The Structure of the Data Telecommunications Industry: An Application of Nagurney's Spatial Oligopoly Variational Inequalities Model.

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Abstract

Modelling the data telecommunications industry as a Spatial Oligopoly Variational Inequalities Model reveals an industry whose structure, in the absence of any meaningful capacity constraints, will result in zero or near zero pricing on each link. This structure is economically unsustainable and has led to accountancy fraud and to so called "Drive Through Chapter 11" arrangements. These bankruptcies do not remove capacity from the industry and leave the competitor firms at a disadvantage. The industry seems to be an example of the failure of markets. This in turn raises the question have policy makers applied the right regulatory or deregulatory model?

1. Introduction.

When deregulating service industries, policy makers should ask themselves a key question. What is the structure of the industry?

Airlines, Power Supply and Distribution and Telecommunications are industries that were privatized or deregulated in the 1980's and 1990's. Each of these industries is struggling. On August 14th, 2003 the lights went out in the Northeastern United States and central Canada. California suffered rolling blackouts during the first years of the new millennium. At least one major U.S. airline seems to be in Chapter 11 Bankruptcy at any given point in time.

Accountancy fraud at Worldcom[1] and scandals at Adelphia Communications Inc. followed by their subsequent Chapter 11 filings[2] were just the most visible signs of an industry in financial meltdown. By July 2002, telecoms industry analysts were describing "Drive-Through Chapter 11"[3] deals in telecoms and billions of dollars of debt had been shed in the industry – see Appendix.

A common feature of these three industries is that they are physical networks. They are also networks of economic agents and as such they are suitable for analysis using the tools of Network Economics. This paper uses Variational Inequalities, in particular the Spatial Oligopoly Model from Nagurney (1993)[4], to study the structure of the Data Telecommunications industry. Readers are referred to Nagurney (1993)[5] for a comprehensive treatment of the application of Variational Inequalities models to Network Economics.

The remainder of this paper is organized as follows: Section 2 describes the history of Telecommunications regulation and deregulation; and the technology that made deregulation possible. It looks at the cost structures and it discusses the possible industry structures that might be used to characterize the Data Telecommunications industry. Section 3 introduces Nagurney's Spatial Oligopoly model; first presenting Nagurney's definition of a Cournot Nash equilibrium; then presenting Nagurney's theorem that states that the equilibrium can be represented as a variational inequality and finally giving Nagurney's formulation of the variational inequality for a Spatial Oligopoly models. Section 4 models data telecommunications as the sum of the individual links. Each link is then modeled as the sum of the suppliers of capacity and the demands for capacity on the link. Each link is suitable for treatment as a Spatial Oligopoly to which Nagurney's Spatial Oligopoly Model can be applied. Section 5 shows that an equilibrium cannot be shown to exist for a link because of the cost structure of the industry. Section 6 discusses the impact that excess of supply has on the industry and the ways in which Chapter 11 and other bankruptcy procedures fail to remove that capacity from the industry. Section 7 provides a summary of the main points and draws out the conclusions. The Appendix lists telecoms firms entering into Chapter 11 and the amounts of debt that were to be shed or restructured.

2. Industry Evolution and Issues.

The distinction between "Voice" and "Data" Telecommunications is really a split between the analog world of people's voices, facsimile and modems on one hand and the digital world of the Internet Protocol (IP) data packet.

Historically "Voice" was operated by a series of national monopolies; usually government owned; and regulated by the International Telecommunications Union (ITU) which is still the forum for setting technical standards and for agreeing prices – the "accounting rate system". Each national monopoly controlled both the local loop and the inter-exchange links.

The physical infrastructure of the local loop comprises switches ("exchanges") in each locality, linking to each building in a star of twisted pairs of copper cables. In the 1980's Cable Television potentially provided another link to each household, but the cable companies did not exploit the opportunity. In the 1990's wireless telephony emerged as a means of providing the service of the local loop, but people retain their fixed link telephones.

Glass fiber technology, first introduced in the late 70's, has revolutionized the economics of inter-exchange links enabling capacity to quickly outstrip demand. Glass fiber technology ha continued to improve allowing greater bandwidth on existing fiber by, for instance, using different spectra of light in the same cable. Computerized switches began to replace electromechanical switches in the 1980's. Computerized switches are much more flexible and in particular allow customers to select the carrier for the inter-exchange parts of the call by dialing a 5-digit code or by 'pre-subscription'[6]; a previously expressed preference.

