Standards and Regulations:
A Unified Approach

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A. Introduction

In this decade, the information technology industry has witnessed two important trends that has 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 are intricately related. For example, the increase in voluntary consensus telecommunications standards is, in part, the direct result of the loss of market leadership of AT&T, who previously set *de facto* standards. In this paper, it will be argued that the net effects of each of these trends on manufacturers and consumers of information technology systems are similar.

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, with the result of increasing consumer choices, whereas voluntary consensus standards have the effect of reducing the number of potential design outcomes (Weiss and Sirbu 1990). When framed in this way, these two phenomena can be considered under the unifying concept of entropy. The trends discussed above can be seen to be contradictory: on the one hand (in deregulation), industry is opening itself to new choices, whereas on the other (in standards) it is constraining choices.

Since standards have been developed well in advance of products performing equivalent functions (Cargill 1988, Wallenstein 1989, Weiss 1991) 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 overstandardization can lead to social welfare losses. Additionally, firms may use standards strategically, so it is important to examine what the optimal level is, and what the incentives are for firms and users to deviate from that optimal range.

Anecdotal evidence suggests that users of information technology are overwhelmed with the choices available[1]. Travelling telecommunications users are also faced with a myriad of choices when calling from a hotel due to competing services (Weiss and Lewis, 1991). 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 (discussed further below), and much has been written about regulation, but none integrates both of these phenomena.

B. 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.

1. Standards and Standardization

Standards have proliferated in recent years, particularly in the Information Technology (IT) sector of the economy (Strauss, 1988). Opinions among industry observers vary as to whether too many standards exist or too few. Preliminary research (Link, 1983) 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

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[1] Evidence of this can be found in virtually every trade publication. Strauss (Strauss 1988) and Kerr (Kerr 1989) are exemplars of articles of this type.

entropic) principles as opposed to mechanistic ones (Dragan and Demetrescu 1986). In this view, economic actors feed on low entropy (*eg*. raw materials) and produce high entropy (*eg*. finished goods). Georgescu-Roegen attempts to explain many human endeavors and conflicts in these terms.

a. 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 the 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. In a thermodynamic system, the change in entropy (DS) of a process is always greater than or equal to zero, $DS \geq 0$. A process is reversible only if $DS = 0$, which can occur only in closed, quasi-static systems (Finkelstein 1969). Thus, in practical systems, entropy is always increasing.

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. This system uses coal (for example) 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 to 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 would clearly not be practical (or even possible) to fully reverse this thermodynamic process, which would require us to regenerate 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 more orderly state (*i.e.*, coal and water were distinct entities) to a more disorderly state (the coal is converted to 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.

In most physical systems, it is not practical to exhaustively count *all* possible microstates due to the large numbers involved[7]. Consequently physicists have observed that a small number of macrostates are most likely to occur. In fact, these macrostates are overwhelmingly more probable than the others, so the analysis is generally performed solely on these most probable states.

b. 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 (warm gas) to pass through an imaginary door to separate them from slow moving molecules (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.

Shannon formalized and adapted the notion of entropy with respect to information, taking 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 (Shannon and Weaver 1949). In developing a general model for communications, he desired a measure for entropy H that had the following characteristics:

It should be continuous in p_i[8].
If all p_i are equal (*i.e.*, $p_i = 1/n$), then H should be a monotonically increasing function of n. Thus, if more possible events, n, can occur, the entropy should be greater.
If a choice can be decomposed into multiple, successive choices, then the entropy of the overall choice should be the weighted sum of the entropy of the sub-choices.

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[7] A liter of gas at normal temperature and pressure contains approximately 10^{23} molecules, each of which may contain dozens of electrons and even more possible energy states.

[8] Where p_i is the probability with which a state or message occurs.

Georgescu-Roegen asserts that economic life feeds on low entropy. Thus, production processes convert raw materials (*i.e.*, a system in a state of low entropy) and energy into finished products. Since these finished products cannot be separated back into their original components, the entropy of the system is higher[10]. Finished products at the end of their useful life become a waste stream, which has high entropy. This entropy is ever increasing.

C. Standards, Markets 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 (by design), 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 (Kwoka 1985). These indices are measures of industrial concentration within markets. While these might be applicable to this purpose in some cases[11], 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, alternately, of rate of return) from the competitive level" (Stigler 1968). Thus, these measures are intended for antitrust application.

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[10] For those that can be separated back into their constituent raw commodities, this separation comes at the cost of energy that must be added to the system. For example, aluminum cans and glass bottles can be recycled into aluminum and glass ingots for use in new products. The color in glass bottles cannot be separated from the glass itself. Humans must therefore apply energy in order to sort these recyclable materials into the correct categories from the waste stream. Furthermore, energy must be applied to melt these materials for use in new products.

