A Regulatory Mechanism for Network Expansion

Juan Rosellón

References

- Hogan, W., J. Rosellón and I. Vogelsang (2007), "A Combined Merchant-Regulatory Mechanism for Electricity Transmission Expansion," proceedings of the 9th IAEE European Energy Conference (Florence)
- Rosellón, J. (2007), "An Incentive Mechanism for Electricity Transmission Expansion in Mexico," *Energy Policy*, 35 (5): 3003-3014, May
- Kristiansen, T. and J. Rosellón (2006), "A Merchant Mechanism for Electricity Transmission Expansion," *Journal of Regulatory Economics,* vol. 29, no.2, March
- Brito, D. L. and J. Rosellón, (2005), "Implications of the Elasticity of Natural Gas in Mexico on Investment in Gas Pipelines and in Setting the Arbitrage Point," in Repsol YPF-Harvard Kennedy School Fellows 2003-2004 Research Papers, William Hogan, editor, Cambridge, MA, Kennedy School of Government, Harvard University, April, http://www.ksg.harvard.edu/m-rcbg/repsol_ypf-ksg_fellows/03-04_research_papers.pdf
- Rosellón J. (2003), "Different Approaches Towards Electricity Transmission Expansion," *The Review of Network Economics* , vol. 2, issue 3, September
- Ramírez, J.C. and J. Rosellón, (2002), "Pricing Natural Gas Distribution in Mexico," *Energy Economics*, Vol. 24, No. 3, pp. 231-248.
- Vogelsang, I., (2001), "Price Regulation for Independent Transmission Companies," *Journal of Regulatory Economics*, vol. 20, no. 2, September

Contents

Introduction

- Few market niches with legal or natural monopolies (e.g.: transmission and distribution of natural gas and electricity)

- Regulation of monopolies is important since they are vertically interrelated with other contestable sectors

“HISTORY” OF OPTIMAL PRICES

- First Best: marginal cost (70´s)
- Second best: Ramsey prices (80´s)
- Third best: Revelation principle/Laffont-Tirole (93)
- Fourth best: Theoretical models under practical restrictions (nowadays)

DESIRABLE PROPERTIES OF APPLIED MECHANISMS

- Pareto superiority

- Efficiency improvements

- Two basic concepts:

- Price level
- Price structure

- Regulation of “price level”: long-run distribution of rents and risks between consumers and the firm

- Regulation of “price structure”: short-run allocation of costs and benefits among distinct types of consumers

Price-level regulation

ALTERNATIVES

- Cost-of-service regulation

- Price caps. Adjustment factors (*RPI*, *X*, etc.)
- “Yardstick” regulation
- Hybrid regulation

Price-structure regulation

ALTERNATIVES

- Fully distributed cost pricing
- Price bands
- Restricted flexibility:

- Average revenue
- Tariff basket

AVERAGE REVENUE REGULATION

- Sets a cap on revenues per unit.
- Does not set fixed weights that limit tariff rebalancing

TARIFF-BASKET REGULATION

- Cap set over an index
- Fixed weights

$$\mathrm{I(p)} = \sum_{i=1}^{h} w_i p_i$$

TYPES OF WEIGHTS

- Chained Laspeyres
- Paasche weights
- Fixed Laspeyres
- Ideal weights
- Flexible weights (average revenue)

LITERATURE REVIEW. THREE RESULTS

1. Under stable cost and demand functions, and myopic profit maximization, the chained Laspeyres index induces convergence to Ramsey prices
2. Assuming stable cost and demand functions, and myopic profit maximization, average revenue regulation causes divergence from Ramsey prices
3. In a dynamic setting with changing cost and demand functions --and/or non-myopic profit maximization-- the chained Laspeyres index generates prices that may diverge from the Ramsey structure

LITERATURE REVIEW: POLICY RECOMMENDATIONS

- Chained Laspeyres index should be used under cost and demand stability
- Under risk and uncertainty there is no reason that justifies the use of the Laspeyres index
- Average-revenue regulation is a softer constraint than the chained Laspeyres index

POLICY OPTIONS

- Price level regulation: Cost of service or incentive regulation?

- Price structure regulation: Tariff basket or average revenue?