This allowed the national monopolies to be broken up and for the introduction of some competition into the markets for long distance and international voice. In 1984; in the USA; this culminated in the break up of AT&T into an Inter-Exchange Carrier (IXC) and seven regional Local Exchange Carriers (LECs); known as "the Baby Bells"; who provide local telephone services and the link between the customer and the IXC. Competitive IXC's such as MCI and Sprint were encouraged to compete with the rump AT&T. The United Kingdom, Sweden, Australia, Finland, New Zealand and Chile also privatized their industries and fostered competitive IXCs.

The 1996 Telecommunications Act further deregulated the industry particularly in data telecommunications.[7]

Historically "Data" was a project of the U.S. Department of Defense, which developed the packet switching protocols in a proprietary backbone. The Internet / World Wide Web emerged from 1994 onwards as a major user of bandwidth and the backbone was transferred from government into the hands of private companies. The Internet is a worldwide phenomenon, which has increased dramatically the volume of data travelling internationally. International Data Telecommunications is not regulated by the traditional accounting rate system[8].

Large Corporate Data is more or less independent of the local loop which it can bypass by running dedicated lines or using microwave links (the cost being low relative to usage). Most domestic users and some small business users dial into an ISP using their local telephone service and the ISP is therefore effectively independent of the local loop. Digital Subscriber Lines (DSL) which provides greater bandwidth than dial-in connections and are used by smaller businesses as well as domestic consumers are dependent on the local loop or on cable television links. DSL remains a small if growing section of the total market for data telecommunications.

IP packets do not travel through a connection setup for the duration of the call as is the case in voice. Two sequential packets can travel completely different paths between the same end points. An IP packet delivered is an IP packet delivered and as such data telecommunications is a homogeneous product. Each link is a commodity; which can be purchased from a number of suppliers. Capacity for Data traffic is in this sense a homogeneous product.

A company entering the data telecommunications industry either lays fiber or purchases capacity on existing fiber or a combination of the two. Since laying the fiber is costly and the fiber itself is relatively cheap; companies lay more fiber than they need, so called "Dark Fiber". The company then lights up the fiber that it plans to use or lease to third parties. The variable costs of running a link are negligible. Electricity powers the network but is not really a variable cost once the decision as to how much fiber to light up has been taken it does not really depend on the volume of traffic. The network requires maintenance, but this is not really a variable cost either.

A third party which leases a given capacity at a given price per period for a given period of time faces a zero marginal cost between zero usage and full usage during the currency of the lease. Meanwhile, the average cost is the fixed cost per period divided by the average usage per period and decreases with increasing volume up to full usage.

Data Telecommunications has been deregulated as if it were an industry in which "Perfect Competition" exists although there are significant barriers to entry. The high fixed cost of setting up a network and recruiting users is a major barrier to entry; which makes that inappropriate. As regulated monopolies, Telecommunications companies were unresponsive to the consumer. Regulation or deregulation that makes the service more responsive to consumers is a highly desirable public policy.

An industry is characterized as a Cournot Oligopoly if there are few firms serving many customers; the firms produce either differentiated or homogeneous products; each firm believes rivals will hold their output constant if it changes its output; and barriers to entry exist. As we have seen, barriers to entry do exist in Data Telecommunications. Although capacity is homogeneous there is spatial price differentiation in the provision of capacity. There are fewer firms supplying capacity than purchasing capacity and in the short run companies cannot readily reduce their capacity because the physical fiber exists or because the leases are for fixed terms. Accordingly it is reasonable to examine the data telecommunications industry as a Cournot Oligopoly.

Nash (cited in Nagurney (1993) 1950 and 1951) generalized Cournot's concept in what has been called a "non-cooperative game" which results in what Nagurney (1993) calls a "Cournot-Nash Equilibrium" and models as a Variational Inequality in the "Spatial Oligopoly Model".

