The Impacts of Technical Standards on Global Trade and Economic Efficiency

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1. Introduction

The globalization of the technology-based economy offers substantial opportunities in the form of larger and more diversified markets that create higher profits and worker incomes than are available in other sectors. At the same time, more competitors are being created as individual economies seek to acquire shares of existing and emerging high-tech markets.

Such competition is being enhanced by recent major trade agreements, in particular, the Trans-Pacific Partnership (TPP) and the Transatlantic Trade and Investment Partnership (TTIP). The broad scope of such agreements, both in terms of national economies covered and scope of economic activity affected, will enable the evolution of truly global markets. The economic benefits are potentially huge. Removal of trade barriers facilitates the establishment of competitive industries in a large number of national economies resulting in substantial gains in overall global economic efficiency and consequent increases in the standard of living for workers. The bottom line is that the nature of modern technologies is such that ample opportunities exist for many economies to successfully participate in global markets with each one adopting specific targets of expertise that will pay off in terms of greater economic growth in domestic output, corporate profits, and incomes for workers.[1]

However, the realization of such advantages will only be achieved if (1) individual economies identify and invest in industries within the broader global supply chain where they can achieve comparative advantage, (2) a technical infrastructure, largely based on standards, is developed and implemented to ensure efficient product portfolio development, production, and commercialization for each economy's selected strategy, and (3) the standards infrastructure is uniform across all economies involved in the global supply chain. Doing so efficiently maximizes global economic growth and welfare.

Critically important is the fact that the above characterization implies a public-private asset growth model. Therefore, given the high costs and risks of developing specific technologies and commercializing them on a global scale and the high costs of establishing the technical infrastructure needed to support a domestic industry capable of competing in global markets, it is essential that investment decisions be based on variables that reflect (1) the complex *systems nature* of modern technologies and (2) the required public and private sector roles for providing the supporting *technical infrastructure*.

The fact that technologies are complex systems means that they are composed of a large number of hardware and software components. This opens up a substantial number of markets for the various components of such systems. Economies can choose to develop expertise in a subset of these markets and compete effectively—as long as the second requirement, an effective technical infrastructure, is in place to define functional interfaces among the components of the global technology system.

That is, if these interfaces are consistent across the global economy, i.e., effective global standards are in place, national economic strategies can be targeted at components for which domestic expertise exists or can be developed. Such a situation is particularly advantageous to smaller economies that only have the resources to compete in a few components of a much broader technology product system. However, the rapid expansion of global technology-based competition means that even the largest economies must adopt some degree of technology specialization.

More broadly, the economic role of interface standards as described above is only one of a number of roles for standards that are required by technologically advanced industries. In fact, standards are a ubiquitous technical infrastructure. As described in more detail below, the development of individual components or system integration activity within a particular domestic economy also needs global standards such as materials characterizations, equipment calibrations, and data format standards that not only increase productivity but assure domestic customers and those in other economies that a component will perform as desired within the broader product system technology. Collectively, they significantly affect the "expansion path" of a technology (direction, scope, and speed of its evolution). The U.S. semiconductor industries

[1] See https://en.wikipedia.org/wiki/Transatlantic_Trade_and_Investment_Partnership and https://en.wikipedia.org/wiki/Trans-Pacific_Partnership for more detail and reactions by stakeholder groups.

have over 1,000 standards covering the various categories identified above. Without them, these industries could not exist.[2]

Thus, standards affect the efficiency of the entire cycle of technology-based economic activity. Because of increasingly intense competition, their timing as well as their quality are crucial to efficient development, commercialization, and expansion of markets for new technologies.

Their aggregate impact on economic efficiency is increasingly needed. According to a 2015 report by the McKinsey Global Institute (MGI), the declining rate of population growth and hence the prime working age population in the United States will require an 80 percent increase in the rate of productivity growth over the next 50 years to enable the same average rate of GDP growth of the past 50 years. Specifically, to compensate fully for slower employment growth, productivity growth would need to be 80 percent faster at 3.3 percent a year (from an average annual growth rate of 1.8 percent) to achieve the same average annual growth in GDP of the previous 50 years (Manyika et al, 2015).

