Lumpy Investment in Regulated Natural Gas Pipelines: An Application of the Theory of the Second Best

Dagobert L. Brito
Department of Economics and Baker Institute, Rice University, and
Centro de Investigación y Docencia Económicas (CIDE)

Juan Rosellón
Centro de Investigación y Docencia Económicas (CIDE), and Dresden University of Technology (TU Dresden)

Conference on "The Economics of Energy Markets". IDEI Toulouse, June 20 and 21, 2008

Contents

Introduction

Gas pipelines requires lumpy investment. Once the pressure limits on a pipeline are reached, the only way to add capacity is to add pipe or add pumping stations.

Three years lead time to increase pipeline capacity.

Rely on forecasts of future demands for the purpose of planning investment in pipeline capacity.

Forecasts are at best uncertain.

In theory, investing in pipelines can be formulated as a dynamic program.

Computing a first-best efficient solution may not very useful.

An optimal investment policy involves some periods where the constraint is binding.

However, in a second best world, consumers may prefer to bear the cost of excess capacity rather than the risk of transfers created by binding constraints: **“C-efficiency.”**

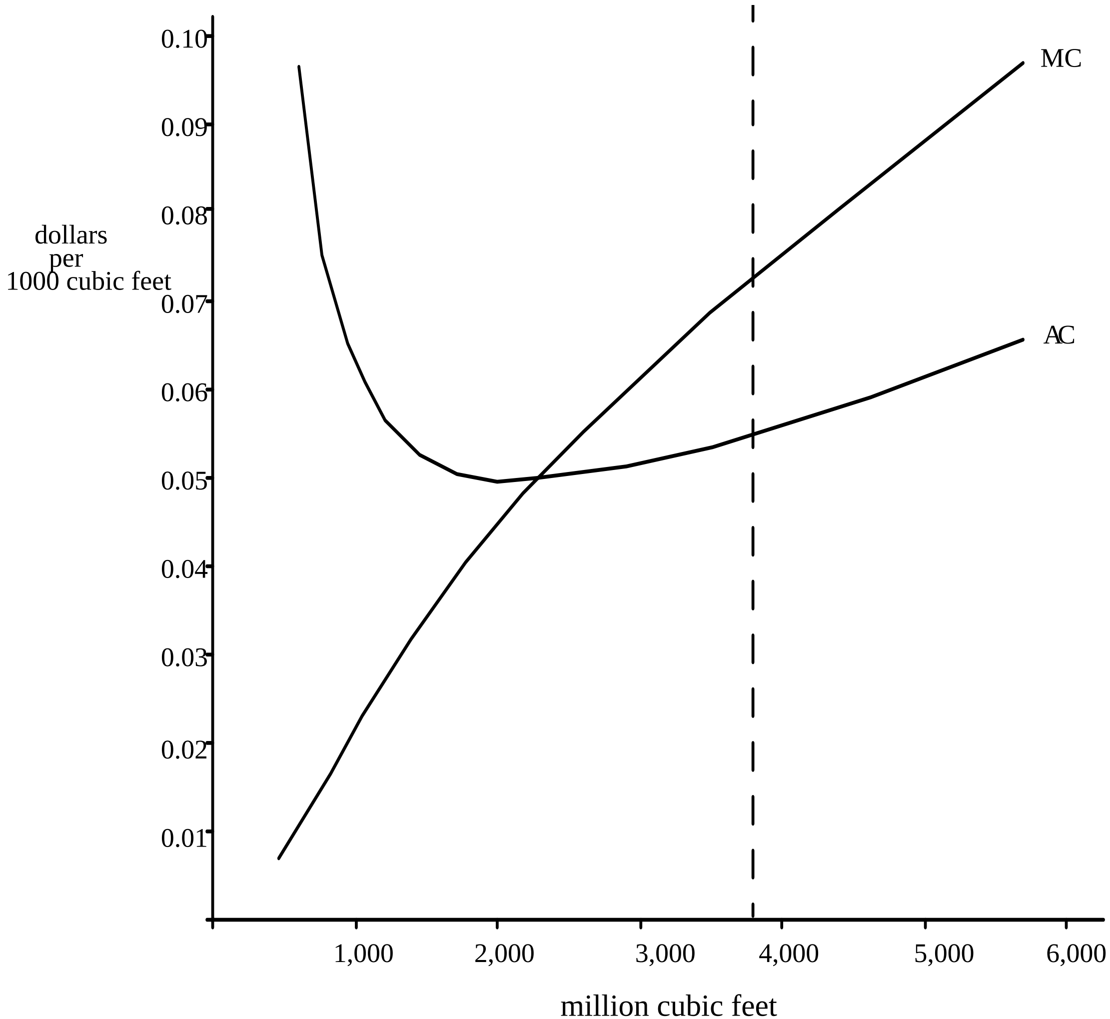
Another issue is the rate structure. The technology of pipelines is such that marginal cost pricing will not cover average costs.