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

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 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 alternatives available.

Two principle effects can occur in such markets: competing standards can be developed that cover a different performance or application range, or 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 can become overwhelmed with the choices available (*i.e.*, the users search may have to include several market segments).

Markets that are under-standardized are likely to overwhelm users with choices, resulting in an increase in the transaction costs (in this case, the cost to acquire the right product or service). 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 ability of humans to process such large amounts of information, as suggested by Simon's bounded rationality.

2. *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 the 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 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[13]. Thus, as the number of market segments increase, due to deregulation or decreased standardization (or an increase in competing standards), the market entropy increases because the number of microstates increases. Likewise, a market that has few market segments due to (over) regulation or (over) standardization, would display lower market entropy.

To make this concept more concrete, consider the market for data communications in the US. Business users may choose from:

analog dialup or leased lines with modems;
Digital Data Services (DDS), which is widely available at 56kbps dedicated or switched;
Fractional T1, at a typical rate of 384kbps (although other rates are possible);
T1 at 1.544Mbps;
T3 at approximately 45Mbps; and
new services such as Frame Relay and Switched Multimegabit Data Service (SMDS), which is being introducted in most localities and are available at a continuum of rates[14].

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. As more services are developed, users have more choices. 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

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[13] 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.

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

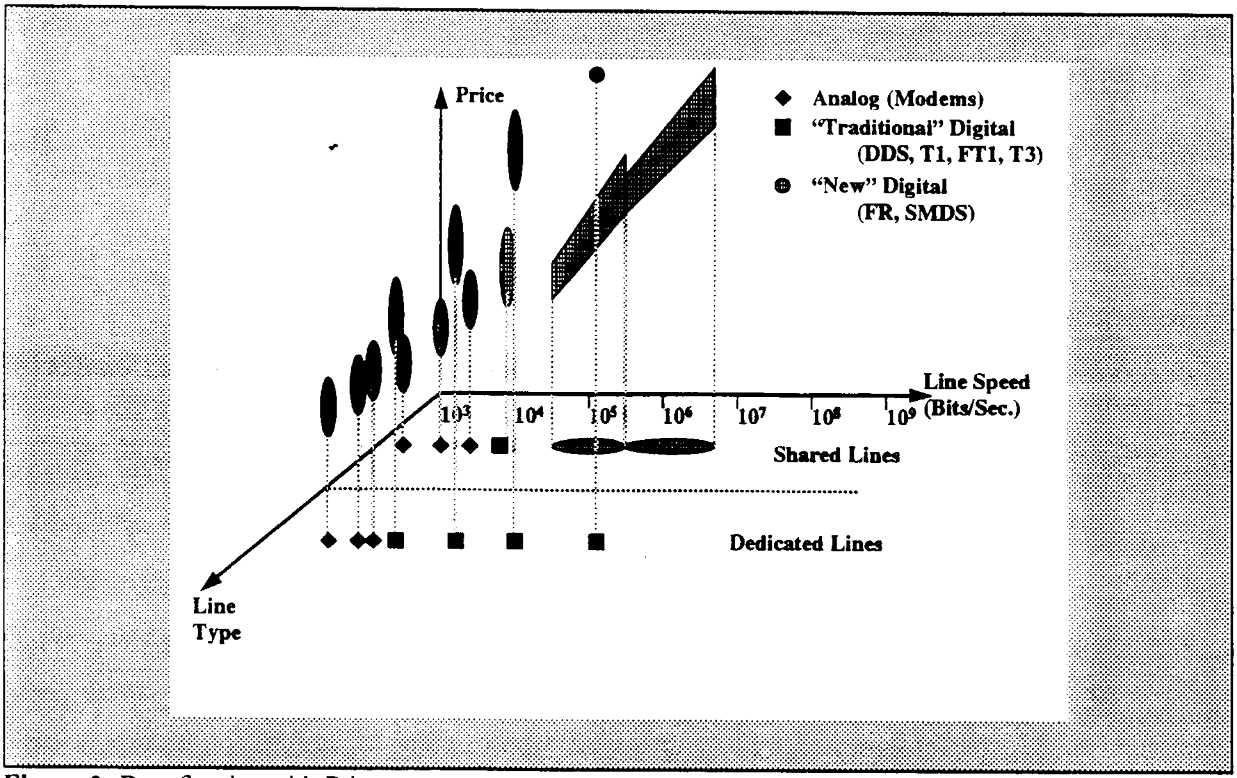

Figure 2: Data Servies with Price

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.

3. Relationship to Prior Research

While none of the previous researchers in standards have 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 a 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

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