Such demographic trends are becoming a worldwide phenomenon. Therefore, to achieve the needed acceleration in global productivity, more investment in technology will be needed and the efficiency of its development and use will have to be increased. In response, annual global R&D is now approximately $1.5 trillion. However, such investment is imposing management challenges on domestic economies to manage R&D investment more efficiently. In addition, the results of the R&D must be quickly transferred into efficient production processes.

In this context, standards have significant implications for regional economic trade agreements. Specifically, their structure directly affects the potential economic benefits from such agreements because access to global markets for all competitors requires conformity to a single set of standards. Nonconforming economies will find transaction costs associated with doing business in global markets to be prohibitively high.

In summary, the fundamental role of multinational trade agreements such as the TPP and the TTIP is to eliminate tariff and non-tariff barriers across substantially all trade categories, which includes goods, services and investments in productive assets. The ultimate objective is to integrate national markets into regional ones and thereby realize greater efficiencies by facilitating specialization on the supply side and the realization of economies of scale through access to larger markets. Individual domestic economies will realize greater market opportunities and easier access to critical inputs, thereby promoting innovation, productivity, and overall competitiveness.

However, such globalization of supply chains and related markets poses a threat to domestic industries protected through previously erected trade barriers. Inefficient industries will have to be restructured and domestic workers will have to be reskilled, in order for targeted comparative advantages to be realized. Thus, the removal of tariffs and quotas will initially cause shifts in location of various high-tech products and services, as effective relative prices adjust. Such

[2] The SEMI International Standards Program lists almost 1,100 standards for semiconductor industries. See http://www.semi.org/en/sites/semi.org/files/data15/docs/ContentsbyTopic0615.pdf.

“transition costs” must be managed by each economy and the international organizations overseeing implementation of trade agreements

2. The Economic Roles of Standards and their Use in High-Tech Industries

As indicated by the above discussion, high-tech industries rely on standards to perform a number of functions at all stages of economic activity. Specifically,

(1) R&D Efficiency. R&D requires measurement and test methods, science and engineering data bases that allow accurate characterization of materials, as well as data formatting and classification frameworks that allow new technologies to be transferred to subsequent steps in the innovation process.

(2) Production Efficiency. Production requires standards to monitor and control processes for quality and yield through such functions as equipment calibration and real-time machine performance monitoring and adjustment.

(3) Variety Reduction. Where large economies of scale are important, product variety reduction may be necessary to achieve acceptable price points.

(4) Commercialization. Innovation and subsequent market penetration require product acceptance standards to reduce transaction costs that can become excessively high when trying to buy or sell complex products, as buyers assurance of adequate component and system performance before consummating purchases.

(5) System Integration. Efficient integration of hardware and software components requires standardized interfaces to allow competition and hence maximum innovation at the component level, which, in turn, increases the productivity of the final technology system.

As a consequence, the growing importance of technology-based economic growth for increasing productivity is beginning to force systematic attention on the role of technical infrastructure, including standards. However, standards have considerable public-good content in that a standard by definition is commonly used by both competitors and their customers. Thus, although standards are ubiquitous in technology-based industries, their public-good content can greatly constrain their *quality* and the *timing* of availability.

Further complicating the standardization process is the fact that the technical bases for industry standards, “infratechnologies,” can be partially excluded from the set of stakeholders (involved suppliers and consumers), at least for periods of time. This is because the underlying intellectual property rights (IPR) can be owned/controlled by individual firms or groups of firms, which allows them to influence the structure of standards and/or their use. This situation is often manifested in the formation of competing market segments that adopt their own versions of a generic standard. In the case of global markets, such segments are frequently individual economies.

When standards first began to be used more than a century ago, they were almost exclusively product standards (either the entire product or a component). As product technologies have become more complex (i.e., intrinsically intricate systems of hardware and software), more and more standards have become needed to specify processes and procedures across all three stages of economic activity (R&D, production, and commercialization/market transactions). It is important to note that the vast majority of these new functions of standards are nonproduct in character. Functions (1), (2), (4), and (5) are nonproduct standards. Function (5) is also significant in that it has a pronounced effect on location because it enables specialization.

