Standards and the diffusion of advanced technologies

By: Albert N. Link and Gregory Tassey

Link, Albert N., and Gregory Tassey. "Standards and the Diffusion of Advanced Technologies," *Evaluation and Program Planning*, 1988, 11(1): 97-102. https://doi.org/10.1016/0149-7189(88)90038-9

Abstract:

There is a long history in the United States of public policy initiatives directed toward the creation of new technology, but very few efforts have been supported to increase the rate of diffusion of these technologies. Given the importance of more rapid technology diffusion as both a spur to increasing productivity growth and as a competitive response to the global technology-based competition this country now faces, an effort should be made by the government to support further investment in infratechnology. We demonstrate the potential impact this may have by examining the historical impact that the adoption of standards has had on the diffusion of numerically controlled machine tools.

Keywords: United States | technology diffusion | infratechnology

Article:

U.S. industries are proficient at developing new technologies; however, U.S. firms have been much slower than their world competitors, the Japanese in particular, in using these or adopting others' emerging technologies. The aggregate effect of such slow technology diffusion has been lower productivity growth and, in some cases, a loss of world market shares. Slow technology diffusion is not the complete explanation for the waning productivity growth that has characterized most industrialized nations over the past several decades. A complete analysis of such factors is in Link (1987).

One may speculate as to the reasons why U.S. firms have been slow to adopt and implement emerging technologies. Perhaps one explanation is related to the historic single-focused nature of innovation-related public policies. The government has a long history of R&D-directed policies—dating as far back as 1789 with the U.S. Navy's sponsored research programs to the 1986 renewal of the R&D tax credit, which was originally part of the Economic Recovery Tax Act of 1981. Only recently has policy broadened its perspective to include complementary influences in the production of innovation through the National Cooperative Research Act of 1984. What is lacking is an explicit policy-based incentive structure to increase the diffusion of new technology.

We argue here that one area in which a diffusion-related policy can be effective is in the support of infratechnology. After describing the role of infratechnology in the process of technological development in the following section, we demonstrate empirically the influence over time of infratechnology embodied in interface standards on the diffusion of numerically controlled machine tools in the United States.

INFRATECHNOLOGY AND THE PROCESS OF TECHNOLOGICAL DEVELOPMENT

Infratechnology is an important element of an industry's technological base. As the name implies, infratechnology encompasses all technologies that support the key elements in the process of technological development—R&D, production, and marketing. Infratechnologies are competitively neutral methods and data which *leverage* (increase the productivity of) the development, production, and marketing of an industry's "core" technology—that is, the technology underlying that industry's product mix, production methods, and marketing approaches. This role can be illustrated in the following way. Let T_1 represent the technology inputs used by firm i, along with other inputs as capital, K_1, and labor, L_1, to produce output Q_1:

$$Q_1 = F(K_1, L_1, T_1)$$

T_1, in turn, can be represented as the output of a second production process:

$$T_1 = G(PT_1, BT_1, IT)$$

where PT_1 represents the firm's proprietary technical knowledge developed from its self-financed R&D efforts, BT_1 represents borrowed or purchased technical knowledge produced by other vertically- or horizontally-related firms, and IT represents infratechnology. Infratechnology, by nature of being a public good, has a neutral competitive influence at the firm level, affecting all firms in the industry to the same degree (hence, there is no subscript on IT above).

Infratechnologies include evaluated scientific data used in the conduct of R&D; measurement and test methods used in research, production control, and acceptance testing for market transactions; and various technical procedures such as those used in the calibration of equipment. They facilitate the development of generic technology by, for example, providing highly precise measurements and creating organized and evaluated scientific and engineering data necessary for understanding, characterizing, and interpreting relevant research findings. Typically, they tie, at root, to the fundamental units of measurement. They also provide the measurement and testing concepts and techniques that enable higher quality and greater reliability at lower cost in production. Finally, infratechnologies provide buyers and sellers with mutually acceptable, low-cost methods of assuring that specific performance levels are met when technologically-sophisticated products enter the market place.

