PRIVATE NETWORKS PUBLIC OBJECTIVES
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Interoperability -- Technical

Standards, Regulations and Private Decisions: A Framework for Analysis

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1. INTRODUCTION

In this decade the information technology (IT) industry has witnessed two important trends that have affected the fundamental operation of the industry. On the one hand, the industry standards have increased in number and importance, and on the other, the telecommunications industry, an important sector of the IT industry, was deregulated. These phenomena have similar effects on private decision makers because of their fundamental effects on the marketplace for products and services. In this paper, I propose a single approach that can be used to explain these effects.

The concept of entropy provides a novel framework for analyzing these trends. Deregulation has the effect of increasing the product offerings of a previously regulated industry, resulting in increased consumer choices, whereas voluntary consensus standards have the effect of reducing the number of potential design outcomes.[1] When framed in this way, these two phenomena can be considered simultaneously under the unifying concept of entropy.

In practice, the number of common carrier offerings have flourished under deregulation. As the telecommunications and computer industry have changed, the number of voluntary consensus and *de facto* standards have also increased. In some cases, these standards were substantially competitive with each other,[2] or complimentary to each other.[3] The network managers for private firms have an extraordinary number of choices when constructing private networks under the present circumstances; so many, in fact, that they cannot reasonably optimize the structure of their network. In addition, these choices are changing continuously as carriers offer new services, as new standards emerge, and as firms enter and leave the marketplace. As a result, they frequently choose to set internal standards to complement the body of public standards and regulations that they face.

In the sense of statistical mechanics, entropy can be qualitatively defined to be a representation of the number of ways in which a system can be arranged.[4] Within this construct, deregulation can be seen as a mechanism or phenomenon that *increases* entropy, since consumers and producers have more choices. That is, there are more states in which the system can exist. Similarly, standards have the effect of *decreasing* the entropy of the market, since designers and consumers are faced with fewer products and services that can be designed.

It is particularly interesting that these two contradictory trends are occurring in the information technology industry at the same time. The telecommunications policies promulgated by the United States' Federal Communications Commission (FCC) since the late

1970s have generally been deregulatory. At the same time, this deregulatory trend and the erosion of market leadership in the information systems area have caused a virtual explosion in the development of voluntary consensus standards. In the context of entropy at a macro level, deregulation has occurred because the "entropy" of the market was too low, and standards because the "entropy" of the market was too high.[5] An entropy level that is too low suggests that a market is too "simple," meaning that insufficient choices exist for buyers. Likewise, an entropy level that is too high suggests that the market is too complex, that users cannot make appropriate choices because they are overwhelmed by the number and kinds of products available. Similarly, producers may be unable to extract sufficient revenues from products to recover costs and/or to finance the R&D on the next generation of products in under-standardized markets.

This view of markets might also suggest that a role of government is to act as an "entropy optimizing" agent. In this role, governments would intervene in markets where entropy is too low by stimulating R&D in the appropriate areas of technology or decreasing regulations; similarly, markets where entropy was too high could be subject to decreasing R&D expenditures, increased regulation, *etc*. Practically speaking, of course, the regulatory structure must have sufficient stability so that producers and consumers are able to make efficient economic decisions.

Since standards have been developed well in advance of products performing equivalent functions[6] in the last decade, this question of the optimal level of standardization becomes more critical. Firms invest substantial resources in the development of standards, so over standardization can lead to social welfare losses.

Anecdotal evidence suggests that users of information technology are overwhelmed with the choices available.[7] Due to competing services, traveling telecommunications users are also faced with a myriad of choices when calling from a hotel.[8] These examples suggest that the market entropy for users could be too high.

The objective of this paper is to develop a model for analyzing standards and regulation in a unified way. Several researchers have already developed economic models of standards, and much has been written about regulation, but none integrate both of these phenomena.

2. BACKGROUND

Considerable work has already been done on the economics of standardization and regulation, as well as notions of entropy. This section contains a brief review of the relevant literature.

2.1. Standards and Standardization

Standards have proliferated in recent years, particularly in the economic sector of Information Technology (IT).[9] Opinions among industry observers vary as to whether or not too few standards exist. Preliminary research[10] has shown a relationship between structure of a particular market and the incentives of producers in that market to promulgate standards. More specifically, the higher a market is concentrated, the more likely it is to have standards, because the producers who develop the standards are more likely to obtain sufficient benefits from them. Link's model is a profit model that examines whether the standards development process will be initiated for a particular market, based on aspects of the independent variables.[11] Lecraw also examined higher level market aspects of standards,[12] using discriminant analysis to predict whether a market will have a standard or not based on the independent variables.[13] Neither of these studies attempt to estimate, even at a macroeconomic level, how many standards are enough in a market given various independent variables.