The Vogelsang (2001) model

Vogelsang, I., (2001), "Price Regulation for Independent Transmission Companies," Journal of Regulatory Economics, vol. 20, no. 2, September

- "Transco" that is regulated through benchmark or price regulation to provide it with incentives to invest in the development of the grid, while avoiding congestion
- Léautier (2000), Grande and Wangesteen (2000), and Joskow and Tirole (2002) propose mechanisms that compare the Transco performance with a measure of welfare loss: the Transco penalized for increasing congestion costs in the network

- Vogelsang (2001) explicitly studies cost and demand functions of transmission, and isolate the monopolistic nature of a for-profit Transco

- The Model:

- Price cap (RPI-X) –regulatory lagged– regulation is the best price-level option
- Price structure regulation: Two-part tariff regulatory model with variable (or usage) charges, and fixed (or capacity) charges
- The Transco is a profit-maximizing monopolist subject to a regulation of its two-part tariff.
- The variable (usage) charge can also be understood as a nodal (congestion) price
- The fixed (capacity) charge recovers fixed capital costs
- **Expansion of the network reached by a rebalancing of the fixed charge and the variable charge**
- Transmitted volumes are weights
- In equilibrium, optimal rebalancing of the fixed and variable charges depends on the ratio between the output weight, and the number of consumers

$$\max \quad \Pi^t = p^t q^t + F^t N - c(q^t, K^t)$$

subject to

$$F^t \leq F^{t-1} + (p^{t-1} - p^t) q^w / N$$

$$q^t \leq K^t$$

Cost function:

$$C(q^t, K^{t-1}) = C(q^{t-1}, K^{t-1}), \ \forall \ q^t, q^{t-1} \leq K^{t-1}$$

$$C(q^t, K^t) = C(q^t, K^{t-1}) + f(K^{t-1}, I^t) \ for \quad q^t > K^{t-1}$$

$$I^t = K^t - K^{t-1}$$

Optimal conditions:

$$\left(\frac{\partial q^t}{\partial p^t}\right)\left(p^t - \frac{\partial C}{\partial q^t}\right) = q^w - q^t$$

$$L^t = -[1 - \frac{q^w}{q^t}] / \varepsilon^t$$

Application 1

Electricity transmission

Rosellón, J. (2007), "An Incentive Mechanism for Electricity Transmission Expansion in Mexico," Energy Policy, 35 (5): 3003-3014, May

- Application of Vogelsang (2001)

- Pricing regulatory method in the context of a combined merchant-regulatory mechanism

- Abstract from loop-flow effects, so as to study two scenarios:

  1. A single two-node radial line that provides the transmission service in all the country. A single firm owns the transmission network, and applies a uniform two-part tariff along the country
  2. The second abstraction studies a hypothetical situation where there are several radial transmission lines serving each of the electricity regions of the country

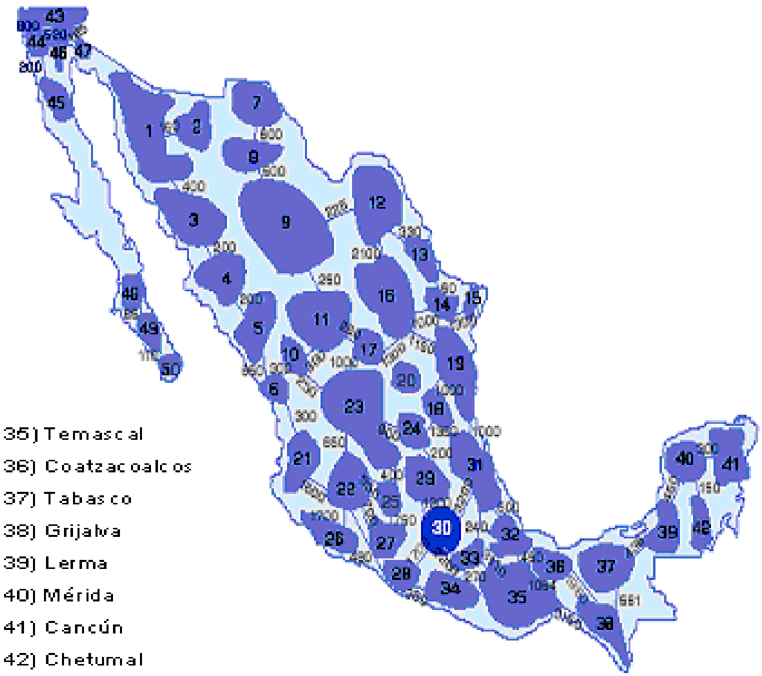
- In case 2, there are two sub-cases:

  a) Different firms charge distinct variable and fixed fees with respect to the other regions

  b) A single firm owns each of the regional systems, and charges the same variable fee across regions but with different fixed fees