Since infratechnologies represent knowledge that is nonproprietary, broad in scope, and widely available for use, they are in the public domain. Many infratechnologies are supported by the government, developed in particular by the National Bureau of Standards, and they influence production through voluntary industrial standards. And, as shown below, standards have a significant positive effect on technology diffusion.

Standards provide four important functions. [This section draws from a more detailed discussion of industrial standards in Link and Tassey (1987), Chapter 4.]

1. *Information:* verified data, terminology, test and measurement methods for evaluating and quantifying product attributes;
2. *Compatibility:* properties that a product should have in order to be compatible with a complementary product or with other components within a "system";
3. *Variety reduction:* limitations in the range or number of allowable levels of product characteristics, such as physical dimensions;
4. *Quality:* specification of an acceptable level of product performance along one or more dimensions including reliability, durability, efficiency, safety and environmental impact;

These four functions have important economic effects:

1. *Information:* Differences between the per se value of information and its value in use depends in large part on the ability of suppliers and users to communicate effectively. The transfer of complex technological information, in particular, requires a logical and comprehensive terminology. Such standardized terminologies may be a basis for effective information transfer. The production of technical information requires standardized test and measurement methods, both to assess accurately research results and to convince users of the validity of these results. In the absence of a standard product acceptance test method, considerable resources must be spent to resolve performance-related disputes.

   The efficient conduct of R&D and the effective control of production processes require comprehensive scientific and engineering data bases with certified levels of accuracy, associated predictive models, standardized methodologies for validating these data bases, and standardized formats and terminology associated with the dissemination of related data. Without standardized information inputs into economic activity, firms will attempt to create their own data, which are typically less complete, less accurate, and frequently conflicting across firms.
2. *Compatibility:* Standards define the physical and/or functional interface between two pieces of equipment which must work together as part of, say, an automated production process. Without this compatibility function, equipment users must either purchase all components of a "system" from a single vendor, or modify the components themselves to achieve compatibility. In either case, the user will likely pay a higher price, which slows market penetration of the new technology. An interface standard allows users to integrate equipment from different vendors into the same production system. The result is increased competition among vendors, as well as increased confidence on the part of the users. The economic impact is a faster diffusion of the technology.
3. *Variety reduction:* Standards are also used to limit the variety of a product along one or more dimensions. Within limits, variety reduction of some physical dimension, say the size of the product, may bring about some economies of scale in production. Also, limits on the number of sizes of a product can induce innovations in equipment which interface with the product, enabling further economies of scale.

4. *Quality:* Standards are used to specify minimum performance levels for one or more product attributes. This function sends a signal to manufacturers which may help structure their R&D and production strategies by, for example, more clearly defining available market segments or niches. Thus, specification of quality levels can also affect variety reduction.

Standards facilitate the diffusion of technology in several ways. Because technology adoption decisions are based, in large part, on risk-adjusted rates of return, standards reduce uncertainty about the risks of buying new technologies and thereby facilitate technology-adoption decisions.

STANDARDS AND THE DIFFUSION OF NUMERICALLY CONTROLLED MACHINE TOOLS

The following example illustrates the importance of standards—of infratechnology in general—on the diffusion of a new technology, numerically controlled machine tools.[1]

Machine tools are the central element in the manufacturing of almost all physical (non-chemical) products. They either produce the machines which in turn produce the final product, or they produce the final product directly.

Much has been written about numerically controlled machine tools over the past three and one-half decades in the popular press, as well as in academic journals and books. Numerical control is a method whereby machine tools can be controlled by programmed instruction using numeric (and also symbolic) codes. The digital programs are "given" to the machine tool either by cards or tape, and most recently the control codes are being delivered in electronic form directly from computers.

The evolution of numerical control was influenced greatly by the federal government. This history began in the 1940s when the Air Force wanted to develop better production methods for high-performance aircraft. In doing so, the Air Force required precise machine tooling for component parts. At the same time, the Navy and Air Force were engaged in developing techniques to advance knowledge about information systems, in general, and industrial automation, in particular.