Much of the previous research, taken collectively, predicts that markets not dominated by single firms will produce excessive standards early in a product life cycle, and that these standards are not necessarily socially optimal.[14] Anecdotal evidence generally supports this result. While researchers do not, as a rule, explicitly discuss the emergence mechanisms for standards (*i.e.*, the *de facto* and voluntary consensus processes), their work is at a sufficiently general level that this difference is not important.

2.2. Entropy

The concept of entropy emerged out of the study of thermodynamics and originally represented the amount of irreversible work that was inherent in a thermodynamic system. It has long been used to analyze thermodynamic systems in and out of equilibrium. Boltzman formulated entropy on a macroscopic, statistical measure that is dependent on the distribution of the microscopic states that a system can occupy, subject to energy constraints. Thus the entropy of a system is a macroscopic measure consisting of a sumulative sum of all microscopic states.

Entropy has wider implications, as was argued by Georgescu-Roegen.[15] Georgescu-Roegen reconceptualized economics and scientific thought based on statistical (*i.e.* entropic) principles as opposed to mechanistic ones.[16] In this view, economic actors feed on low entropy (*e.g.* raw materials) and produce high entropy (*e.g.* finished goods). Georgescu-Roegen attempts to explain many human endeavors and conflicts in these terms.

2.2.1. Entropy in Statistical Thermodynamics

Thermodynamics generally concerns thermal energy flows in physical systems. The Zeroth Law is the thermal equation of state, indicating that the temperatures of all bodies in equilibrium will be equal. The First Law is a caloric equation of state, which is used to calculate energy (*i.e.*, the quantity of heat) that flows among bodies in a closed system to achieve equilibrium. The Second Law of Thermodynamics is used to examine the reversibility of thermodynamic processes. It is in connection with the Second Law that the concept of entropy is introduced.

Attempts to define entropy on a less mathematical level have led to the notion of "disorder." To understand this, imagine a steam engine as a thermodynamic system, using coal to heat water to the boiling point. The steam generated by the boiling water is used to drive pistons that convert thermal energy to mechanical energy. Throughout this process energy is lost because of imperfect insulation of the steam pipes, friction in the steam engine, and other inefficiencies inherent in that particular method of converting thermal energy to mechanical energy. It is clearly not practical or even possible to fully reverse this thermodynamic process, which would require the regeneration of the coal that was used to heat the water, without using more energy. Thus, in thermodynamic terms, entropy was increased. One can observe that the system moved from a more orderly state of coal and water as distinct entities to a more disorderly state of ash and gasses, the water was converted to steam, some of which mixed with the atmosphere, and some of which condensed. It is this irreversible march to disorder that captured the interests of Georgescu-Roegen and Campbell.

While this view is interesting, a more detailed examination of entropy that is based on Boltzman's statistical characterization of the microscopic state that a system can occupy as needed. It was this characterization that made possible the connection between modern particle physics and classical Newtonian physics.[17]

Boltzman represented the entropy of a system as $S = k \ln W$, where S is the entropy, k is Boltzman's constant,[18] and W is the number of possible microstates that a system can assume given a set of energy constants.[19] In statistical thermodynamics, a *macrostate* consists of a specific distribution of particles among possible energy levels for a given system energy level. The manner in which specific particles are distributed in a macrostate is called a *microstate* of the macrostate. Several microstates can exist for each macrostate, and a system can have several possible macrostates.

For example, if particles A, B, C, and D can occupy states P, Q, R, S, and T, the macrostate "two particles in P and two particles in Q" refers to six different possible microstates for that macrostate.[20] Another possible macrostate that satisfies the system energy constraint could be "one particle in P and three particles in R." This macrostate has four possible microstates.[21] Given these two macrostates, it is now possible to compute the probability of observing each of them. Between the two macrostates, 10 microstates are possible, 6 in the first macrostate, 4 in the second macrostate. Thus the probability of observing the system in macrostate 1 is 60%, and the probability of observing macrostate 2 is 40%. The entropy of the system is then found using Boltzman's equation, $S = k \ln W$. For the example described above, $W = 10$, and $k = 1.38*10^{-23}$, so $S = 2.3k = 3.17*10^{-23}$, a very small number indeed. It is easy to see, however, that entropy increases as the number of available microstates increases. Sonntag and Van Wylen[22] and Finkelstein[23] show how this measure can be related to the entropy measure of classical thermodynamics.