Figure 1

Capacity of the Mexican Transmission System



Regions

1) Hermosillo
2) Nacozari
3) Obregón
4) Los Mochis
5) Culiacán
6) Mazatlán
7) Juárez
8) Moctezuma
9) Chihuahua
10) Durango
11) Laguna
12) Río Escondido
13) Nuevo Laredo
14) Reynosa
15) Matamoros
16) Monterrey
17) Saltillo
18) Valles
19) Husteca
20) Tamazunchale
21) Tepic
22) Guadalajara
23) Aguascalientes
24) San Luis Potosí
25) Salamanca
26) Manzanillo
27) Carapan
28) Lázaro Cárdenas
29) Querétaro
30) Central
31) Poza Rica
32) Veracruz
33) Puebla
34) Acapulco
35) Temascal
36) Coatzacoalcos
37) Tabasco
38) Grijalva
39) Lerma
40) Mérida
41) Cancún
42) Chetumal
43) WECC (EUS)
44) Tijuana
45) Ensenada
46) Mexicali
47) San Luis Río C.
48) Villa Constitución
49) La paz
50) Los Cabos

Source: Comisión Federal de Electricidad

- Other assumptions:
  - The inflation rate and the *X* efficiency adjustment factors are equal to zero
  - Operation costs are equal to zero
  - Previous period transmission output is used as *Laspeyres* weights
- Transmission expansion is shown to be the highest in scenario 1

	Total Profits (pesos)	Capacity increase (MWh)	Network expansion (Kilometers)
Case 1 fix no. consumers	26,049,682,377	42,927,045,660.01	10,165.7231
Case 1 var. no. consumers	27,419,831,988	42,816,298,038.15	10,139.4966
Case 2	28,061,340,345	37,427,028,092.75	8,863.2423
Case 3	5,920,638,442	28,644,674,371.59	7,236.4919

Hogan, W., J. Rosellón and I. Vogelsang (2007), "A Combined Merchant-Regulatory Mechanism for Electricity Transmission Expansion," proceedings of the 9th IAEE European Energy Conference (Florence)

- We concentrate on the merchant and regulatory approaches in an environment of price-taking generators and loads. Extract the best properties of these two mechanisms
- Extension of Vogelsang (2001) for large and lumpy *meshed* projects. Designed for Transcos but it could also be applied under an ISO institutional setting.
- Transmission output is redefined in terms of incremental LTFTRs
- Our model also addresses the problem of transmission pricing and expansion:
  - a) The variable part of the tariff is based on nodal prices
  - b) Fixed costs are allocated so that the variable charges are able to reflect nodal prices
  - c) Fixed charges over time partially counteract the variability of nodal prices, giving some price insurance to the market participants

Characterization of Transmission Outputs

- The literature on price cap regulation considers the electricity transmission activity as an output (or throughput) process. It assumes that transmission demand functions are differentiable and downward slopping, and that transmission marginal costs curves cut demands only once. These assumptions are unrealistic under loop flows
- Alternatively, the FTR literature does not consider the electricity transmission activity as an output process. It concentrates on “point-to-point” (PTP) financial transactions
- In our paper, we capture the delivery function of electricity among nodes through LTFTRs (obligations) defined between nodes. An LTFTR q_{ij} represents the right to inject electricity in the amount of *q* at node *i* and to take delivery of the same amount at node *j*. The FTR does not specify the path taken between *i* and *j*. It is a flow concept

Formal Model

$$c^*\left(q, K^{t-1}, H^{t-1}\right) = \underset{K^t \in \mathrm{K}, H^t \in \mathrm{H}}{Min} \left\{ c\left(K^t, K^{t-1}, H^t, H^{t-1}\right) \middle| H^t q \leq K^t \right\}.$$

q_t = the net injections in period t (FTRs are derived from q_t)
K_t = available transmission capacity in period t
H_t = transfer admittance matrix at period t
ι^t = a vector of ones

$$\underset{\tau^t, F^t}{Max}\, \pi^t = \tau^t \left(q(\tau^t) - q^{t-1}\right) + F^t N^t - c^*\left(q\left(\tau^t\right), K^{t-1}, H^{t-1}\right)$$

s.t. $\tau^t Q^w + F^t N^t \leq \tau^{t-1} Q^w + F^{t-1} N^t$

τ^t = vector of transmission prices between locations in period t
F^t = fixed fee in period t
N^t = number of consumers in period t
Z^t = vector of impedances at period t
$Q^w = (q^t - q^{t-1})^w$
w = type of weight.