The theoretical solution to the non-lumpy version of this problem is a two-part tariff (Vogelsang, 2001).

Demand for gas is very inelastic, the welfare losses associated from small deviations from a first best optimum are minimal.

Since the demand for gas is very inelastic, the welfare losses associated with average cost pricing are small.

Average Cost Pricing for Gas Pipelines


0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
dollars
per
1000 cubic feet
MC
AC
1,000
2,000
3,000
4,000
5,000
6,000
million cubic feet

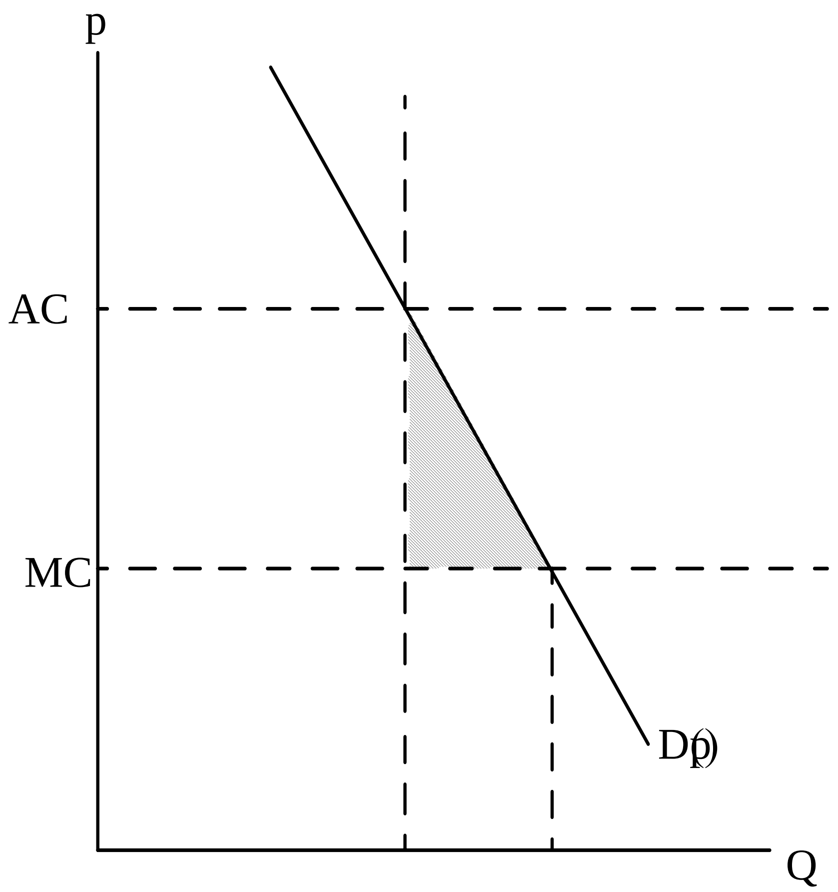
Marginal cost pricing results in a loss of rents.

Two-part tariff with a price cap. The marginal cost of transporting gas equals the variable change for moving gas.

Joskow and Tirole (2005): lumpiness in transmission investment makes total value paid to investors less than social value created.

A two-part tariff regulatory system for lumpy transmission projects is thus an unsolved issue in the regulatory-economics literature.

$$L = \frac{\left(AC - MC\right)^2 Q\eta}{2p}$$



The welfare loss associated with using a rate of return fee structure is small.