2.2.2. Entropy and Information

The relationship between entropy and information can be attributed originally to James Clerk Maxwell in connection with the discussion of Maxwell's Demon. Maxwell's Demon was a thought-experiment designed to test the notions of entropy in thermodynamics. The demon attempted to reverse entropy by allowing fast moving molecules of warm gas to pass through an imaginary door to separate them from slow moving molecules of cold gas in a closed system without consuming energy. If successful, the demon would lower the entropy of the system. In order to accomplish this formidable task, the demon would have to be able to distinguish fast molecules from slow ones, *i.e.*, he would have to acquire *information* about each of the molecules before deciding whether to let them pass through the imaginary door. This information requirement lies at the heart of the argument about Maxwell's Demon.

The notion of entropy with respect to information in the context of communications systems was fomalized and adapted by Shannon, who took advantage of the prior work of Hartley and Wiener. His formalization dealt with uncertainty (entropy) in the context of the communication of information across a channel.[24] Subsequent researchers have developed the notion of the information of an event, related to the likelihood of that event, such that the information is greater in events that are less likely. This representation is intuitively satisfying because we learn more from uncommon statements than from statements that we expect.

2.2.3. Non-Technical Applications of Entropy

The entropy measure has been used outside the fields of information science and thermodynamics since the 1950s. Premier examples of its use in psychology can be seen in the work of Garner.[25] Brooks and Wiley[26] have demonstrated the application of entropy to biological evolution. This application of entropy is of most interest here.

The entropy concept was first applied in the economic context by Theil.[27] Theil's was the first analytical application of information theory to economics. He focussed on macroeconomic issues such as optimal firm location, input/output analysis, and comparing economic data, such as wages, across multiple economies. Georgescu-Roegen also considered entropy in the context of economics. In contrast to Theil, he examined entropy from a very general, philosophical viewpoint, and then considered economic applications of this theory.[28] The application of entropy in economics were reviewed and criticized by Brumat.[29]

2.2.4. Standards, Market and Entropy

This section presents a more detailed discussion of how these concepts might be tied together. Earlier in this paper, it was asserted that standards have the effect of decreasing entropy. Since standards and regulations have the effect of limiting consumer and producer behavior, they reduce the number of choices that both designers and consumers have. In thermodynamic terms, the number of states that the "system" (*i.e.* the market) can achieve are reduced, resulting in a reduction of the entropy of the system.

Introducing another global measure for markets cannot be done without justification. Other methods that have been developed to characterize markets have been the four-firm concentration ratio and the Herfindahl Index.[30] These indices are measures of industrial concentration within markets. While these might be applicable to this purpose in some cases,[31] they do not always capture the market complexity abstraction that is the focus of this paper. Indeed, Stigler captured the intent of these measures when he stated that "the purpose of a measure of concentration is to predict the extent of departure from price (or, alternatively, of rate of return) from the competitive level."[32] Thus, these measures are intended for antitrust application.

Market complexity can be uncorrelated with measures of concentration because different manufacturers can dominate in different market segments. For example, the market for modems can be segmented into speed (*e.g.*, 1200bps, 2400bps, *etc.*) and application (*i.e.*, dialup or leased line). One manufacturer may dominate in the market for 1200bps dialup modems, and another in 9600bps leased line modems. Thus, a market of complexity is not necessarily the same as the concentration of the modem market.

2.3. Market Model

We assume that consumers have a need for a product. They formulate their product or systems requirement based on an examination of their situation or system and their understanding of the technology that is available to them in the market. They then proceed to search the market for solutions to their needs. When they find a product or system that best fits their needs, they purchase it.[33] Thus, a market can be viewed as a search space for consumers. This view of markets was first suggested by Stigler,[34] with improvements and enhancements suggested by subsequent researchers. Philips[35] presents a thorough review of the literature, and Wilde[36] discusses the results of the psychological literature with respect to various search rules proposed by economists. According to the model proposed by Stigler, consumers search over a known number of shops using various search rules (several have been proposed, the most common being a sequential rule) to find the lowest price. Since searching may not be costless, the model attempts to identify the number of outlets a consumer may search and to explain price dispersion among outlets, a phenomenon that is not explained by traditional microeconomics.

