millions
2015 GDP/cap:	$525.0
2015 HDI ranking:	180 *(out of 188 countries)*
2012 Electrification rate:	20.2%

- **2010: prolific gas discoveries in the North**

  Reserves (Rovuma Basin): 3,700 Bcm *(i.e., 2.5 x Troll in Norway)*

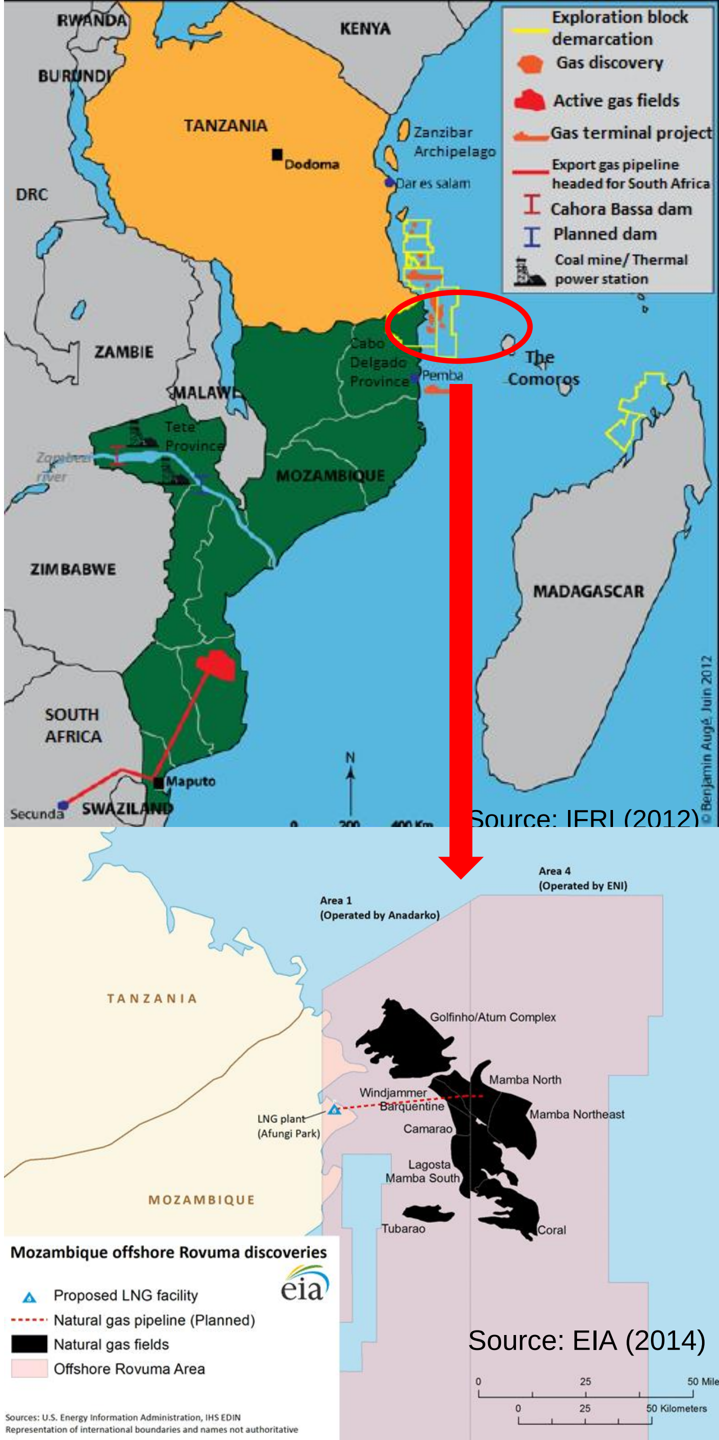
  E&P investment needs: ~ $10 billion

- **The IOCs**

  Favor large scale, export-oriented, LNG projects

  Condition investment in E&P developments to LNG sales

  Overlook the domestic market



BACKGROUND 2: MOZAMBIQUE'S AMBITIONS

- **Government of Mozambique**
  - Obtains a share of the volumes extracted (PSA)
    - Mega-project developers have applied to GoM for gas supply (e.g.: fertilizers, methanol, steel, aluminum)
  - Ambitions the deployment of a national pipeline system
  - The local NOC is unable to support such an investment
- Foreign investors are skeptical about the potential of the domestic market
- **A proposal by the World Bank (2012)**
  - **A phased pipeline development**
  - Gas-Based Industries (GBI) can provide the "anchor" load needed for pipeline development
  - Strategically locate them in **Nacala**, a natural deep harbor
    - the *Nacala Development Corridor* to Malawi and Zambia
    - a rapid and steady growing electricity demand in the region
    - A potentially emerging local market: Clusters of smaller gas-using industries are expected to develop once gas infrastructure is in place