Product Standards. Product-element standards focus on one of the key attributes or "elements" of a product, as opposed to the entire product. That is, the product as an entity is not standardized. When a product is new, i.e., an innovation has recently occurred, most or even all product attributes are fluid. As time goes on, competitors enter the market with competing designs. With subsequent growth in the aggregate market for the product, users begin to resist excessive diversity because substitution (switching) costs can be high and economies of scale—and hence lower prices—are not realized. Eventually, therefore, one or more major attributes of the generic product technology achieves dominant market status and becomes a *de facto* standard (Function 3).[3]

As implied above, market dynamics usually determine the timing of product-element standards and the sources of scale and scope economies determine the product element to be standardized. The evolutionary process by which a product element becomes standardized is important because standardization of the design of the entire product is increasingly unlikely in an era of complex system technologies where complexity facilitates competition among suppliers and better serves the increasingly heterogeneous demand of users. In fact, complete standardization would most likely mean "lock-in" to a dominant supplier, which would be a suboptimal result (David and Greenstein, 1990).[4]

Frequently, alternative technologies compete until one version gains sufficient market share to become the single *de facto* standard. If the innovator is a large firm, its market control can subvert the competitive process by which a product-element standard is achieved. Such control can accelerate increasing returns by forcing acceptance of the monopolist's proprietary technology element as the standard. However, the globalization of high-tech markets with more competitors is making single-firm dominance more difficult. In response, various combinations of vertical and horizontal consortia are promulgating product-element standards by consensus, at least within a single large economy or a regional trading block.

Non-Product Standards and System Productivity. Functions (1) (2), (4), and (5) in Table 1 all leverage economic efficiency at one or more of the major stages of technology-based economic activity. Because they are product-technology neutral, their existence leverages the efficiency of

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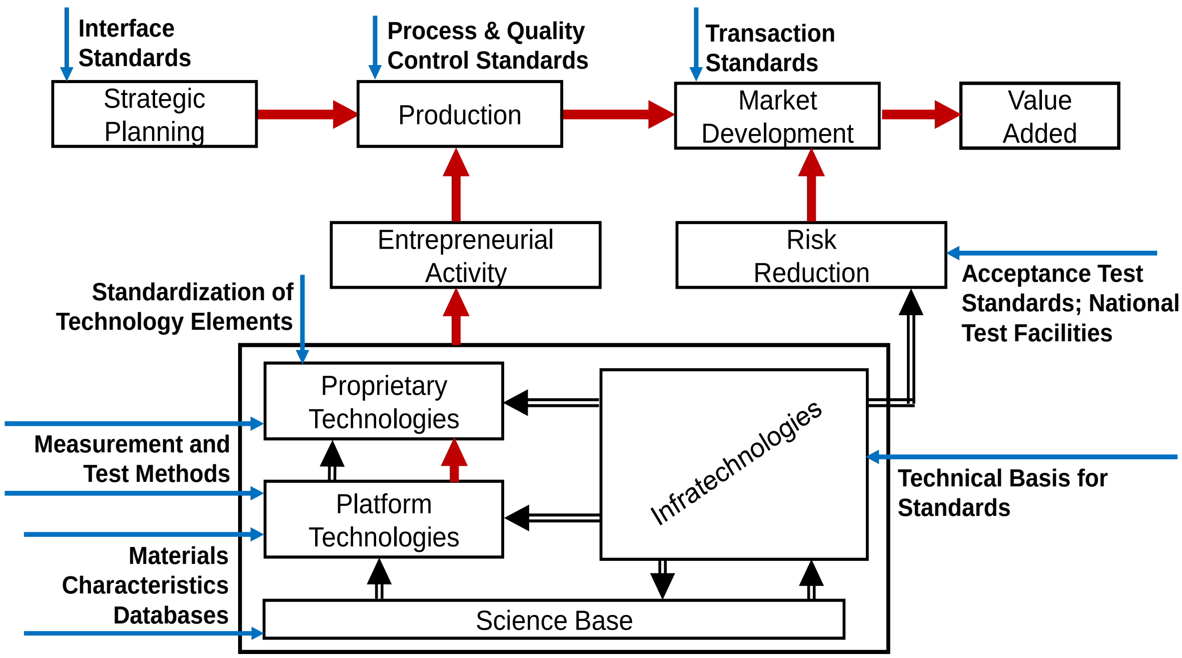
[3] An example is the architecture of a microprocessor, which refers to the layout of components within a computer's central processing unit (CPU). A microprocessor's architecture drives the structure and function of the other components of a computer and all software that runs on it. This situation means consumers will incur significant "switching" (re-learning) costs, if the decision is made to adopt an alternative computer technology platform. The growing number of existing users attracts new users who can interact with (learn from) existing users and a growing infrastructure. This process leads to the lock-in phenomenon.