Markets that are "over-standardized" or "over-regulated" are likely to produce insufficient kinds of products to meet the range of requirements that users have. In the context of the previous work, consumers will have exhausted the possible search space before they have reached their "cutoff" level (*i.e.*, their reservation price). That means that they would have continued to search, had there been more alternates available. Two principle effects can occur in these kinds of markets: 1) competing standards can be developed that cover different cost, performance, or application ranges, or 2) some of the standards can be dissolved (as in the case with deregulation). Markets that exhibit excessive numbers of competing standards can begin to take on the characteristics of an under-standardized market because users become overwhelmed with the choices available. Markets that are under-standardized are likely to overwhelm users with choices, resulting in an increase of search costs or increases in user uncertainty due to the risk of being stranded when network effects are present.[37] Producers have difficulty extracting sufficient profits from products in under-standardized markets because of the intense competition to achieve lock-in among potential users. The potential source of the problem is the limited human ability to process large amounts of information, as suggested by Simon's theory of bounded rationality.

3. MARKET ENTROPY

The underlying hypothesis of this paper is that standards and regulations reduce the entropy of a market. The product selection process of a user (*i.e.*, a consumer) can be viewed as a search of the space of existing products. Standards and regulations can be viewed as mechanisms that reduce the space that must be searched. Since consumers are faced with fewer choices, the entropy must be lower (by Shannon's second requirement for the entropy measure).

The lowest entropy level of a market would occur when a single standard encompasses the entire search space of the user. This standard would be optimal if it also met all of the user's requirements. Multiple standards would increase the entropy of a market, and could be optimal if a single standard was incapable of meeting the entire marketplace demand. The lowest entropy levels of multiple standards would occur if they are mutually exclusive. Overlaps in the functionality and scope of standards increases the number of choices available to a buyer, and hence increases entropy. Thus, additional standards (*i.e.*, the search space will be divided) will be added to the market until all user demands are satisfied. Similarly, users will disregard standards if too many exist.

To illustrate how all this can be applied to a real market, consider that the market entropy measure can be defined as a function of the number of market segments. Under this formulation, markets are characterized by several distinct market segments, each of which may have a standard associated with it. In order to formalize the notion of market entropy, it is useful to create analogies with the atomic models that underlie thermodynamic energy. In atomic theory, particles, such as electrons, are distributed among different energy levels within the atom. The manner in which they are distributed are dependent on the atom itself and its energy level. The macrostate of a thermodynamic system (*i.e.*, collection of atoms) is defined as the manner in which particles in general might be distributed among the energy levels within the atom, subject to the constraints of the system. In economics, consumers are the equivalent of particles and market segments are equivalent to atoms. Thus, a macrostate consists of the ways in which consumer purchases of products can be distributed over all market segments so that all economic and technical constraints are met. A microstate is the way in which specific consumers are distributed over the market segments within a particular macrostate.

As stated above, Boltzman formulated entropy to be proportional to the number of microstates that can exist within a system.[38] Due to deregulation, decreased standardization, or an increase in competing standards, the market entropy increases because the number of microstates increases. Similarly, a market that has few market segments due to over-regulation or standardization displays lower market entropy. To make this concept more concrete, consider the market for long distance data communications in the US (LAN products are explicitly excluded from this example). Business users may choose from a variety of products and services, each of which could potentially address the need. They include:

- Analog dialup or leased lines with modems
- Digital Data Services (DDS), which is widely available at 56kbs dedicated or switched
- Fractional T1, at a typical rate of 384kbs (although other rates are possible)
- T1 at 1.544 Mbps
- T3 at approximately 45 Mbps
- New services such as Frame Relay and Switched Mulitmegabit Data Service (SMDS), which are being introduced in most localities and are available at a variety of rates[39]