Issue:

Attracting an adequate degree of infrastructure investment

Building Ahead of Demand?

- **So, the GoM has to attract FDI in a gas pipeline system**
  - **Joskow (1999)**: simple regulatory instruments should be favored to attract FDI in the infrastructure sectors of developing economies.

  ⇒ Mozambique has implemented a simple form of rate of return regulation

- **But foreign investors are reluctant to consider the potential of the domestic market**
  - they tend to solely consider the proven demand of large gas-based industries

- **Chenery (1952), Manne (1961): « build ahead of demand »**

  In case of **investment irreversibility** and **pronounced economies of scale**, it is justified to **install ex ante an appropriate degree of overcapacity** to minimize the expected cost of production over time if the future output trajectory is expected to rise over time.

Can planners/regulators leverage on the Averch Johnson (1962) effect to adequately build "ahead of demand"?

Research Questions

How should the allowed rate of return be determined?

- to attract investment
- to achieve the installation of an "adequate" degree of overcapacity

Roadmap

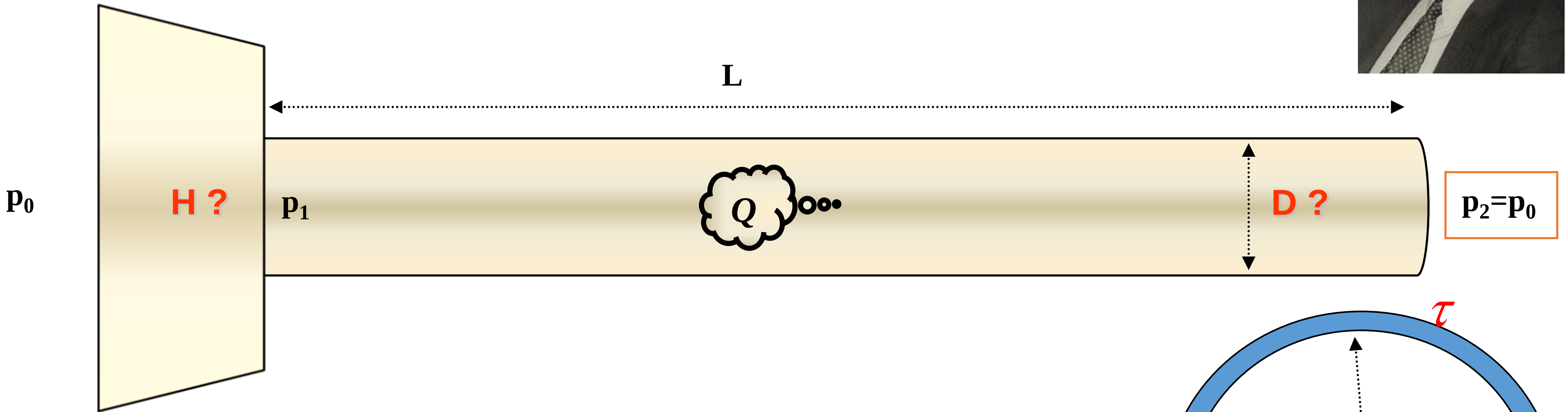
1 – Technology, an engineering economics approach