[4] Occasionally, a single product element standard is imposed on an industry to ensure economies of scale. An example is the specification of the number of lines of resolution for HDTV broadcasts (see http://en.wikipedia.org/wiki/High-definition_television).

all participants in global markets. Without such standards, the evolution of a technology will be significantly retarded as costs at each of the three stages of technology-based economic activity will be high. Figure 1 indicates the multiple types of non-product standards and the points in the

Figure 1 Roles of Non-Product Standards in Technology-Based Industries



Source: Tassey (2015)

technology development and commercialization process where each type of standard delivers its infrastructure role. The thin solid (blue) arrows indicate the points of impact, while the thick solid (red) arrows show directions of proprietary technical knowledge flows. The double stem thick arrows indicate flows of public technical knowledge (often in the form of standards).

3. The Interaction of Global Market Structure and Standardization

Local vs. Global Product Standards for Single Markets. Changes in the nature a technology over its life cycle result in iterative changes in both rate and nature of standardization and also in market structure. For example, early in a technology's evolution, global product standards are hard to achieve because technological content is changing, which can lead several versions of the product technology co-existing. As a result, submarkets often evolve around existing versions of a product standard (referred to as "local" standards). Alternative versions can exist for some time and historically have evolved within large economies, which are frequently the innovators of new technologies and have large diversified internal markets. Today, however, increasingly intense global competition is shifting the meaning of "local" to individual competing economies.

On the one hand, the competition among submarkets helps sort out the most productive technology alternatives, which eventually maximizes economic welfare. On the other hand, scale economies are not realized and customers are faced with the risk of choosing the wrong local standard (the risk that it doesn't become the eventual global standard). The "risk" is the potential to incur high costs incurred in switching between local standards relative to perceived benefit accruing to users. These switching costs are perpetuated when suppliers with monopolistic control of portions of the market for the generic product (such as a computer) fail to agree on a single standard for a complementary product (such as a computer operating system).

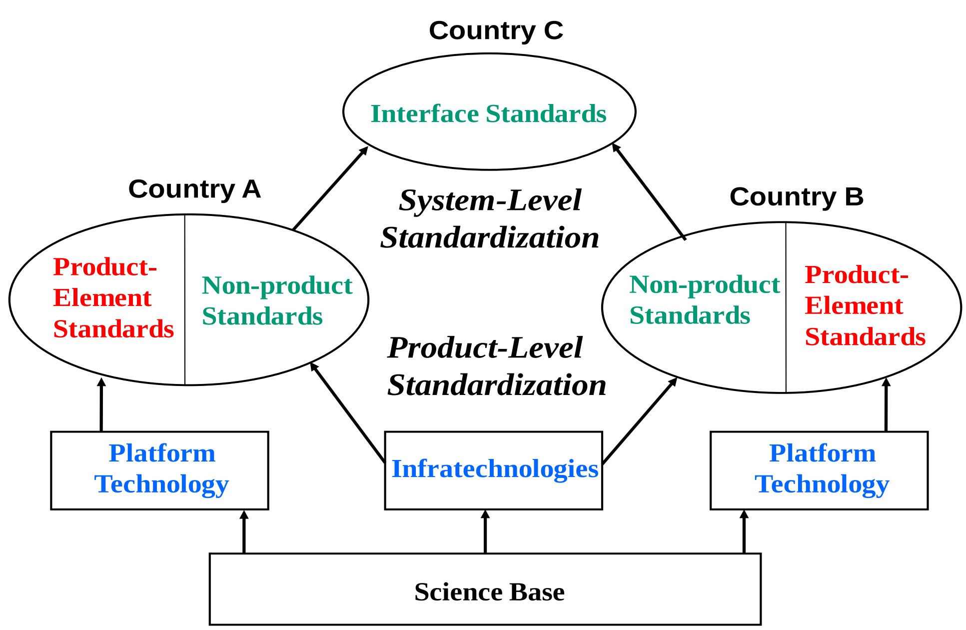
Within national economies, companies participate in organizations that set industry standards, while at the same time they are developing and marketing products based on proprietary standards. These firms have installed bases of customers and are attempting to gain global market leadership by forcing/enticing the rest of the global industry to accept their standards.