Numerical control is not a machining method, but rather a concept of machine control. Types of numerical control for machine tools include programmable control, direct numerical control, and computer numerical control. Programmable control allows the machine tool operator to interrupt the programmed operation and change the program or sequence, typically by installing a new paper tape. Direct numerical control is a system by which one or more numerically controlled machines are connected to a mainframe computer to establish a direct interface between the computer and the machine tools. The machine tools are controlled directly by the computer without the use of a tape. Computer numerical-control systems utilize minicomputers in the machine tools' controls in order to store instructions for controlling the machine.

---

[1] A preliminary discussion of these results was presented at the International Conference on Product Standardization as a Tool of Competitive Strategy, at INSEAD, Fountainebleau, France in June 1986, and at the American Economic Association meetings in New Orleans in December 1986. All data related to the analysis are available from the authors upon request.

Despite the potential advantages of flexibility, precision, and reliability associated with numerically controlled machine tools, their acceptance by U.S. manufacturers has been extremely slow. One important reason for the slower than expected diffusion of numerically controlled equipment is that for at least a decade most numerically controlled technology was designed for military specifications which were at the upper end of the spectrum of performance requirements associated with various industrial applications. As a result, the machinery tended to be very complex, and thus unreliable for many commercial uses. The support requirements were expensive and technically demanding. Also, while numerical control is obviously useful for batch manufacturing, an investment risk remains for the purchaser owing to volatility in output demand.

Increasingly, numerically controlled machine tools have become part of a manufacturing system rather than a stand-alone piece of equipment. Whenever such a tool is purchased by a metal products manufacturer, it must interface with other equipment. Generally, a numerically controlled machine tool is attached to a computer-based parts design system (often referred to as Computer Aided Design, or CAD).

Once the design has been finalized, the design data must be transmitted to the machine tool. First, the design is translated into a parts programming language, or "cutter location" file. Because wide variation exists in the performance attributes of a particular class of machine tools, the cutter location file must be con verted into a format which can be understood by the controller of a particular machine tool. This translation is accomplished by a post processor which converts the cutter location file into a machine-specific (that is, vendor-specific) data format. Once the data are received, the programmed controller "operates" the machine tool.

Over time, standards have been developed to facilitate the operations of numerically controlled machine tools. Generally speaking, the standards were promulgated in two time periods, one occurring in the late 1950s and early 1960s, and the other in the 1970s and early 1980s. In the earlier time period the standards were aimed at variety reduction and in the latter time period they were primarily targeted at compatibility. Several are noteworthy.

To deal with the fact that design data, whether from CAD system or not, can take many forms, and that adapting these data for use by a machine tool's controller would be both time consuming and expensive, a parts programming language, APT, was developed in 1955-1956. It was the implicit standard by 1957, as a result of efforts by the Aircraft Industries Associated Subcommittee for Numerical Control, although it was not formally adopted as ANSI X 3.37 until 1974. Today a user typically buys an APT processor from the CAD vendor.

Post processors convert cutter location data into a format understood by the controller. These data formats were standardized to an extent by EIA RS-274 beginning in 1963, but the formats still vary beyond classes of very similar machine tools. Post processors (that is, the software for data conversion) are typically developed by third parties, although they may be sold as a bundle with the controller/machine tool. Because controllers are made by a group of firms largely different from the manufacturers of the machine tools, the physical interface between the two was standardized by EIA RS-281 in 1963. In addition, the functional interface between the operator of the machine tool and the controller was standardized, to some degree by EIA RS-441 in 1979.

Together, these standards permitted specialization by different classes of firms in the components for which they have a comparative advantage. More important, they allowed metal products manufacturers to benefit from competition among suppliers at the component level. For example, the degree of standardization that exists for position data formats allows for some economies of scale in post processors. Similarly, controllers from different vendors can, as a result of physical interface standards, be attached to the same machine tool. The existence of such a standardized interface not only benefits the user in terms of price competition, but also reduces the expected cost from technological obsolescence. That is, when a more advanced controller becomes available, it can be substituted for the existing one with a lower probability of having to scrap the tool or, at least, undertake expensive modifications.