- Idealized weights provide incentives for marginal cost pricing

- Under Laspeyres weights and assuming that cross-derivatives have the same sign:
  - When goods are complements and if prices are above marginal costs, current quantities will exceed last period’s quantities, which mean that prices are intertemporally lowered
  - If goods are substitutes, we get this effect if the cross effects are smaller than the direct effects. If prices are below marginal costs we get the opposite results. So, we get a closer approximation of prices to marginal costs unless cross effects are too large

Transmission Cost Functions

- The cost function is defined by the minimum costs necessary to produce each level of output, subject to feasibility constraints and the relationship between net injections and output:

$$C(X) = \min_{k_i} \sum_{i=1}^{10} f_i(k_i)$$

$$-Hx \leq k$$

$$x = Xe$$

Transmission Cost Functions

- The marginal costs of FTRs are linear combinations of the marginal costs of all lines. The weights of these linear combinations are constant
- As a result, marginal costs of FTRs should be well-behaved as long as marginal costs of lines do not differ too widely from each other and as long as marginal costs of all individual lines are well-behaved

Transmission Cost Functions

$$C(X) = \min\{\sum_{i=1}^{10} f_i(-H_i Xe)\} =$$

$$f_1(\frac{1}{2}\sum_i q_{1i} - \frac{3}{16}\sum_i q_{2i} + \frac{3}{16}\sum_i q_{3i} + \frac{1}{16}\sum_i q_{5i} - \frac{1}{16}\sum_i q_{6i}) + f_2(...) + ..f_{10}(...)\}$$

F.O.C:

$$\frac{\partial C(X)}{\partial q_{17}} = \frac{1}{2}\frac{\partial f_1}{\partial k_1} + \frac{1}{2}\frac{\partial f_2}{\partial k_2} + \frac{1}{6}\frac{\partial f_3}{\partial k_3} + \frac{1}{3}\frac{\partial f_4}{\partial k_4} + \frac{1}{6}\frac{\partial f_5}{\partial k_5} + \frac{1}{3}\frac{\partial f_6}{\partial k_6} + \frac{1}{6}\frac{\partial f_7}{\partial k_7} + \frac{1}{6}\frac{\partial f_8}{\partial k_8} + \frac{1}{2}\frac{\partial f_9}{\partial k_9} + \frac{1}{2}\frac{\partial f_{10}}{\partial k_{10}}$$

$$\frac{\partial C(X)}{\partial q_{37}} = \frac{3}{16}\frac{\partial f_1}{\partial k_1} - \frac{3}{16}\frac{\partial f_2}{\partial k_2} - \frac{1}{48}\frac{\partial f_3}{\partial k_3} + \frac{5}{24}\frac{\partial f_4}{\partial k_4} + \frac{17}{48}\frac{\partial f_5}{\partial k_5} + \frac{11}{24}\frac{\partial f_6}{\partial k_6} + \frac{5}{48}\frac{\partial f_7}{\partial k_7} + \frac{11}{48}\frac{\partial f_8}{\partial k_8} + \frac{9}{16}\frac{\partial f_9}{\partial k_9} + \frac{7}{16}\frac{\partial f_{10}}{\partial k_{10}}$$

Transmission Demand Functions

- How does the Transco get the demand information necessary to optimize investments in transmission capacity? It derives from demands at consumption nodes and supplies at generation nodes
- Simultaneous estimation of market equilibria in all electricity markets is involved. The Transco would have to know the supply functions at generation nodes and the demand functions at the consumption nodes
- Assume there are *L* generation nodes indexed by '*l*' and *M* demand nodes indexed by '*m*'. Also assume generators supply electricity competitively and ultimate buyers demand electricity competitively
- The Transco can now find the set of transmission demand functions for point-to-point transmissions by maximizing total surplus net of transmission charges