Initially, one or even several of these competing domestic economies may maximize profits subject to the efficiency constraints of local standards. However, long-run global profits will be diminished as aggregate growth is constrained by customer dissatisfaction and hence reduced demand resulting from (1) lack of price competition and (2) lower productivity from an inability to optimize system design by integrating components from a larger number of vendors in other economies whose market participation would be made possible by standardized interfaces.

In contrast, a local standard can sometimes rapidly become the global standard due to aggressive marketing by the innovator or initial buy-in by a large user. The resulting increasing returns can result in a monopoly position for the innovator. While economies of scale are realized quickly, the probability is high that this version of the technology is not the optimal one. Further, if the product happens to be an especially critical component, the monopoly can be extended into related component markets; that is, the component innovator can evolve into a "turnkey" product system supplier.

The general industry supply chain framework for these interactions is depicted in *Figure 2*. Platform technologies provide the conceptual basis for specific product innovations, which include product attributes that eventually become standardized (examples: microprocessor

Figure 2 The Structure of Industrial Standardization



architecture and HDTV broadcast system specifications such as frame size, scanning system, and frame rate). Infratechnologies provide (1) the technical basis for a range of measurement and testing methods, equipment calibration procedures, evaluated science and engineering data, etc., at the component industry level (Countries A & B) to enable R&D and production efficiency; (2) interface standards at the system integration level to enable efficient system design and integration (Country C); and, (3) efficient market transactions (countries A and C and countries B and C).

One issue raised by this framework is whether system-level standards are simply the result of the aggregation of specific product-element standards, or do they have a structure based on the intrinsic nature of the system technology. The reality is that a technology system is determined to a significant extent by the structure of its components, but system design also drives both component structure and the interfaces among components (Jervis, 1997 and Meadows, 2008). Thus, economies where system design/integration is located will have considerable influence on both product and non-product standards.

The lack of conformity to interface standards by the supply side of a market can be a conscious strategy or a reflection of the poor quality of the standards. Large firms with market strategies focusing on turnkey systems have an incentive to resist open systems to protect their market shares resulting from their horizontally integrated strategies. In cases of increasing returns, such strategies may result in a monopoly position being attained by one supplier or prolonged market segmentation by several competing suppliers. Either situation has the potential to constrain economic efficiency (David and Greenstein, 1990). Yet, some economies will condone or even encourage the belief that local (national) standards will retain more value added within the domestic economy.

Clearly, the industry structure impacts from global standardization have important effects on the achievement of individual national economic growth objectives. "Open systems" allow small and medium companies in all economies to participate in markets for system technologies by supplying components in which they have a competitive advantage. This diversification on the supply side of the market allows system optimization by users (increases productivity) and greater price competition (lowers costs).[5] Trade pacts facilitate this approach to the detriment of nonparticipants.

It should be noted that in rare cases, open and closed systems coexist. The most prominent example is the smart phone. Apple is the innovator and, based on its early monopoly position, adopted a closed system. That is, it is the sole provider of phones based on its operating system (OS X) and controls all applications that run on it. In contrast, Google's (Alphabet's) Android is a "quasi-open" operating system that smart phone developers, such as Samsung and LG, can cheaply license to produce their own line of phones. However, Android companies' phones are not interoperable; that is, applications from one company's phones will not run on another

[5] In the case of information infrastructures, attaining truly open systems has been extremely difficult. One of the major reasons for this difficulty is the complexity of IT systems technology. Each one of a number of layers in the hierarchical structure of a typical information system must have its own architecture and these architectures must be integrated into a larger network. Today, systems technologies not only have complex hardware and software platforms, but require "portability" rules and protocols to manage information flows.

company's phones. Still, this quasi-open system strategy has resulted in a collective global market share that is much larger than Apple's (Tassey 2015).