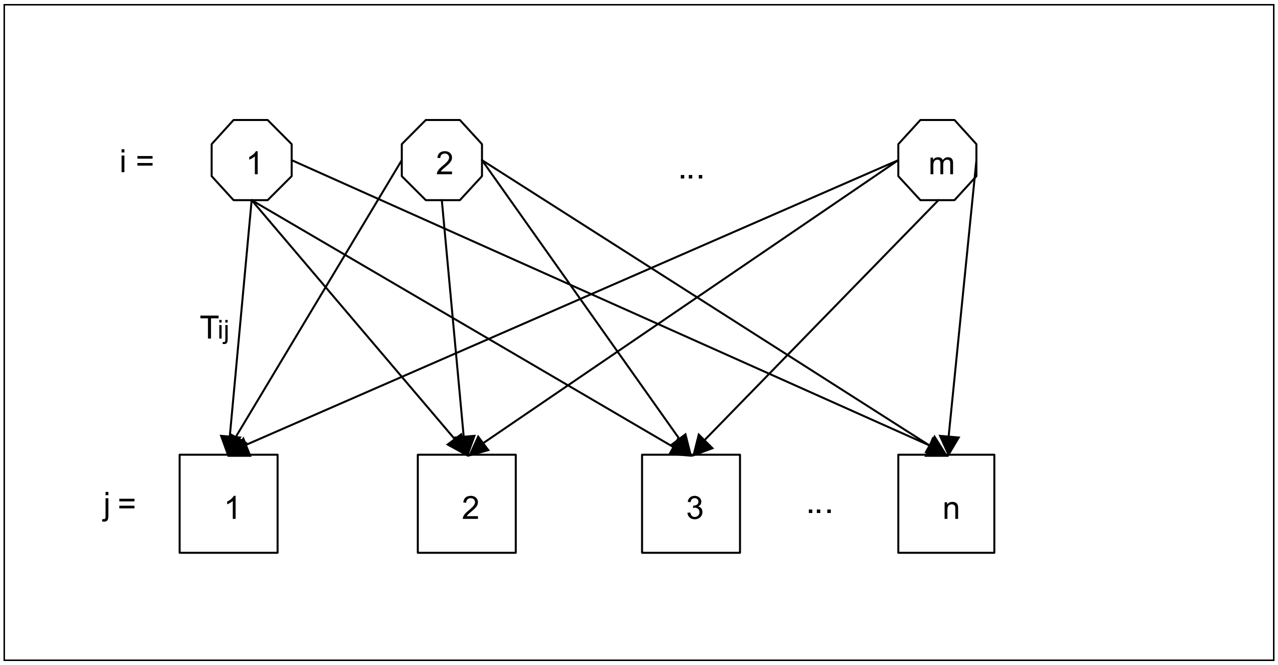
3. The Spatial Oligopoly Model.

The model, definition and theorem presented here are due to Nagurney (1993).

The Spatial Equilibrium Model assumes that suppliers and buyers of a product are physically separated. Buyers meet their demand from the suppliers that offer them the lowest price, including shipment costs and suppliers meet the demand of the buyers who give them the highest price excluding shipment costs.

Suppliers i = 1 to m are assumed each to have a total supply capacity of C_i. There are j = 1 to n buyers. Let T_{ij} be the nonnegative amounts purchased by buyer j from supplier i. Let q_i be the quantity sold by supplier i and d_j be the total quantity purchased by buyer j.

This situation can then be modeled as follows.



The following conservation of flow equations must hold:

$$q_i = \sum_{j=1}^{n} T_{ij}, \text{ for all i}$$

$$d_j = \sum_{i=1}^{m} T_{ij}, \text{ for all j}$$

Where $T_{ij} \geq 0$ for all i, j.

Let t_{ij} be the unit shipment cost from supplier i to buyer j which depends on the entire shipment pattern $t_{ij} = t_{ij}(T)$

Let the column vector $q \in \Re_{+}^{m}$ be the supplies; and the column vector $d \in \Re_{+}^{n}$ be the demands and group the actual quantities supplied in a column vector $T \in \Re_{+}^{mn}$.

Let f_i be the production cost of capacity where the production cost of firm i may depend on the entire production pattern i.e. $f_i = f_i(q)$.

Let p_j be the demand price of a particular ISP or corporate j and let this demand price be dependent, in general, upon the entire requirement for capacity on all links, i.e. $p_j = p_j(d)$.

The profit u_i of each supplier i is then: $u_i = \sum_{j=1}^{n} p_j T_{ij} - f_i - \sum_{j=1}^{n} t_{ij} T_{ij}$

Since p_i is a function of d and f_i is a function of q and using the conservation of flow equations the u_i can be represented as a function of T in the form $u_i = u_i(T)$.