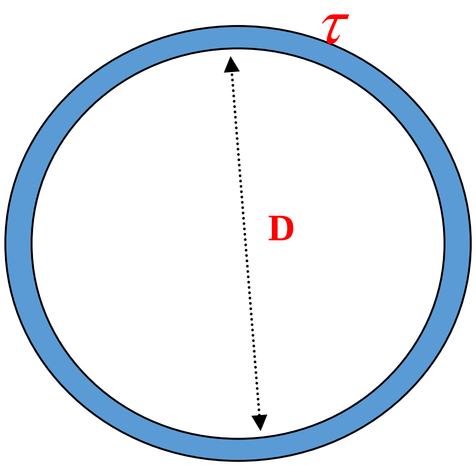
2 – Examine and characterize the ***ex ante*** behavior of the regulated firm

3 – Characterize the ***ex post*** behavior of the regulated firm in case of an *ex-post* expansion of the demand

1: Technology

TECHNOLOGY: CHENERY (1949) – YEPEZ (2008)





1 - Compressor equation

$$H = c_1 . \left[\left(\frac{p_1}{p_0} \right)^b - 1 \right] Q$$

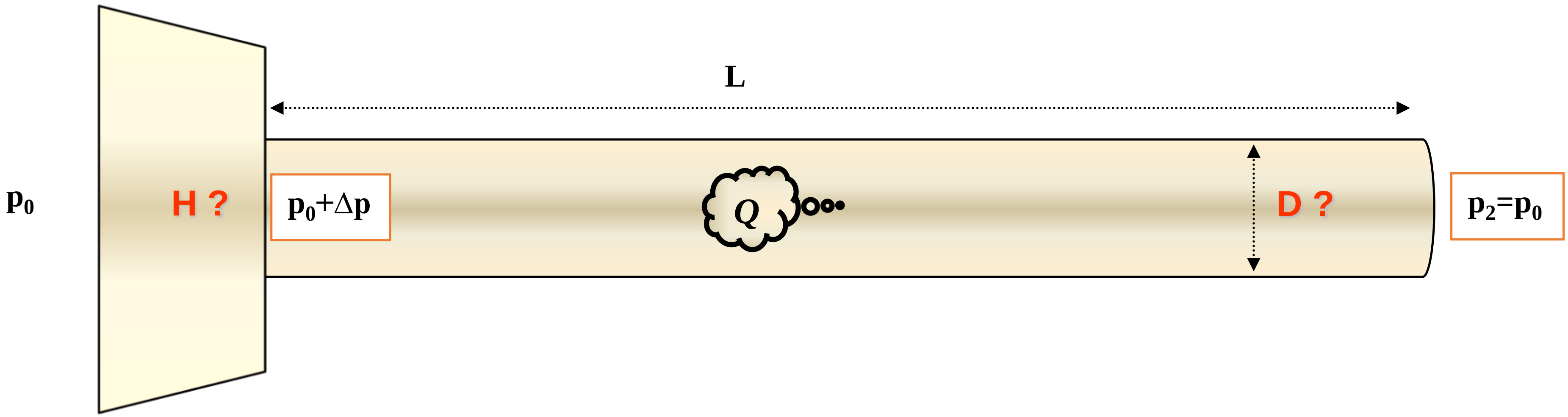
2 - A flow equation (Weymouth)

$$Q = \frac{c_2}{\sqrt{L}} D^{8/3} \sqrt{p_1^{\ 2} - p_2^{\ 2}}$$

3 - Mechanical stability

$$\tau = c_3 D$$

TECHNOLOGY: AN APPROXIMATION



1 - Compressor equation

$$H = c_1 . \left[\left(\frac{p_0 + \Delta p}{p_0} \right)^b - 1 \right] Q \approx c_1 b \frac{\Delta p}{p_0} Q$$