Finally, because many standards exist within modern technology systems, standards development cannot take place totally from the bottom up. For example, two machines can be made to communicate through interface standards. However, as more machines are added to, say, automate a factory (the "system"), chaos ensues without some overall "system architecture". An architecture provides an integrating force for all product-level standards in the system, driving the structure of the interfaces among the several layers constituting the control hierarchy of the automated factory.

In summary, the interactions over a technology's life cycle between technology elements and types of standards (Figure 1) are complex. As described, the potential benefits of standardization are significant. However, inappropriate use of standards can result in negative economic effects, such as restricting global competition by promulgating standards that favor certain proprietary domestic technologies. Further, standards in high-tech industries frequently are based on intellectual property rights (IPR) of one or several companies, who can withhold the IPR in an attempt to maintain monopoly positions or they can extract monopoly rents for its use in the standard. Finally, as technologies are increasingly complex systems (Figure 2), system design will drive standardization simultaneously with standardization at the product/component level.

4. Degree and Timing of Standardization

From both the corporate strategy and public policy points of view, standardization is not an all-or-nothing proposition. In complicated system technologies, such as distributed data processing, telecommunications, or factory automation, standardization typically proceeds in an evolutionary manner in lock step with the evolution of both embodied and disembodied technologies. The pattern of evolution is determined by several factors: the pace of technological change embodied in each component category; disembodied technology development, which determines the overall system architecture and organization; and changes in market structure, which affect the incentives and ability to force the standardization process.

The evolution of numerically controlled machine tools would have suffered from early total standardization of data formats in that doing so would have severely compromised the range of performance attributes potentially available to different users in future generations of machine tools. This is because standardized data formats are used to compare and assess different vendors' products, so the format for comparison is developed based on current technology platforms. Investment in new platforms that might not be able to be evaluated by existing data formats would therefore be inhibited.[6] Thus, only a degree of standardization was initially optimal in the technology's evolution. The policy message is that complete standardization too early in a technology's life cycle can constrain innovation.

[6] The more performance oriented the standard, the less will be the risk of inhibiting innovation. See http://news.thomasnet.com/IMT/2001/05/18/the_move_toward/.

In contrast, delaying the decision of standardization of a critical product technology element can retard private investment and thereby impede realization of consumer and producer surplus. This situation creates an incentive to choose a standard early in the technology's life cycle.

The bottom line is that as technology-based systems become increasingly important and "windows of opportunity" for making successful investments in the associated markets continue to shrink, the relevant standards will have to be efficiently managed—both in content and in time. If a standard is fixed, even if it is competitively neutral, it will stifle the eventual introduction of new technology into the system. However, if the standard is updated frequently, then version consistency (forward mobility of standardization among current system components) can be a problem.

For example, efficient data processing and communications networks are possible only if standard interfaces are provided on all the communication paths in the network. Such interfaces need to be defined between application programs, data formats, network protocols, printer control codes, human/machine interfaces, and so on. But, these system elements are all evolving at different rates and therefore need updated interfaces at different points in time. Thus, with new technologies continuously being introduced into ever expanding networks, the pressure on the standards infrastructure to adapt is substantial.

The systems nature of the technology-based economy increases the importance of the need for all components of a system—both public and private—to be assessed within the context of not only their intrinsic performance but also how such performance affects the performance of the system—for it is the system that delivers the ultimate economic benefit. Moreover, a system's elements are all evolving at different rates and thus need updated interfaces at different points in time.

Further, just as modern systems technologies have a hierarchical structure, so must the associated set of standards (Figure 2). The evolution of component technologies drives the need for standardization at each level in the product system. Standardization at one level then creates demand for standards at adjacent levels in the system. For example, a numerically controlled machine tool is a system of components such as the controller and numerous sensors. The multiple interface standards involved in a machine tool allow modularization of the product, which permits custom design and prevents overall tool obsolescence. However, these standards must be linked by a common data format, if all components are to function together as an efficient system (Link and Tassey, 1987).

Within a technology system, the establishment of a new standard, no matter how well conceived, can be costly to comply with. For example, a new interface standard for electronic product data exchange can require conversion of existing databases, which can be time-consuming and expensive. Also, introducing such a data format standard may solve one problem (data exchange) but create another (security).