Nagurney (1993) provides the following definition:

"A commodity shipment distribution $T^* \in \Re_+^{mn}$ is said to constitute a Cournot-Nash equilibrium if for each firm i : i=1,…,m,

$$u_i\left(T_i^*, \hat{T}_i^*\right) \geq u_i\left(T_i, \hat{T}_i^*\right), \forall T_i \in \Re_+^n$$

where

$$T_i \equiv \{T_{i1}, \ldots, T_{in}\} \text{ and } \hat{T}_i^* \equiv \left\{T_1^*, \ldots, T_{i-1}^*, T_{i+1}^*, \ldots, T_m^*\right\}$$ "

i.e. for each firm there is no better strategy.

Nagurney (1993) also provides the following theorem:

"Assume that for each firm i the profit function $u_i(T)$ is concave with respect to the variables $\{T_{i1}, \ldots, T_{in}\}$, and continuously differentiable. Then $T^* \in \Re_+^{mn}$ is a Cournot-Nash equilibrium if and only if it satisfies the variational inequality

$$-\sum_{i=1}^{m}\sum_{j=1}^{n} \frac{\partial u_i(T^*)}{\partial T_{ij}} \bullet \left(T_{ij} - T_{ij}^*\right) \geq 0, \text{ for all T} \in R_+^{\text{mn}}$$

Using the conservation of flow equations this becomes:

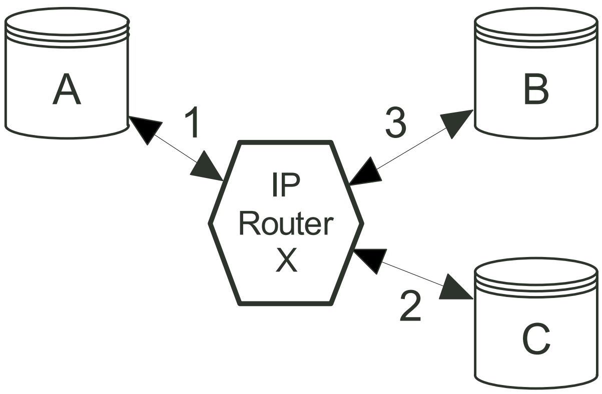
$$\sum_{i=1}^{m} \frac{\partial f_i(q^*)}{\partial q_i} \bullet \left(q_i - q_i^*\right) + \sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}(T^*) \bullet \left(T_{ij} - T_{ij}^*\right) - \sum_{j=1}^{n} p_j(d^*) \bullet \left(d_j - d_j^*\right)$$

$$-\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{n}\left[\frac{\partial p_l(d^*)}{\partial d_j} - \frac{\partial t_{il}(T^*)}{\partial T_{ij}}\right] T_{il}^*\left(T_{ij} - T_{ij}^*\right) \geq 0, \text{ for all (q,T, d) } \in \text{K},$$ "

$$\textit{where } K \equiv \left\{(q, T, d) \mid T \geq 0 \mid \text{ the conservation of flow equations hold}\right\}$$

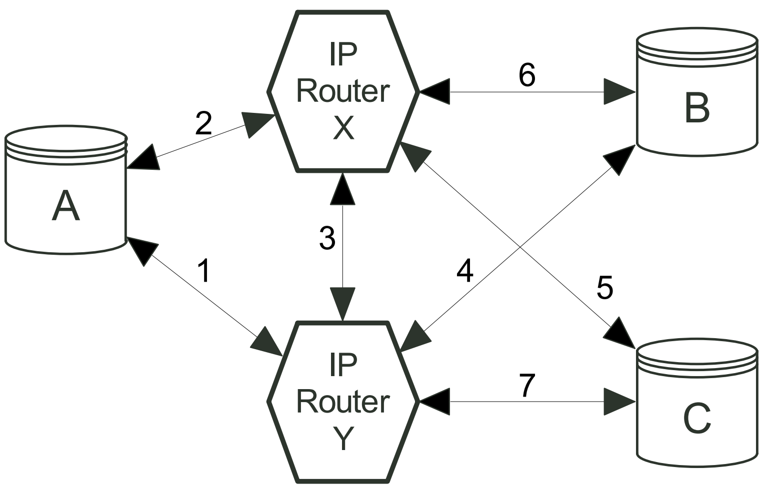
4. A Data Telecommunications Model.