Transmission Demand Functions

- Given an arbitrary set of transmission prices between locations, from *i* to *j* ($\tau = (\tau_{ij})$), choose:

  Max $W(\{q_{lm}\}) = \Sigma_m CS_m(q_m) - \Sigma_l C_l(q_l) - \Sigma_l \Sigma_m \tau_{lm} q_{lm}$

s.t. $\Sigma_l q_{lm} = q_m$ and $\Sigma_m q_{lm} = q_l$

  $CS_m(q_m)$: Consumer surplus for electricity at node *m*

  $C_l(q_l)$: Area under the supply curve for electricity at node *l*

- Maximizing w.r.t. q_{lm} gives *l*x*m* first order conditions of the form $p_m - p_l = \tau_{lm}$. By substituting the electricity supply and demand functions for the *p*'s provides *l*x*m* equations in *l*x*m* unknowns that can be solved for the q_{lm}'s as functions of the τ_{lm}'s. This yields the vector demand function $q(\tau)$

Formal Model

The first order optimality conditions are

$$\nabla q(\tau - \nabla_q c^*) = Q^w - (q(\tau) - q^{t-1})$$

Example

$$\underset{\tau_{17}^t,\tau_{37}^t,F^t}{Max}\ \tau_{17}^t(q_{17}^t(\tau^t) - q_{17}^{t-1}) + \tau_{37}^t(q_{37}^t(\tau^t) - q_{37}^{t-1}) + F^t N^t - c^*(q(\tau^t), K^{t-1}, H^{t-1})$$

s.t.

$$\tau_{17}^t Q_{17}^w + \tau_{37}^t Q_{37}^w + F^t N^t \leq \tau_{17}^{t-1} Q_{17}^w + \tau_{37}^{t-1} Q_{37}^w + F^{t-1} N^t$$

F.O.C.

$$(\tau_{17}^t - \frac{\partial c}{\partial q_{17}^t})\frac{\partial q_{17}^t}{\partial \tau_{17}^t} + (\tau_{37}^t - \frac{\partial c}{\partial q_{37}^t})\frac{\partial q_{37}^t}{\partial \tau_{17}^t} = Q_{17}^w - q_{17}^t + q^{t-1}{}_{17}$$

$$(\tau_{37}^t - \frac{\partial c}{\partial q_{37}^t})\frac{\partial q_{37}^t}{\partial \tau_{37}^t} + (\tau_{17}^t - \frac{\partial c}{\partial q_{17}^t})\frac{\partial q_{17}^t}{\partial \tau_{37}^t} = Q_{37}^w - q_{37}^t + q^{t-1}{}_{37}$$

Formal Model

- Idealized weights [$Q_{17}^{w} = q_{17}^{*} - q_{17}^{t-1}$ and $Q_{37}^{w} = q_{37}^{*} - q_{37}^{t-1}$] are sufficient for transmission nodal prices to equal marginal costs only if:

$$(\frac{\partial q_{17}^{t}}{\partial \tau_{17}^{t}}) \cdot (\frac{\partial q_{37}^{t}}{\partial \tau_{37}^{t}}) \neq (\frac{\partial q_{37}^{t}}{\partial \tau_{17}^{t}}) \cdot (\frac{\partial q_{17}^{t}}{\partial \tau_{37}^{t}})$$

- Laspeyres (last period's) weights. F.O.C. imply:

$$(\tau_{17}^{t} - \frac{\partial C}{\partial q_{17}^{t}})\frac{\partial q_{17}^{t}}{\partial \tau_{17}^{t}} + (\tau_{37}^{t} - \frac{\partial C}{\partial q_{37}^{t}})\frac{\partial q_{37}^{t}}{\partial \tau_{17}^{t}} = (q_{17}^{t-1} - q_{17}^{t-2}) - (q_{17}^{t} - q_{17}^{t-1})$$

$$(\tau_{37}^{t} - \frac{\partial C}{\partial q_{37}^{t}})\frac{\partial q_{37}^{t}}{\partial \tau_{37}^{t}} + (\tau_{17}^{t} - \frac{\partial C}{\partial q_{17}^{t}})\frac{\partial q_{17}^{t}}{\partial \tau_{37}^{t}} = (q_{37}^{t-1} - q_{37}^{t-2}) - (q_{37}^{t} - q_{37}^{t-1})$$