Within a technology life cycle, initial standards can be hard to modify/update due to time and cost requirements coupled with installed-base effects. This can be particularly true for standards such as those providing interoperability as markets grow and the number of participants increases. And, participants can include stakeholders other than producers and consumers (e.g., system consultants) who want to have a say in evolving standards. In summary, standards can facilitate innovation and subsequent market penetration. However, the content, timing and flexibility of standards have to be right or new technologies will have difficulty penetrating markets or even reaching the marketplace (Branscomb and Kahin, 1995).

Finally, within technology life cycles, a central characteristic of standards is that they remain relatively fixed across individual *product* life cycles that emanate from a particular technology platform. However, they typically change between generations of a technology and therefore must frequently be completely restructured when radically new technologies emerge.

With respect to the basic economics discussed earlier, once a product-element standard is set, network externalities are typically realized. However, the marketplace dynamics that result in one firm's version of the technology becoming the standard do not guarantee that this version is the optimal one. As the lock-in effect ensues, many developers of related products conform to the standard and purchasers of the standardized technology invest substantial resources in learning to absorb and use it as well as complementary technologies and infrastructures. These sunk costs create a reluctance to switch to a new standard and related cluster of technologies. Considerable resources are then allocated to an inferior technology, which can extend over long periods of time.[7]

As described above, the firm that controls the product-element standard captures increasing returns to scale as initial market penetration begets dominance. This may be an acceptable price for rapid market growth from an economic welfare perspective, as long as the standardized version of the technology element is at least a good one and sufficient opportunity exists for market forces to periodically replace the standard.[8]

Unfortunately, the tendency for modern technologies to have systems structures increases the economic consequences of the lock-in phenomenon. In particular, most technologies today have clusters of standards embedded in them. One, however, is frequently the dominant or driver standard. Thus, the controller of that standard can have even greater impact on the evolutionary development of the overall technology and related markets.

While lock-in affects the demand side, the installed base effect impacts the supply side. Dominant suppliers of a technology, who either control or adhere to the standard, have invested substantial resources in developing and servicing the markets based on this standard. Their established market positions promote evolutionary as opposed to revolutionary migration of customers, who demand backward mobility to existing technology.[9] Mobility is more difficult and expensive, the more radical the new technology. If Microsoft, Apple, and IBM were freed from

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[7] For more than a decade, DOS— a clearly inferior operating system to alternatives such as Apple Computer's operating system (Mac OS)—dominated the personal computing market because the Microsoft/IBM combination was able to lock in the PC market.

[8] Arthur (1996) provides an excellent analysis of the increasing returns-to-scale phenomenon that characterizes many technology-based industries and the consequent motivation for firms to set and control product-element standards.

[9] The "installed-base" and related "installed wisdom" effects can significantly delay adaptation to changing global economic conditions. See Tassey (2007, 2010).

maintaining compatibility with existing hardware and software, new generations of systems software would likely evolve at a faster pace.

5. Conclusion

The complexity of modern technologies has created the demand for an equally complex supporting technical infrastructure, implemented largely through a variety of standards affecting all stages of technology-based economic activity. These standards not only must be structured to promote access to the relevant markets for all competitors, but a management system must be in place to facilitate standards development and to assure proper timing of their implementation.

In contrast to local (intra-industry or national economy) standards, uniform multinational standards will lead to considerably greater global economic growth. Global standardization of the various functions of standards described in this paper will greatly increase economic efficiency, not only by opening new markets to domestic companies and the consequent realization of economies of scale but also by increasing the efficiency of domestic resource allocation through the promotion of specialization (comparative advantage) in specific technologies and related markets while also enabling efficient system integration across economies to achieve commercially successful innovative products and services.

However, it is also a fact that transitions from local/national to global standards will require new strategic foci and consequently new investment and commercialization strategies. Thus, given the relentlessly growing complex of modern system technologies, a complete and uniform set of standards for all stages of technology-based economic activity along with implementation assistance are essential to enable specialization and thereby include more companies from more economies in the global marketplace. Increasing breadth of participation will enhance innovation and overall economic efficiency, leading to greater economic benefits for the global economy.

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