2 - A flow equation (Weymouth)

$$Q = \frac{c_2 p_0}{\sqrt{L}} D^{8/3} \sqrt{\left(\frac{p_0 + \Delta p}{p_0} \right)^2 - 1} \approx \frac{c_2 p_0 \sqrt{2}}{\sqrt{L}} D^{8/3} \sqrt{\frac{\Delta p}{p_0}}$$

$$Q = \sqrt[3]{\frac{2 \left(c_2 p_0 \right)^2}{c_1 b L}} D^{16/9} H^{1/3}$$

Further Assumptions

<u>H1:</u> The amount of energy ***E*** used for the compression is proportional to ***H***

<u>H2:</u> The capital expenditures ***K*** is proportional to the weight of steel (i.e., to the volume of an open cylinder)

$$K = P_S L\pi\left[\left(\frac{D}{2}+\tau\right)^2 - \frac{D^2}{4}\right]W_S$$

So, using the mechanical stability condition: $\tau = c_3 D$

$$K = P_S L\pi D^2\left[c_3 + c_3^2\right]W_S$$

We obtain the Cobb-Douglas production function $Q = M\ K^{8/9}E^{1/3}$

$Q^{\beta} = K^{\alpha}E^{1-\alpha}$ with $\alpha = 8/11$ and $\beta = 9/11$

The cost function

Long-run

$$\min_{K,E} \quad C(Q) = r\,K + e\,E$$

$$\text{s.t.} \quad Q^{\beta} = K^{\alpha} E^{1-\alpha}$$

Long-run cost function

$$C(Q) = \frac{r^{\alpha} e^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} Q^{\beta}$$

with $\beta = 9/11$

LR cost-minimizing capital

$$K(Q) = \left(\frac{e\alpha}{r(1-\alpha)}\right)^{1-\alpha} Q^{\beta}$$

Short-run

K is fixed

E is variable $E(Q,K) = K^{\frac{-\alpha}{1-\alpha}} Q^{\frac{\beta}{1-\alpha}}$

Short-run cost function

$$SRTC_K(Q) = rK + eK^{\frac{-\alpha}{1-\alpha}} Q^{\frac{\beta}{1-\alpha}}$$

2: THE *EX ANTE* BEHAVIOR OF THE REGULATED FIRM

A Regulated Monopoly

- We assume a constant elasticity demand schedule

$$P(Q) = A\,Q^{-\varepsilon} \quad \text{with} \quad \varepsilon \in (1-\beta, 1)$$

and examine the behavior of the regulated monopoly

$$\max_{K,Q} \quad \Pi(Q) = P(Q)Q - r\,K - e\,E(Q,K) \qquad (1)$$

$$\text{s.t} \quad P(Q)Q - e\,E(Q,K) = s\,K \qquad (2)$$

- Solution: see Klevorick (1971).

Static comparisons

- We compare the solution (*) with two benchmarks:

  (M) Monopoly

  (a) Average cost pricing

- Comparing metrics: output, capital, and cost ratios

	$\frac{Q^*}{Q^M}$	$\frac{K^*}{K\left(Q^*\right)}$	$\frac{C^*}{C\left(Q^*\right)}$
gradient wrt s/r	<0	<0	<0

These ratios are determined by: the ratio s/r, the demand elasticity and the technology parameters.