Since the majority of an ISP's customers dial into the ISP and so meet the connection cost directly; this link is not included in the model. Assume there are three ISPs or Corporates (A, B and C) and one provider of data telecommunications capacity (X). A, B and C will be able to purchase capacity from X to link to each other.



The model shows X as a monopoly, but it is useful to consider the cost from A to B or from A to C before we move on to a more complex model. One way to think of the cost from A to B is that it is the negotiated cost from A to X plus the given cost of link 3. The cost of link 1 is the cost of the product and the cost of link 3 is the cost of the shipment.

Assume now that there is a further physical supplier Y and that every one is connected through suppliers to everyone else; the model becomes.

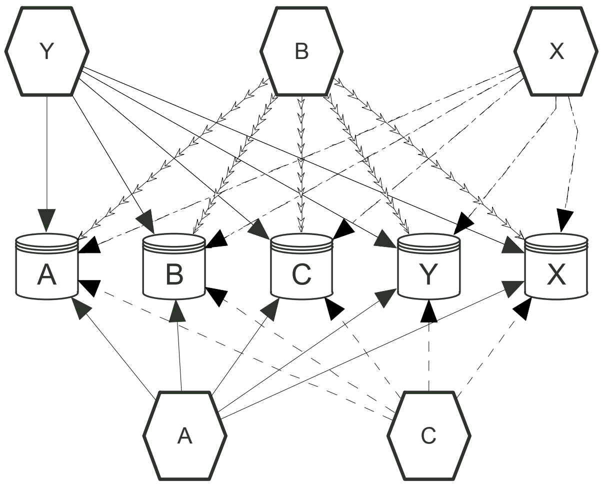


A now has a number of choices as to how to purchase capacity to link to B. A-X-B and A-Y-B to name just the two most obvious. If A treats the costs of the remaining links in a path from A to B as being the shipment costs inherent in purchasing capacity on a particular link, then the purchase of capacity on each link, in turn, can be treated like the purchase of a commodity from suppliers spatially separated.

Since capacity on the physical links is leased to companies that are building their own networks in order to sell or lease capacity; there can be many more logical links than there are physical links. Suppose link 1 (A-Y) is owned by Y who leases capacity to A, B, C and Y. If A needs more capacity than it leases from Y it could lease more from any one of Y, B, C or X.

A can get the same commodity from 4 vendors on 4 logical links derived from a single physical link number 1. Each logical link is separable and capacity will be purchased separately on each logical link, to achieve a network.

Conceivably Y lease back capacity it sold on physical link 1 and also A, B, C and X, as buyers (cylinders) could lease capacity from any of Y, A, B, C or X as suppliers (hexagons). So physical link 1 would look as follows.



So each link and its set of logical links takes on the structure of a spatial oligopoly.

The data telecommunications industry is the sum of the supply and demand across each logical and physical link. For a company building or leasing and selling capacity on such links the profit will be the sum of the profit on each of the links on which the company has capacity to sell. Each player will buy and sell capacity in a strategy with which they make the most profit or the smallest loss. Assuming concave and differentiable profit functions each player, executing its strategy, will leave the industry in a Cournot-Nash equilibrium and this equilibrium can be expressed, as we have seen, as a variational inequality. Further examination of this inequality in the context of the Data Telecommunications industry follows in section 5.

5. Applying the Spatial Equilibrium Variational Inequality Model to Data Telecommunications

The final variational equality from section 3 is reproduced below to assist in analysis.

$$\sum_{i=1}^{m}\frac{\partial f_i\left(q^*\right)}{\partial q_i}\bullet\left(q_i-q_i^*\right)+\sum_{i=1}^{m}\sum_{j=1}^{n}t_{ij}\left(T^*\right)\bullet\left(T_{ij}-T_{ij}^*\right)-\sum_{j=1}^{n}p_j\left(d^*\right)\bullet\left(d_j-d_j^*\right)$$

$$-\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{n}\left[\frac{\partial p_l\left(d^*\right)}{\partial d_j}-\frac{\partial t_{il}\left(T^*\right)}{\partial T_{ij}}\right]T_{il}^*\left(T_{ij}-T_{ij}^*\right)\geq 0,\ \text{for all (q,T, d)} \in \text{K},$$

$$where\ K\equiv\left\{\left(q,T,d\right)|\,T\geq 0\,|\ \text{the conservation of flow equations hold}\right\}$$