Application 2

Natural gas distribution

- The regulatory reform process in distribution combined the design of auctions for exclusivity in distribution geographical areas (competition for the market), as well as incentive regulation for distribution tariffs, so as to attract investment
- Auction design sought to reach a balance in the trade-off between risk management (through the granting of exclusivity) and incentive provision (implicit competition between the LDCs and Pemex)
- The design of price regulation tried to reach equilibrium in the trade-off between investment attraction to *greenfield* projects (average-revenue incentive regulation) and consumer-surplus maximization (through tariff-basket incentive regulation and competition for the market)

CRE´S PLAN

- Competition for the distribution market. Greenfield projects. Biddings grant 12-year distribution exclusivity
- Average-revenue regulation used during the first five-year period. Tariff-basket is used later on
- Prices must be set at the start of the period based on a forecast of $Q_{t.}$
- Need of a correction factor to adjust for estimation errors
- Average revenue regulation provides the needed flexibility in tariff rebalancing during the initial stages of greenfield projects

The model

Ramírez, J.C. and J. Rosellón, (2002), "Pricing Natural Gas Distribution in Mexico," Energy Economics

- Under changing demand conditions, what are the effects of average-revenue regulation and competition for the distribution market on consumer surplus?
- Two effects: strategic effect and stochastic effect
- Solution: set usage charge close to zero while fixed charge strategically set to bear burden of misprediction
- Stochastic effect alone: Consumer surplus decreases (increases) as the firm is more risk loving (averse) and when there is less (more) demand uncertainty

Average-Revenue Constraint

- Static constraint: $$\left\{ p \,/\, \sum_i Q_i(p_i)\,p_i \le p_0 \sum_i Q_i(p_i) \right\}$$

- Dynamic constraint:
$$AR_t = p_t + \frac{F_t}{Q_t}$$
$$E(AR_t) = p_t + \frac{F_t}{E(Q_t)} \le M_t$$
$$F_t \le E(Q_t)\left[M_t - p_t\right]$$

DYNAMIC CONSTRAINT

$$M_{t+1} = K_t + M_t$$

$$M_t = M_0 + K_1 + \ldots\ldots K_{t-1}$$

DYNAMIC CONSTRAINT

- K_t will be positive, zero or negative whenever $AR_t < M_t$, $AR_t = M_t$ or $AR_t > M_t$, respectively

- The strategic effect:

$$E(Q_t) = Q_t : \quad F_t \leq Q_t \left[M_t - p_t \right]$$

DYNAMIC CONSTRAINT

The stochastic effect: Q_t stochastic $\Rightarrow$ $E(Q_t) \neq Q_t \Rightarrow AR_t \neq M_t \Rightarrow K_t \neq 0$ and, therefore, more (or less) flexibility to set F_{t+1}

The stochastic model

$$\max_{p_t, F_t} E\left\{ \sum_{t=1}^{T} \beta^t \left(p_t Q_t - c(Q_t) + F_t \right) \right\}$$

subject to

$$Q_{t+1} = Q_t(p_t) - K_t$$

$$F_t \leq E\{Q_t(M_t - p_t)\}$$

$$Q_T \geq N$$

$$\beta^t \in [0,1]$$

SOLUTION

- Static scenario: set the usage charge *P* close to zero and set fix charge *F* to the level that satisfies the average-revenue and cumulative constraints
- Dynamic scenario with strategic pricing: The usage charge in period *t* (P_t) is kept close to zero while the fixed charge in period *t+1* (F_{t+1}) is strategically set so as to bear all the burden of misprediction

SOLUTION

- Dynamic scenario with no strategic pricing: the static-case solution is applied in each period
- However, we proceed to isolate the effect of the stochastic effect alone on consumer surplus. We assume the fixed fee is kept constant in each period and study how the firm manipulates its expected profits subject to the average revenue and cummulative constraints, and under the stochastic behavior of the correction factor K