3: THE CASE OF AN EX-POST EXPANSION OF THE DEMAND

The ex-post behavior of the regulated firm

- *Ex ante:*

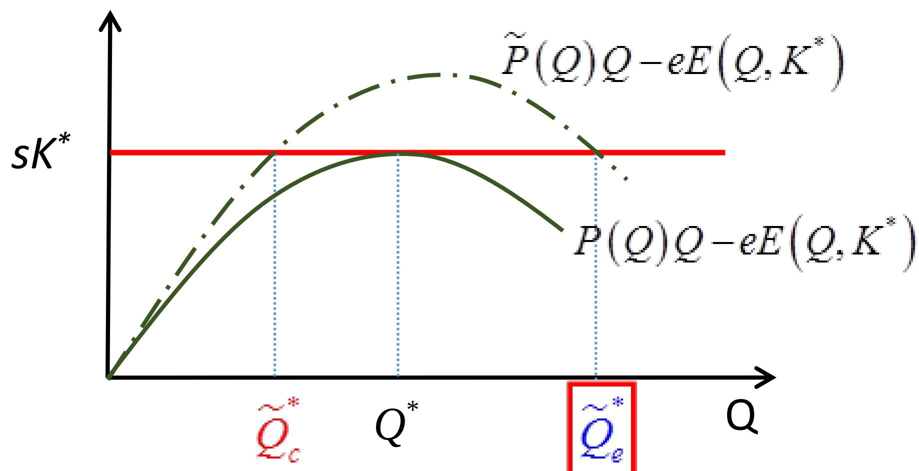
  The regulator sets ***s*** that will remain fixed hereafter

  The regulated firm decides its investment and thus ***K****

- *Ex post:*

  A larger demand: $\tilde{P}(Q) = (1+\lambda)P(Q)$ with $\lambda > 0$

Lemma: The regulated firm must adjust its output, and there are exactly two candidates: $\tilde{Q}_c^* < Q^* < \tilde{Q}_e^*$



We focus on the case of the expanded output $\tilde{Q}_e^*$

This output is monotonically increasing with λ

A COST EFFICIENT EX POST OUTPUT LEVEL

- We now consider a **<u>cost-efficient</u> capital-output combination** (K_{ce}, Q_{ce}) …

$$K_{ce} = K(Q_{ce})$$

where $K(Q)$ is the LR cost minimizing capital

… that also verifies the ***<u>ex post</u>*** rate-of-return constraint:

$$(1+\lambda)P(Q_{ce})Q_{ce} - eE(Q_{ce}, K_{ce}) = sK_{ce}$$

- Solving, we obtain a closed form expression of (K_{ce}, Q_{ce})

QUESTION

- **Can we set *s* so that the *ex post* capital-output combination is cost efficient?**

Proposition: *For any* $\lambda \in \left(0, \bar{\lambda}\right)$ *with* $\bar{\lambda} \equiv \left[\frac{\beta-(1-\varepsilon)(1-\alpha)}{(1-\varepsilon)\alpha}\right]^{\frac{\eta}{\beta}}\left[\frac{1-\varepsilon}{\beta}\right]-1$

there exists a unique rate of return $s_{\lambda} \in \left(r, s^{M}\right)$ *such that:* $K^{*} = K\left(\tilde{Q}_{e}^{*}\right)$

3: Policy Discussion

THE *EX ANTE* SOCIALLY DESIRABLE *s*

$$\underset{s}{\text{Max}} \quad W(s) = \int_0^Q P(q)\,dq \; - \; r\,K \; - \; e\,E(Q,K)$$

$$\text{s.t.} \quad \begin{cases} \underset{K,Q}{\text{Max}} \quad \Pi(Q) = P(Q)Q \; - \; r\,K \; - \; e\,E(Q,K) \\ \text{s.t.} \quad P(Q)Q \; - \; e\,E(Q,K) \; = \; s\,K \\ \qquad K \geq 0 \;\; , \;\; Q \geq 0\,. \end{cases}$$