The lack of complete standardization of post processors might be interpreted as an efficiency loss because market segmentation reduces competition and prevents maximum realization of economies of scale. However, because of the large variation in machine tool performance attributes—a desirable situation from the machine tool user's point of view—a highly standardized contouring/positioning data format would likely restrict flexibility of machine tool operation. Thus, the competitive advantages of standardization must sometimes be traded off against the need for flexibility of operation.

As a first step toward examining the influence of standards on the diffusion of numerically controlled machine tools in U.S. manufacturing, we gathered information on the proportion of metal-cutting machine tools shipped between 1965 and 1984, inclusive, that were numerically controlled.

Based on a chronology of standards relevant to numerical controls, nine important standards adopted between 1973 and 1984 were identified, all of which related to interfacing.[2] These included EIA RS-441 and ANSI X 3.37, which were discussed above. The others, with dates of adoption in parentheses, are: EIA RS-408(1973), RS-431(1978), RS-447(1978), RS-474(1982), RS-491(1982), RS-484(1983), RS-494(1983). EIA RS-408 is an interface standard related to the tape reader and the controller. RS-431 is an interface between the controller and the numerically controlled machine. RS-447 standardized the operational commands and data formats for the numerically-controlled machine. RS-474 is a flexible disk format for numerically-controlled equipment information interchange. RS-491 relates to the interface between a numerically controlled unit and peripheral equipment. RS-484 is an electrical and mechanical interface standard between the direct numerically controlled system and the equipment. Finally, RS-494 relates to binary input formats.

To examine empirically the effect that the adoption of these standards has had on the diffusion of numerically controlled machine tools, we estimated the following diffusion model:

$$\log\{m/(n-m\} = \mathrm{a} + \mathrm{b}t$$

[2] This information comes from unpublished information gathered by A. T. Bacheter, Westinghouse Corporation Industry Electronics Division.

where *m* represents the current population of users, *n* is the population of potential users, and *t* stands for time (in years). The estimated regression coefficients, $\hat{b}$, is generally interpreted as a speed of diffusion parameter.

The current population of users, *m,* is approximated by the number of numerically controlled metal cutting machine tools shipped in a given year, and the population of potential users, *n,* by the total number of metal cutting machine tools shipped that same year. These data come from U.S. Bureau of the Census publications. Adjustments for imports and exports could only be made for the post-1980 period; however, for most years prior to 1980, net imports appeared to be small relative to domestic shipments.

To test explicitly for a change in the speed of diffusion parameter after the adoption of interface standards, we included two additional regressors in the model above. The first was a binary variable, *D,* equalling "l" for the years 1974 (assuming a one year lag since EIA RS-408) through 1984, and "0" otherwise. The time period 1978-1984 brackets the promulgation of interface related standards. This binary variable was also interacted with the trend variable, *t.*

The least squares results reveal that the speed of diffusion parameter corresponding to the post-1974 period is nearly four times that of the earlier period. The speed of diffusion parameter corresponding to the earlier period equals –0.03 (significant at the .05 level), and to the later period it equals 0.21 (significant at the .01 level):

$$\log\{m/(n-m\} = -4.37 - 2.05D - 0.03t + 0.24t \cdot D;$$
$$(-44.43)(-9.41)(-2.17)(11.33)$$

$R^2 = 0.98$
$D - W = 1.84$
(t-statistics in parentheses).

This finding supports the proposition that standards (interface standards here) do influence the diffusion of technology (numerically controlled metal cutting machine tools).

CONCLUSIONS AND RECOMMENDATIONS

In terms of today's economic realities, economic text books give a narrow and over-simplified analysis of standardization and its economic roles. Standardization is limited to the single role of variety reduction for the purpose of achieving economies of scale in production. The reason is that from the industrial revolution until the present time, the economic efficiency of the majority of technologies depended on *specialized* machinery organized in a *rigid* system for high-volume production. Thus, scale economies dominated production strategies and were an important objective of standardization.