These services are plotted in Figure 1 as a function of line speed and line type (dedicated or shared). Users can select one of these services for their needs. Users have more choices as more services are developed. These represent the "macrostates" that users could occupy. The entropy of the market would be computed by observing the distribution of users over these services. If services such as Frame Relay and SMDS had not been standardized, or if they had been proscribed by government regulation, they would not have been choices available to users. Users that would otherwise occupy these "states" would be forced to different states, presumably ones that most closely met their needs. This would have an entropy reducing effect, since it would force users to cluster more than they would in the current marketplace. If prices and multiple carriers are included, the number of macrostates multiplies, since each users could use a service from a carrier at a given price, whereas another could use the same service at a different price. Figure 2 illustrates this. In fact, anecdotal evidence from telecommunications managers indicates that they are not able to dynamically optimize their networks. As soon as a particular implementation of a network is completed the network manager might learn of a new service or a new price of an existing service.[40] Changing networks is not without costs, so network managers are forced to operate sub-optimal networks. The strategy adopted by some managers to cope with this

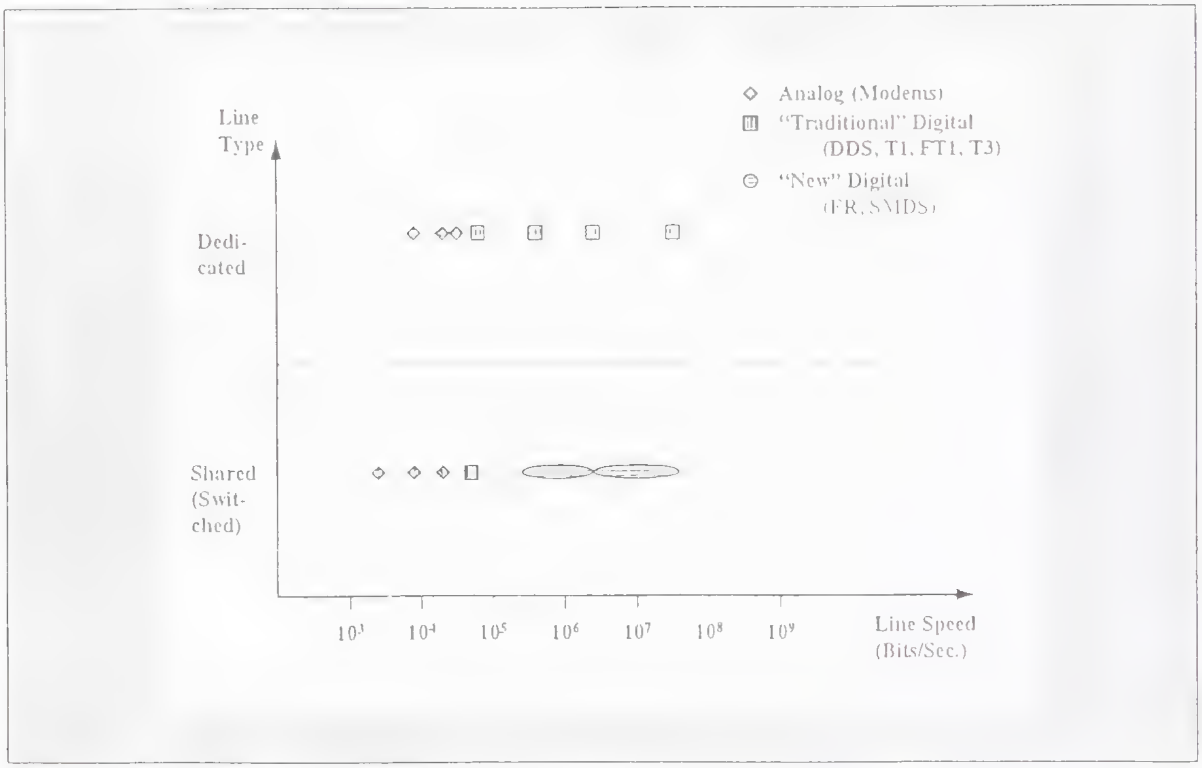

Figure 1: Long Distance Data Services

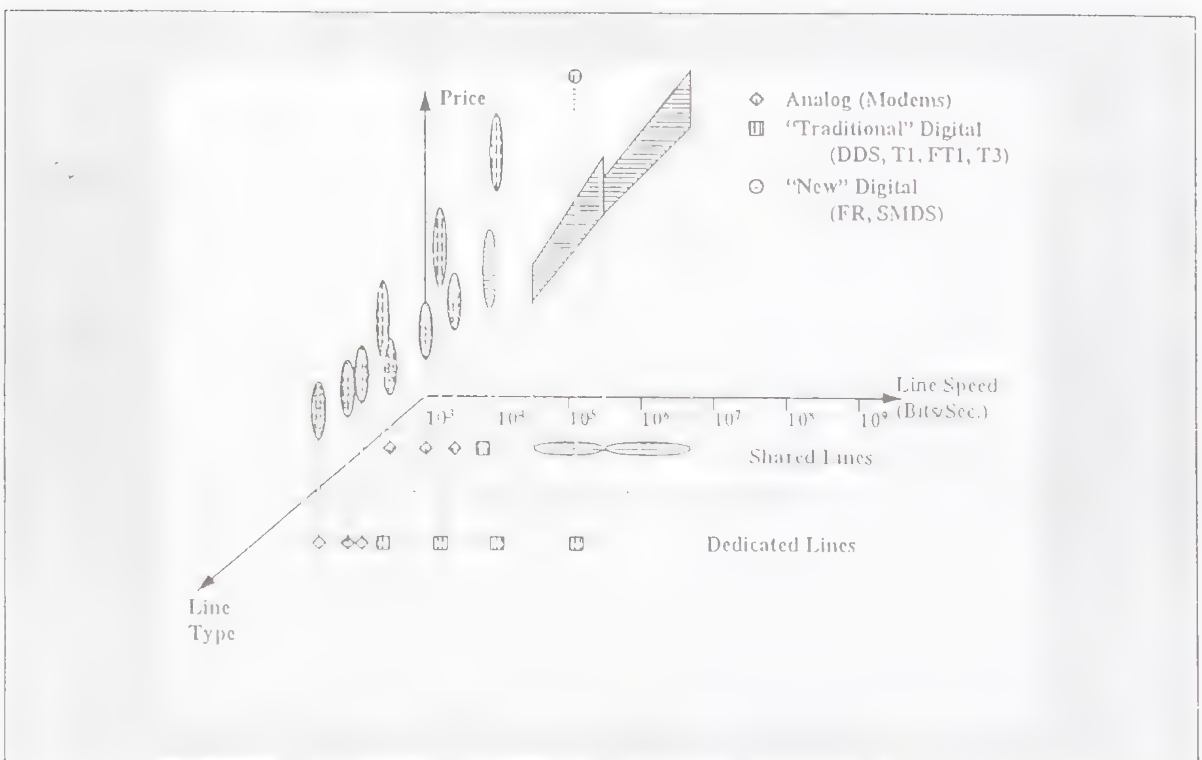

Figure 2: Data Services with Price

problem is to reduce the search space by adopting internal standards, such as identifying a preferred vendor, or selecting from a limited portfolio of available services. In this way, network managers reduce the perceived market entropy, even though the actual market entropy is much higher. The range of technology and price offerings is not without costs to vendors either, but these costs are normally viewed as a necessary part of doing business in the competitive information technology marketplace.

4. RELATIONSHIP TO PRIOR RESEARCH