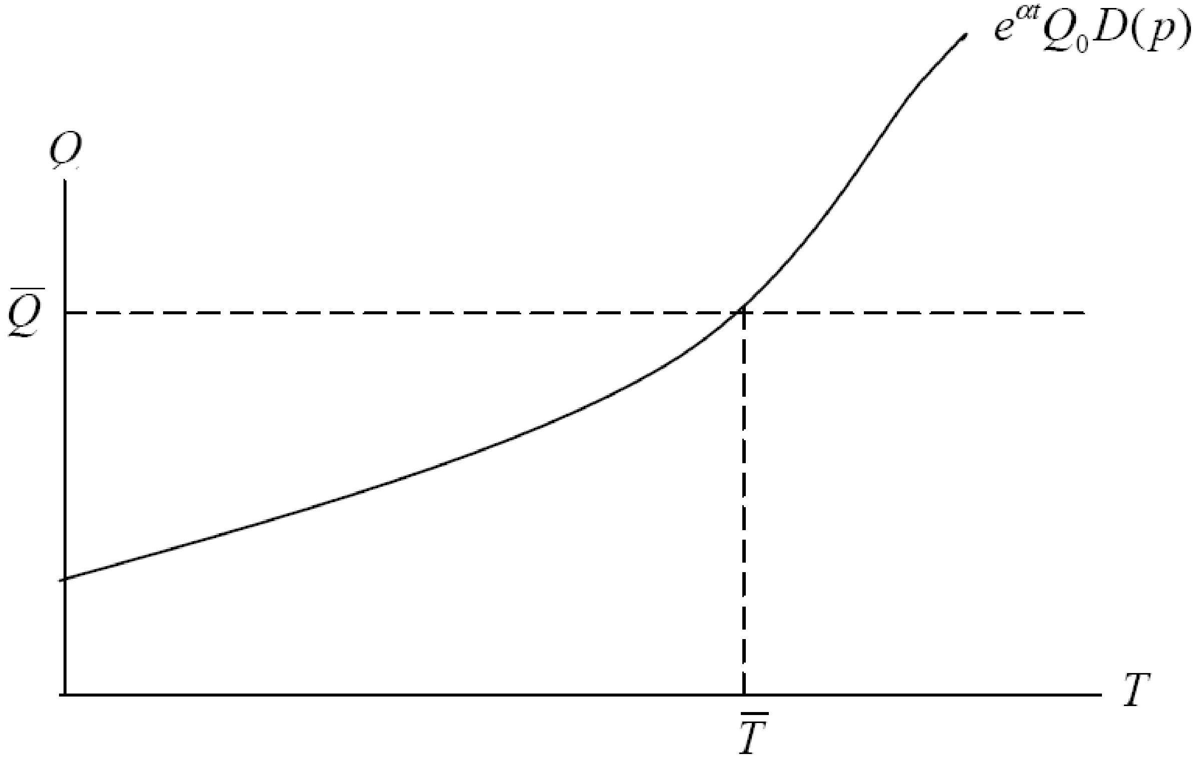
AC-MC	Change in Demand MCF	Welfare Loss for 4,000,000 MCF
0.10	6,667	333.33
0.11	7,333	403.33
0.12	8,000	480.00
0.13	8,667	563.33
0.14	9,333	653.33
0.15	10,000	750.00
0.16	10,667	853.33
0.17	11,333	963.33
0.18	12,000	1080.00
0.19	12,667	1203.33
0.20	13,333	1333.33

Table 1

Timing of Investment in Pipeline Capacity

Demand for gas

$$Q(t) = e^{\alpha t} Q_0 D(p) \qquad \bar{Q} = e^{\bar{\alpha} T^0} Q_0 D(\bar{p})$$



Two possible stationary investment strategies such that pipeline capacity is doubled when the pipeline reaches a given fixed target.

Investment occurs when capacity doubles, the time between investment is the doubling time, T^0.

Investment strategies have the same timing after first investment. They differ only in the timing of the first investment, and the amount of throughput.

The first investment strategy we will consider is the strategy that would result from investing when the pipe is expected to reach full capacity. This policy is implemented by a sequence of investments, $\{2K_0, \ldots, 2^n K_0\}$, at $T_i^0 = T_{i-1}^0 + T^0$, $i = 1 \ldots N$. The present value of the cost of this investment sequence is

(5)
$$V^0 = e^{-reT^0} \sum_{i=0}^{N} e^{-irT^0} 2^{i+1} K_0 + K_0 = e^{-reT^0} \overline{V} + K_0$$

Let us consider the revenue streams necessary to pay for the two investment strategies. First, consider the case where there will be a doubling of capacity when the system reaches full capacity. The first investment occurs at time T^0 and let $Q_0(t)$ be the flow of gas through the pipeline given this investment sequence. Let c^0 be the charge for transporting gas that will pay for this investment. Then

(7)
$$PV^0 = \int_0^{NT^0} c^0 e^{-rt} Q_0(t)\, dt = c^0 \int_0^{NT^0} e^{-rt} Q_0(t) dt .$$

The second investment strategy we will consider is the strategy where the first investment occurs at at $T^1 = \beta T^0$, and subsequent investments occur every time demand doubles, $T_i^1 = T_{i-1}^1 + T^0, i = 2,\ldots,N$. The present value of the cost of this investment sequence is