In the 1980s, rapid technological advances and the proliferation of market niches or segments have combined to shift the emphasis of production technology from economies of scale to economies of scope. That is, economic efficiency is increasingly being measured in terms of ability to service related but different market segments with the same production technology.

This trend will place a premium on innovation in product design and flexibility in production, while maintaining the high levels of quality demanded by intense foreign competition. The technical and organizational concepts underlying this new set of economic strategies are radically different from the past and their diffusion into the U.S. economic system is therefore encountering significant barriers. One of these barriers to the adoption of many emerging technologies is the lack of appropriate standards at critical points in each technology's evolution.

A good example of the economic importance of standards to a critical emerging technology is automated batch manufacturing. Beginning in the 1950s, a slowly growing demand for *precision engineering* and *flexibility* in production created a derived demand for *generalized* or flexible machines, which could execute smaller production runs or "batches" of related products without significant increase in unit cost. In the current decade this concept has been escalated to systems of machines, and in the coming decades to entire factories. Numerically controlled (NC) machine tools were the first implementation of this trend in production strategy toward computer-integrated flexible manufacturing.

Such integrated technology systems, based on the use of computers at all levels of operation within the manufacturing plant, require a broad array of standards for *effective* and *timely* implementation. Within such systems, standards perform four important categories of functions: information, compatibility, variety reduction, and quality. The information function, in particular, is pervasive across all stages of technology-based economic activity from R&D, through production, to marketing.

Many of these standards, such as the *interface* standards analyzed here, do not affect the design of individual components (such as NC tools, or the components of NC tools) which make up advanced manufacturing systems. In fact, such standards allow multiple proprietary component designs to coexist. An important economic impact is a substantial increase in competition at the component level, and therefore in design variety and price advantages for the user. Moreover, interface standards greatly increase the efficiency of systems integration: (a) by substantially reducing the cost of physically- and functionally-interfacing components from different manufacturers to form an optimal system for a particular user, and (b) by allowing efficient substitution of more advanced components as they become available over time, thereby greatly reducing the risk of obsolescence. With reference to the case study, widespread factory automation as it is evolving in advanced economies would likely not occur without these standards.

As the case study indicates, standardization is not an all or nothing proposition. In a complicated systems technology such as communications or, as examined here, factory automation, standardization proceeds sequentially, presumably in lock-step with the evolution of the technology embodied in individual components as well as with the disembodied technology of the overall system architecture. The implication is that the amount or degree as well as the timing of standardization is important for the effective diffusion of a technology. In the case of NC machine tools, total standardization of data formats would have severely compromised the range of performance attributes desired by different users in the machine tools they purchased. Thus, a "degree" of standardization has been optimal, at least up to this point in the technology's evolution.

Finally, having the necessary standards in place at the appropriate points in time relative to the technology's development can be critical for a domestic industry's international competitive position. If several firms from a competing nation can show compliance with a set of standards, the advantages described above accrue to the domestic users doing business with these firms, so that market shares may shift away from domestic suppliers.

In sum, standards are pervasive in many of the emerging technologies which will collectively dominate industrial structures and international trade in the coming decades. They are therefore an essential element of corporate strategic planning and government growth policy. Even though most standards are set voluntarily by industry, they are based to a significant degree, on nonproprietary infratechnologies and are competitively neutral elements of industrial activity. Thus, their provision requires a direct government role in the underlying infratechnology research.

REFERENCES

LINK, A.N. (1987). *Technological change and productivity growth.* London: Harwood Academic Publishers.

LINK, A.N., & TASSEY, G. (1987). *Strategies for technology-based competition: Meeting the new global challenge.* Lexington, MA: D.C. Heath.

U.S. BUREAU OF THE CENSUS. (annual). *Metalworking machinery,* (MQ-35W). Washington, DC: Government Printing Office.

U.S. BUREAU OF THE CENSUS. (annual). *U.S. imports for consumption and general imports,* (FT-246). Washington, DC: U.S. Government Printing Office.