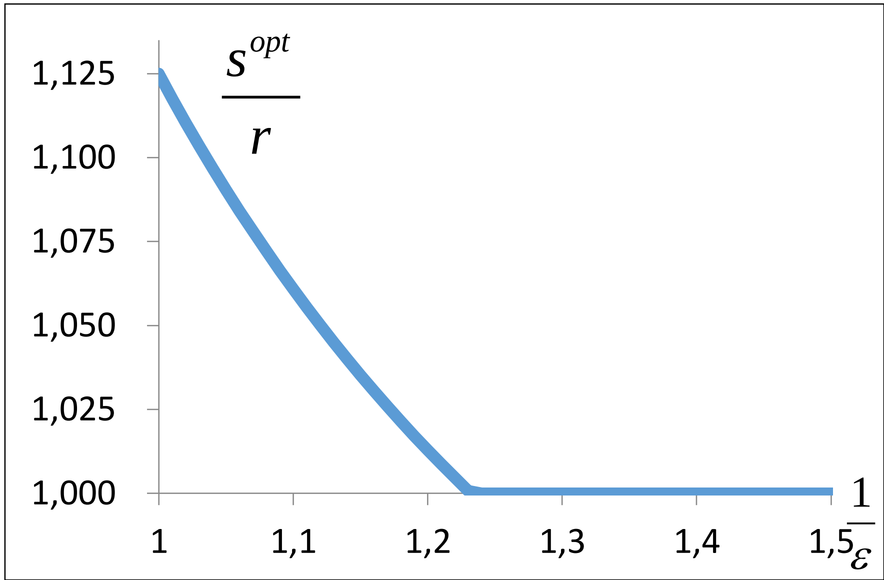
<u>Solution:</u> $s^{opt} = \dfrac{\left[\beta-(1-\varepsilon)(1-\alpha)\right]^2 r}{\alpha\left[\beta-(1-\alpha)(1-\varepsilon)^2\right]}$ iff $r < s^{opt}$

s^{opt} is monot. decreasing with (1/ε)

and s^{opt} >r iff $\dfrac{1}{\varepsilon} < \dfrac{11}{2+4\sqrt{3}} \approx 1.23$

As ε < 1, s^{opt} is bounded:

$$\frac{s^{opt}}{r} < \frac{\beta}{\alpha} = 1.125$$



$\frac{1}{\varepsilon}$	$\underline{\lambda}$	$\overline{\lambda}$	$\frac{\widetilde{Q}_e^*}{Q^*}(\underline{\lambda})$	$\frac{\widetilde{Q}_e^*}{Q^*}(\overline{\lambda})$	$\text{Min}\left\{\frac{\Delta W^*}{\Delta W^a}(1), \frac{\Delta W^*}{\Delta W^a}\left(\frac{\beta}{\alpha}\right)\right\}$	$\frac{\Delta\widetilde{W}^I}{\Delta\widetilde{W}^a}\left(\frac{\beta}{\alpha}\right)$
1.05	0.251	0.287	2.053	2.498	0.723	0.990
1.15	0.170	0.200	1.547	1.757	0.727	0.980
1.30	0.106	0.131	1.337	1.440	0.738	0.964
1.50	0.063	0.082	1.223	1.274	0.748	0.937

This table details the range of ***λ*** for which it is possible to: (i) build ahead of demand while (ii) maintaining a fair rate of return ***s*** lower than the threshold **βr/α**.

For $\lambda < \underline{\lambda}$, one has to follow Joskow (1999) who points that regulators in developing economies often face possibly conflicting public policy goals and have to clearly define and prioritize these goals

CONCLUSIONS

- The technology of a natural gas pipeline can be approximated by a Cobb-Douglas production function that has two inputs ***K*** and ***E.***

  Discussion: relevance of the empirical analyses of the A-J effect that solely consider the relations between K and L?

- **Case λ=0:** It can be justified to use a fair rate of return ***s*** larger than ***r*** the market price of capital in the gas pipeline industry.

  Note: welfare maximization suggests that the ratio s/r has to be lower than β/α = 1.125

- **Case λ>0:** It is possible to use the A-J effect to "build ahead of demand"

  Note: the range of λ for which this strategy does not hamper the welfare obtained ex ante is quite narrow.