(6) $$V^1 = e^{-reT^1} \sum_{i=0}^{N} e^{-irT^0} 2^{i+1} K_0 + K_0 = e^{-reT^1} \overline{V} + K_0$$

Second consider the case where there will be a doubling of capacity when first investment occurs at time $T^1 = \beta T^0$. Let $Q_1(t)$ be the flow of gas through the pipeline given this investment sequence. Let c^1 be the charge for transporting gas that will pay for this investment. Then

$$PV^1 = \int_0^{NT^1} c^1 e^{-rt} Q_1(t) dt = c^1 \int_0^{NT^1} e^{-rt} Q_1(t) dt \,.$$

If the revenue from the transport of natural gas is paying for the cost of the pipeline, then:

$$c^0 \int_0^{NT^0} e^{-rt} Q_0(t)\,dt = e^{-reT^0}\overline{V} + K_0$$

$$c^1 \int_0^{NT^1} e^{-rt} Q_1(t)\,dt = e^{-reT^1}\overline{V} + K_0$$

The present value of the cost per thousand cubic feet of gas a day for one investment cycle for maintaining a $T^0 - \beta T^0$ buffer of excess capacity has an upper bound given by

$$\Delta C = \left(\frac{e^{-rT^1}}{e^{-rT^0}} - 1 \right) c^0 \int_0^{T^0} e^{-rt}\,dt = \left(\frac{e^{-rT^1}}{e^{-rT^0}} - 1 \right) \frac{c^0}{r} \left(1 - e^{-rT^0}\right)$$

Cost per MCF of Pipeline Buffer Capacity			
	Tariff per MCF		
	0.10	0.25	0.50
Weeks of Buffer Capacity	Present Value of Cost dollars	Present Value of Cost dollars	Present Value of Cost dollars
1	0.44	1.11	2.22
2	0.89	2.22	4.45
3	1.33	3.34	6.67
4	1.78	4.45	8.91
5	2.23	5.57	11.15
6	2.68	6.69	13.39
7	3.13	7.82	15.63
8	3.58	8.94	17.89
9	4.03	10.07	20.14
10	4.48	11.20	22.40
11	4.93	12.33	24.66
12	5.39	13.47	26.93
13	5.84	14.60	29.20
14	6.30	15.74	31.48
15	6.75	16.88	33.76
16	7.21	18.02	36.05
17	7.67	19.17	38.34
18	8.13	20.32	40.63
19	8.59	21.47	42.93
20	9.05	22.62	45.23
21	9.51	23.77	47.54
22	9.97	24.93	49.85
23	10.43	26.09	52.17
24	10.90	27.25	54.49
25	11.36	28.41	56.82
26	11.83	29.57	59.15

Table 1

Cost of Congestion

Rents at time *t* due to congestion:

$$\Delta p(t) = \bar{p}(t) - p(t)$$

Present value of the expected rents:

$$E[Z] = \int_0^{T^0} e^{-rt} \Delta p(t) dt$$

Consider the case where congestion starts at some time $\hat{T} < T^0$, and demand grows at the rate $\bar{\alpha}$ in the interval $\left[\hat{T}, T^0\right]$. Let $\Delta\hat{p}(t)$ be the associated rents. The present value of congestion is given by:

$$V^0 = e^{-reT^0} \sum_{i=0}^{N} e^{-irT^0} \int_{\hat{T}}^{T^0} e^{-rt} \Delta \hat{p} \, dt$$

Cost per MCF of Congestion			
	Price per MCF		
	4.00	6.00	8.00
Weeks of congestion	Present Value of Rents dollars	Present Value of Rents dollars	Present Value of Rents dollars
1	0.11	0.17	0.23
2	0.43	0.64	0.86
3	0.95	1.42	1.90
4	1.68	2.51	3.35
5	2.61	3.92	5.22
6	3.76	5.64	7.52
7	5.12	7.68	10.25
8	6.70	10.06	13.41
9	8.50	12.76	17.01
10	10.53	15.79	21.06
11	12.78	19.17	25.56
12	15.26	22.89	30.52
13	17.97	26.96	35.94
14	20.92	31.38	41.84
15	24.10	36.16	48.21
16	27.53	41.30	55.06
17	31.20	46.80	62.40
18	35.12	52.68	70.24
19	39.29	58.93	78.58
20	43.71	65.57	87.42
21	48.39	72.59	96.78
22	53.33	80.00	106.66
23	58.54	87.80	117.07
24	64.01	96.01	128.01
25	69.75	104.62	139.50
26	75.77	113.65	151.53