SIMULATION

$$\max_{p_t} E\left\{\sum_{t=1}^{T} \beta^t (M_t[a - bp_t] - [F + cp_t])\right\}$$

subject to

$$Q_{t+1} = a - bp_t - K_t$$

$$Q_T \geq N$$

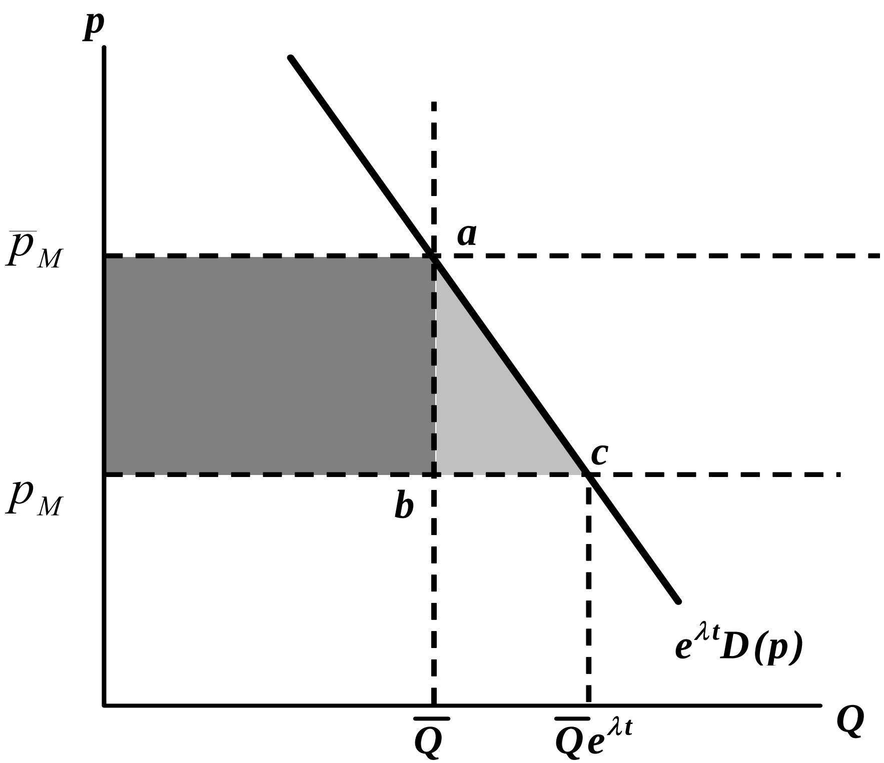
SIMULATION RESULTS

- Results obtained under the assumption of no strategic behavior
- Consumer surplus tends to decrease (increase) as the firm is more risk loving (averse) and when there is less (more) demand uncertainty

Alternative proposal

Brito, D. L. and J. Rosellón, (2005), "Implications of the Elasticity of Natural Gas in Mexico on Investment in Gas Pipelines and in Setting the Arbitrage Point," in Repsol YPF Harvard Kennedy School Fellows 2003-2004 Research Papers, William Hogan, editor, Cambridge, MA, Kennedy School of Government, Harvard University, April, http://www.ksg.harvard.edu/m-rcbg/repsol_ypf-ksg_fellows/03-04_research_papers.pdf

- Sufficient investment in pipeline capacity so that bottlenecks do not develop
- A policy that makes sure that there is always sufficient pipeline capacity so that the gas market can always clear should be followed
- Such a policy would generate sufficient savings to the consumers of gas that they will be willing to pay for such investment in the rate structure. Consumers would be willing to pay for this capacity


p
$\overline{p}_M$
a
c
p_M
b
$e^{\lambda t}D(p)$
$\overline{Q}$
$\overline{Q}e^{\lambda t}$
Q