While none of the previous research in standards has taken this particular view, this framework is not incompatible with some of the previously obtained results. Critical to most of the formal models developed above is the notion of technical externality that is a function of the number of compatible units in the market. In the entropic model, the externality is represented explicitly as the probability with which a particular product type is selected. Thus, non-standard products can be in the market, they just have a lower probability of being selected by a user. New technologies enter the model as new states that the market can assume, *i.e.*, they increase the entropy of the market.

4.1. Application to Private Networks

How does this theory matter to private networks? Consider the manager of a corporation with varying user needs. In principle, each of the users could contract privately to meet their needs. Corporations realize that economies can be gained by negotiating collectively, resulting in a private network for users. The private networks are economical for several reasons:

- Service providers are more likely to negotiate lower prices with a collection of users than with single users
- "Standard" internal products reduce the training requirements for network service personnel
- By developing a set of "standard" solutions to common problems, the corporation reduces the search space in under standardized markets, reducing the search costs for solutions to user's needs
- Users gain from the network benefits of internally standardized solutions

An ideal private network solution would be the superset of each of the individual's needs. It is possible that this superset will be smaller than the set of available products. In the context of the theory of market entropy proposed here, the entropy of the solution space is reduced, so firms gain economies by going to private networks. In fact, it is quite possible that the savings in going to a collective private network exceed the savings from collective bargaining for low cost.

Such a private network may be sub-optimal in several respects. First, since the public network service and equipment alternatives are changing rapidly, it is likely that the network is of a higher cost than it would be otherwise. Second, users' needs are dynamic; if the private network does not adapt to user needs with sufficient speed, than users will lose efficiencies that they might have had. Third, a collective decision to back a "losing" technology when standards rivalry occurs can have a larger net effect than if the decision were made individually, because some of the individual users would probably have backed the technology that was the winner, *ex post*.