Table 2

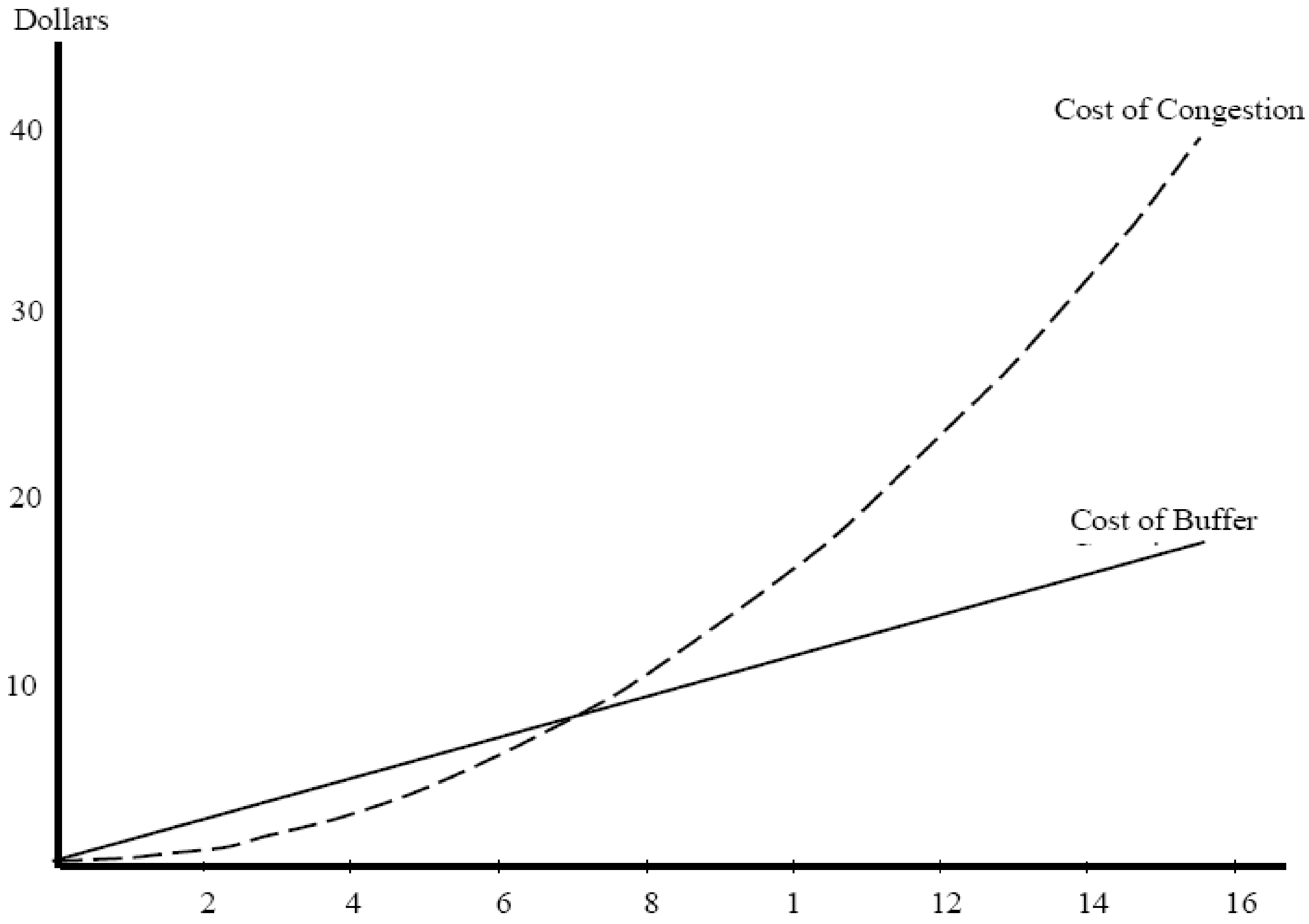

Dollars
40
30
20
10
Cost of Congestion
Cost of Buffer
2
4
6
8
1
12
14
16

Figure 4

Conclusions

The cost of buffer capacity is low, and the cost of transfers that result from congestion to the consumers of gas is very high.

The transfers are of such magnitude that consumers are willing to pay for substantial buffer capacity.

Inelastic demand also permits the implementation of a very simple rate structure.

If the objective of regulators is to protect the consumers, our calculations suggest that consumers would prefer to pay for excess capacity in the pipeline system rather than to risk the consequences of congestion.