In the case of data telecommunications, $\frac{\partial f_i(q^*)}{\partial q_i} = 0$ or put another way the change in the variable cost of logical link i is zero i.e. the marginal cost is zero. Given that this is the case the variational inequality becomes.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}(T^*)\bullet(T_{ij}-T^*_{ij}) - \sum_{j=1}^{n} p_j(d^*)\bullet(d_j - d^*_j)$$
$$-\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{n}\left[\frac{\partial p_l(d^*)}{\partial d_j} - \frac{\partial t_{il}(T^*)}{\partial T_{ij}}\right]T^*_{il}(T_{ij}-T^*_{ij}) \geq 0, \text{ for all T, d } \in \text{K},$$

In the absence of marginal cost of supply a supplier believing that other firms will hold their output constant if it changes its output (see section 2 for the assumptions for a Cournot Oligopoly) will supply up to its total capacity, reducing its price at the rate of its average cost's decline or more slowly. If total capacity exceeds total demand then the equilibrium price will be zero and the marginal demand price will also be zero and the variational inequality becomes.

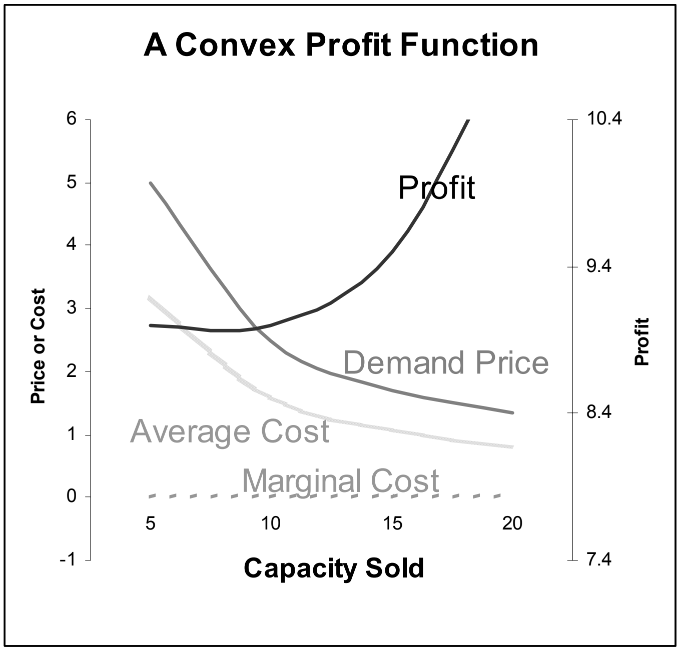
$$\sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}(T^*)\bullet(T_{ij}-T^*_{ij}) + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{l=1}^{n}\left[\frac{\partial t_{il}(T^*)}{\partial T_{ij}}\right]T^*_{il}(T_{ij}-T^*_{ij}) \geq 0, \text{ for all T } \in \text{K},$$

Now, given that the equilibrium price of a link is zero and that the t_{ij} terms are in fact the costs of moving packets to the logical link, along other links for which the equilibrium prices will also be zero. Then the $t_{ij} = 0$ for all i and j and the marginal price of "shipment" will also be zero. So by a process of reduction the variational inequality becomes

$$0 \geq 0, \text{ since}$$
$$\sum_{i=1}^{m}\sum_{j=1}^{n} t_{ij}(T^*)\bullet(T_{ij}-T^*_{ij}) = 0$$
$$-\sum_{j=1}^{n} p_j(d^*)\bullet(d_j - d^*_j) = 0$$
$$\frac{\partial p_l(d^*)}{\partial d_j} = 0$$
$$\frac{\partial t_{il}(T^*)}{\partial T_{ij}} = 0$$

This is a useful result because it tells us that the data telecommunications industry is not suitable for treatment as an oligopoly in the form that seems, from the conditions attached to the various different forms of oligopoly, to be the most appropriate form.

This result also confirms the conditions attached to the profit function in Nagurney's theorem concerning the Spatial Oligopoly Model being a Cournot-Nash equilibrium, namely that the profit function should be concave in quantities supplied and differentiable. The graph of a convex profit function shows that where a zero marginal cost applies the profit function can be convex.



At some point all conceivable demand will be satisfied and the demand price will be zero and the profit will become a loss equal to the fixed costs, so the profit function is not differentiable, since it is not continuous.