5. CONCLUSION

A theory of standards and regulation has been proposed that is based on the concept of entropy. This theory was qualitatively demonstrated in a study of the market for long distance data services. This theory provides an additional factor influencing buyer behavior that traditional economic theory does not capture. The effect of market entropy that is too high is that buyers establish internal standards to which they adhere. While this means that they do not always purchase the optimal system for a particular application, it does result in a purchasing process that is less costly and more easily manageable. Similarly, a market whose entropy is too low would find users clamoring for other solutions, and potentially building systems privately that circumvent the overly restrictive marketplace.[41] This theory has some implications for policy-makers as well. While it is difficult to imagine an "entropy knob" that increases or decreases market entropy as needed, it is possible to imagine a deregulatory climate with lax enforcement when market entropy is too low, and a more regulatory and enforcement-oriented posture when market entropy is too high. In the latter case, one can even imagine lax enforcement of antitrust regulations so that market leadership could develop to reduce the market entropy. Since this measure can be used to determine the over- or under-standardization of a market, it can be used by the planning committees of standards development organizations as a strategic planning tool. For example, no new standards activities should be initiated in markets that exhibit low entropy and where user needs are being met. Instead, the standards development committees should concentrate on markets where the entropy is high, or on those markets with low entropy where user needs are not being met. While using this as a standards management tool, it is important to note that many factors affect the satisfactory outcome of a standards development effort. Just as product planning helps developers focus their activities, this notion of entropy may help standards planning committees focus their limited resources more effectively.

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[1] Weiss, Martin B.H. and Marvin A. Sirbu, "Technological Choice in Voluntary Standards Committees: An Empirical Analysis," *Economics of Innovation and New Technology*, Vol. 1, No. 1, pp. 111-134, 1990.

[2] For example, the V.22*bis* modem standard competes with the V.26*ter*, and the Ethernet LAN standard (IEEE 802.3) can be viewed as competing with the Token Ring LAN standard (IEEE 802.5).

[3] For example, the TCP/IP protocol suite can be thought to build on Ethernet; the X.25 packet switched network standard builds on HDLC.

[4] Campbell, Jeremy, *Grammatical Man*, New York: Simon and Schuster, 1982. Georgescu-Roegen, Nicholas, *The Entropy Law and the Economic Process*, Cambridge MA: Harvard University Press, 1971.

[5] There are many detailed explanations for the need for particular standards and regulations that are available. The use of entropy at a macro level is not intended to and does not void these explanations.

[6] Cargill, Carl F., *Information Technology Standardization: Theory, Process, and Organizations*, Bedford, MA: Digital Press, 1989. Weiss, Martin B.H., "Compatibility Standards and Product Development Strategies: A Review of Data Modem Developments," *Computer Standards and Interfaces*, Vol. 12, pp. 109-121, 1991(a).

[7] Evidence of this can be found in virtually every trade publication. Strauss, Paul R., "The Standards Deluge: A Sound Foundation or a Tower of Babel?" *Data Communications*, Vol. 17 No. 10, pp. 150-164, September 1988. Kerr, Susan, "Cutting Through Network Control," *Datamation*, Vol. 35, No. 20, pp. 30-34, October 15, 1989.

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[10] Link, Albert, "Market Structure and Voluntary Product Standards," *Applied Economics*, Vol. 15, pp. 393-401, 1983.

[11] Link uses the following independent variables for his analysis: seller market concentration, technological complexity (which is a function of R&D), and the percentage of unionization.

[12] Lecraw, Donald J., "Some Effects of Standards," *Applied Economics*, Vol. 16, pp. 507-522, 1984.

[13] Lecraw's independent variables are Buyer Concentration, Seller Concentration, proportion of government sales, product safety role, elasticity of demand, advertising intensity, R&D intensity, product complexity, and producer good/consumer good. Note their similarity to the independent variables used by Link. Link, Albert, "Market Structure and Coluntary Product Standards," *Applied Economics*, Vol. 15, pp. 393-401, 1983.