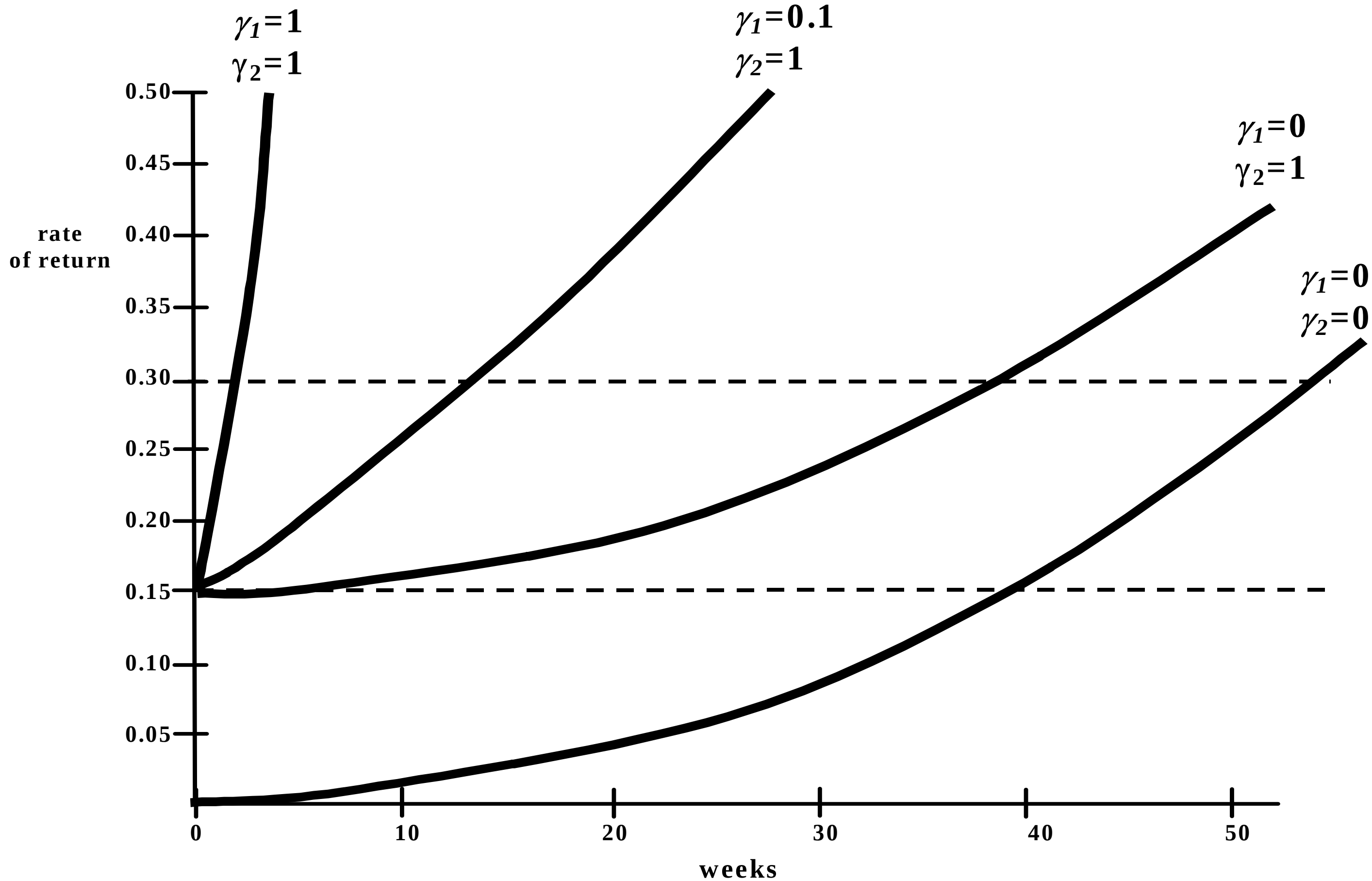
Pipeline capacity

WELFARE LOSS FUNCTION

$$\varphi = \int_0^T e^{-rt}\left\{\frac{\overline{Q}\left(e^{\lambda t}-1\right)\left[\theta\left(\overline{Q}e^{\lambda t}\right)-\overline{p}_M\right]}{2}+\gamma_1\overline{Q}\left[\theta\left(\overline{Q}e^{\lambda t}\right)-\overline{p}_M\right]-\gamma_2\varphi\right\}dt+e^{-rT}C_0$$

F.O.C.

$$\frac{\dfrac{\overline{Q}\left(e^{\lambda T}-1\right)\left[\theta\left(\overline{Q}e^{\lambda T}\right)-\overline{p}_M\right]}{2}+\gamma_1\overline{Q}\left[\theta\left(\overline{Q}e^{\lambda T}\right)-\overline{p}_M\right]-\gamma_2\varphi}{C_0}=r$$



γ_1=1
γ_2=1
γ_1=0.1
γ_2=1
γ_1=0
γ_2=1
γ_1=0
γ_2=0
rate
of return
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
10
20
30
40
50
weeks

Conclusion

- Incentives both for firms and consumers to expand networks in any type of industry

- Decisions on price regulation should consider reaching equilibrium in at least two trade-offs:
    1. Risk management vs. Incentives
    2. Investment attraction vs. Consumer-surplus maximization

- Our study on electricity transmission is just a first step in a research agenda that should evolve into various modeling exercises as well as simulations and applications