6. The Issue of Excess Capacity

Capacity in Data Telecommunications exceeds absolute demand. Even if the price were zero there would not be demand for infinite supply. The lure of high profits and a "build it and they will come" mentality, combined with technology improvements in fiber optic telecommunications technologies and with the prevalence of "dark fiber" and also combined with the accounting problems of allocating the costs to the various links in a network have ensured an excess in capacity in the industry.

The financial meltdown described in section 1 might have been expected to remove capacity from the industry as firms went out of business to the point where supply would equal demand at a price which would cover the fixed costs. However this has not been the case in the Data Telecommunications Industry. Where a bankrupt firm was leasing capacity the capacity may have reverted to the physical supplier of capacity. The fiber did not disappear.

Where the bankrupt firm owned fiber it has either been sold to other telecommunications companies at a knock down price or equivalently the firm has gone through a "Drive Though Chapter 11" process to emerge as a company owned by the creditors with much reduced or zero levels of debt. The firms emerging from Chapter 11 do so as fiercer competitors in a market place, which is already fiercely competitive.

The structure of the Data Telecommunications industry means that there are barriers to exit or more exactly barriers to the removal of capacity from the industry.

7. Summary and Conclusions.

This paper has described the financial meltdown of the telecommunications industry, traced the industries evolution and some of the technology changes, which resulted in the emergence of a Data Telecommunications Industry as well as of significant overcapacity.

A discussion of industry classifications concluded that the Data Telecommunications Industry might be a Cournot Oligopoly. Nagurney's Spatial Oliopoly Variational Inequality model, which is a representation of the Generalized Cournot-Nash equilibrium, was presented.

From a model of Data Telecommunications it was shown that each link could be represented as a set of logical links and that this set corresponds to a spatially separated commodity supply market and therefore that each link could be analyzed using Nagurney's Spatial Oligopoly Variational Inequality model.

It has been shown that in the presence of zero marginal costs, that the total supplied by each supplier falls out of the model. The amounts supplied on each logical link depend only on the total demand and the demand price. Given that total capacity exceeds total demand, each supplier will bid down the price in an attempt to acquire market share. At the limit the price demanded will be zero. This leaves an industry with fixed costs and debt with zero of close to zero revenues or an industry in financial meltdown. Profitability is only restored if all the suppliers co-operate to remove or withhold capacity.

In many industries, bankruptcy removes capacity. In Data Telecommunications this is not the case. The industry seems to be an example of the failure of markets. This raises questions about the regulatory or deregulatory model that should be applied.

Appendix Sample Telecommunications Company Failures

Date	Company	Debt Millions Dollars
June 2003	Touch America Holdings Inc. [9]	554
March 2003	Ntelos Inc. [10]	660
November 2002	Genuity Inc. [11]	3,000
August 2002	Metromedia Fiber Network. [12]	975
August 2002	Williams Communications Group. [13]	6,000
July 2002	Worldcom Inc. [14]	40,000
July 2002	Birch Telecom Inc. [15]	310
July 2002	ITC Delta Com [16]	515
July 2002	XO Communications [17]	1,000
July 2002	Arch Wireless Inc. [18]	2,000
June 2002	Neon Communications Inc. [19]	250
June 2002	McLeodUSA Inc. [20]	3,000
March 2002	Adelphia Business Solutions[21] [22]	882
February 2002	Mpower Holding Corp. [23]	580
January 2002	Global Crossing.[24]	12,000
November 2001	PSINet.. [25]	2,900
November 2001	Verio Inc. (NT&T write off 4.5billion) [26]	4,500
October 2001	Excite@Home. [27] [28]	1,100
September 2001	Exodus Communications Inc. [29]	3,000
August 2001	Covad Communications Group[30]	1,400
August 2001	Metricom.[31]	106
August 2001	Rhythms Netconnections Inc.[32]	Unknown
July 2001	Pathnet Telecommunications Inc. [33]	350
May 2001	Teligent Inc. [34]	1,650
April 2001	Winstar Communications Inc. [35]	4,000
April 2001	ICG Communications Inc. [36]	32
March 2001	Northpoint Communications[37]	500
December 2000	Quentra Networks Inc.[38]	Unknown
August 2000	GST Telecommunications Inc.[39]	1,200
March 1999	Heartland Wireless Communications Inc.[40]	325

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