[14] David, Paul A., "Some New Standards for the Economics of Standardization in the Information Age," in P. Dasgupta and P. Stoneman (eds.), *Economic Policy and Technological Performance*, Cambridge: Cambridge University Press, 1987. Katz, Michael L. and Carl Shapiro, "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy*, Vol. 94, No. 4, pp. 822-841, August 1986. Katz, Michael L. and Carl Shapiro, "Product Compatibility Choice in a Market with Technical Progress," *Oxford Economic Papers*, Nov. 1986. Farrell, Joseph and Garth Saloner, "Standardization, Compatibility, and Innovation," *RAND Journal of Economics*, Vol. 16, No. 1, pp. 70-83, Spring 1985. Farrell, Joseph and Garth Saloner, "Installed Base and Compatibility: Innovation, Product Preannoucements, and Predation," *American Economic Review*, Vol. 76, No. 5, pp. 940-955, December 1986.

[15] Georgescu-Roegen, Nicholas, *The Entropy Law and the Economic Process*, Cambridge MA: Harvard University Press, 1971.

[16] Dragan, J.C. and M.C. Demetrescu, *Entropy and Bioeconomics: The New Paradigm of Nicholas Georgescu-Roegen*, Pelham NY: Nagard Publishers, English Translation, 1986.

[17] Finkelstein, Robert J., *Thermodynamics and Statistical Physics*, San Francisco: W.H. Freeman, 1969.

[18] Boltzman recognized the need for a constant to calibrate the model to the physical phenomenon. While this constant is required for physical interpretation in statistical thermodynamics, it is incidental to the *structure* of the phenomenon.

[19] In the case of thermodynamics, it represents the number of energy states that the electrons in an atom could possibly assume. Sonntag, Richard E. and Gordon J. Van Wylen, *Introduction to Thermodynamics: Classical and Statistical*, New York: J. Wiley, 1982.

[20] Microstate 1 - AB in P, CD in Q; Microstate 2 - AC in P, BD in Q; Microstate 3 - AD in P, BC in Q; Microstate 4 - BC in P, AD in Q; Microstate 5 - BD in P, AC in Q; Microstate 6 - CD in P, AB in Q.

[21] Microstate 1 - A in P, BCD in R; Microstate 2 - B in P, ACD in R; Microstate 3 - C in P, ABD in R; Microstate 4 - D in P, ABC in R.

[22] Sonntag, Richard E. and Gordon J. Van Wylen, *Introduction to Thermodynamics: Classical and Statistical*, New York: J. Wiley, 1982.

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[31] Link (1983) and Leecraw (1984) use these measures as independent variables in their macroeconomic studies of standards in markets.

[32] Stigler, George J., "The Measurement of Concentration," in Stigler, George J. (ed.), *Organization of Industry*, Homewood IL: Richard D Irwin, 1968.

[33] This model of purchase behavior perhaps fits corporate purchasing behavior better than consumer purchasing behavior. This model is consistent with the corporate purchasing behavior literature (Moriarty 1983). Similar models have been considered by several economists for other purposes, for instance Nelson and Winter (1982) used a search model to analyze economic change. Stigler (1961) discusses price search when consumers have imperfect information (See also Philips (1988).

[34] Stigler, George J., "The Economics of Information," *Journal of Political Economy*, Vol. 69, pp. 213-282, 1961.

[35] Phlips, Louis, *The Economics of Imperfect Information*, New York: Cambridge University Press, 1988.

[36] Wilde, Louis L., "Consumer Behavior Under Imperfect Information: A Review of Psychological and Marketing Research as it Relates to Economic Theory," in Green, Leonard and John H. Kagel (eds.), *Advances in Behavior Economics (Vol. 1)*, Norwood NJ: Ablex Publishing Corp., 1987.

[37] For example, the choice of video recording format (VHS or Beta) made decision-making more risky that in would have been had a standard been agreed upon in advance. Most adopters of the Beta standard have since switched to the rival VHS format, losing any investment in Beta-based tapes and VCRs that they had made.

[38] Boltzman's constant, k, is of no meaning here and can be dropped without loss of generality. Boltzman's constant is used to calibrate the entropy measure to the appropriate physical dimensions. This is not necessary in this application.

[39] Integrated Digital Services Network (ISDN) services are deliberately omitted from this because they are not widely available in the US.

[40] This is by no means unique to network managers. Buyers of personal computers and computer workstations also face this situation.

[41] For example, if frame relay service were unavailable publicly, then a corporation could choose to construct a network privately by leasing lines and purchasing the appropriate hardware. In some cases, such privately constructed networks are more economical than purchasing a public service in today's market.