# “INDUSTRIAL LEGISLATURES”: CONSENSUS STANDARDIZATION IN THE SECOND AND THIRD INDUSTRIAL REVOLUTIONS

by

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**Abstract**

Consensus standardization is a social process in which technical experts from public, private, and non-profit sectors negotiate the direction and shape of technological change. Scholars in a variety of disciplines have recognized the importance of consensus standards as alternatives to standards that arise through market mechanisms or standards mandated by regulators. Rather than treating the consensus method as some sort of timeless organizational form or ever-present alternative to markets or laws, I argue that consensus standardization is itself a product of history.

In the first two chapters, I explain the origins and growth of consensus standards bodies between 1880 and 1930 as a reaction to and critique of the existing political economy of engineering. By considering the standardization process—instead of the internal dynamics of a particular firm or technology—as the primary category of analysis, I am able to emphasize the cooperative relations that sustained the American style of competitive managerial capitalism during the Second Industrial Revolution. In the remaining four chapters, I examine the processes of network architecture and standardization in the creation of four communications networks during the twentieth century: AT&T's monopoly telephone network, the Internet, digital cellular telephone networks, and the World Wide Web.

Each of these four networks embodied critiques—always implicit and frequently explicit—of preceding and competing networks. These critiques, visible both in the technological design of networks as well as in the institutional design of standard-setting bodies, reflected the political convictions of successive generations of engineers and

network architects. The networks described in this dissertation were thus turning points in the century-long development of an organizational form. Seen as part of a common history, they tell the story of how consensus-based institutions became the dominant mode for setting standards in the Third Industrial Revolution, and created the foundational standards of the information infrastructures upon which a newly globalized economy and society—the Network Society—could grow.

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## Introduction

The standards bug bit me sometime in the late 1990s. I'm not sure exactly when it happened, but the symptoms were unmistakable: standards were everywhere I looked, and I began to see the world as a massive compilation of standards. It started with computers—why did the new machines have USB ports and Zip drives, and where was I supposed to put my 3.5 inch floppy disks?—but soon spread to almost everything else I noticed in my daily activities. Who decided if a #2 pencil is not a 3 or a 1.5? Why were all the cement bricks in the high school gym 8 inches by 16 inches? How was it that any telephone would work when I plugged it into the jack in the wall?

Although the presence of standards—once I noticed them—was puzzling, the *lack* of standards was infuriating. When my cell phone battery died, I couldn't use my friend's charger (or his battery) to power my phone. My web page looked fine on Netscape Navigator, but awful on Internet Explorer. The nuts and bolts aisle of Home Depot was utterly baffling, a vivid demonstration that the term "standard" could very well be somebody's idea of a sick joke. Andrew Tanenbaum, a Dutch computer scientist, captured the irony of the situation in his 1981 textbook *Computer Networks*: "The nice thing about standards is that you have so many to choose from; furthermore, if you do not like any of them, you can just wait for next year's model."[1]

My conclusion from this initial exploration was: standardization is the social process by which we come to take things for granted. Through standardization, inventions become commonplace, novelties become mundane, and the local becomes

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[1] Andrew S. Tanenbaum, *Computer Networks* (Englewood Cliffs, NJ: Prentice Hall, 1981), 168.

universal. It is, in short, the *historical* process by which discoveries are rendered into the material and immaterial substance of our everyday lives. The standardization process is lengthy, laborious, and often contested at every step. However, for standards to be successful, this contested process must be transparent (or at least opaque) so that the resulting standards are perceived as authoritative and objective. The history of standardization provides opportunities to explore this authority and objectivity and reveal how people sought to resolve fundamental tensions—scientific, economic, political, and cultural—as they laid the technological foundations of modern society.

In this dissertation I examine the creation of our modern communication networks—telephone networks, the Internet, digital cellular networks, and the World Wide Web—by keeping an eye on the standardization process. There are, of course, other ways to examine the history of these networks. Previous studies have mentioned standards in passing, but typically these analyses revolve around a particular person or company, a specific technology, the processes of invention and research, government regulation, or user adoption. While many of these studies are excellent, they often fail to examine what occurred within the black box of standardization.

My dissertation began with a hunch—that this history might look different if I adopted the standardization process itself as my primary unit of analysis. Standardization could be interrogated, not assumed. Because its effects are so pervasive, standardization provides an ideal vantage point for integrating insights produced by historians who have focused on other units of analysis—individuals, firms, innovation, regulation, adoption, and so on. Because they are crucial components of the infrastructure of modern society,

communication networks provide important examples of standardization in action, and are thus an ideal subject for this study.

One of the many ironies of standardization is that there are no standard definitions of what standards are, what they do, and how they are made. The term "standard" often refers to customs, norms, and regular social practices. In technical realms, however, it has more specific meanings that refer to documented practices. In my usage of the term, I follow a definition that the economic historians Paul David and Shane Greenstein articulated in a seminal 1990 article, in which they defined a standard as "a set of technical specifications adhered to by a producer, either tacitly or as a result of a formal agreement."[2]

Having adopted this basic definition of what a standard is, two fundamental questions remain: first, what do standards accomplish? And second, who makes standards? In response to the first question, theorists of standardization agree that most standards fall into three general categories: performance, measurement, and compatibility.

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[2] Paul A. David and Shane Greenstein, "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology* 1 (1990): 4. This section draws on a large body of literature that offer various versions of my general typology. See for example Carl Cargill, *Open Systems Standardization: A Business Approach* (Upper Saddle River, NJ: Paladin Consulting, 1997); Ross E. Chiet, *Setting Safety Standards: Regulation in the Public and Private Sectors* (Berkeley: University of California Press, 1990); U. S. Congress, Office of Technology Assessment, *Global Standards: Building Blocks for the Future* (Washington, DC: U.S. Government Printing Office, 1992); Geoffrey Bowker and Susan Leigh Star, *Sorting Things Out: Classification and its Consequences* (Cambridge: The MIT Press, 1999); and Urs von Burg, *The Triumph of Ethernet: Technological Communities and the Battle for the LAN Standard* (Stanford: Stanford University Press, 2001).

1. *Performance*: These standards specify ways to perform certain tasks. Performance standards seek to ensure a minimum level of quality by specifying either a *process*, such as the ISO 9000 "Quality Management Principles," or a *result*, such as a safe and accident-free workplace.

2. *Measurement*: These standards specify an objective quantifiable unit of measurement, such as a meter, a gallon, or ohm. Measurement standards make it possible for people to compare physical qualities, such as length, volume, or electrical current.

3. *Compatibility*: These standards define interfaces between discrete objects. Compatibility standards create efficiencies and economies of scale in the production process, and promote interoperability between complementary products. Interfaces between various components of computer hardware—as well as computer software—provide many familiar examples of compatibility standards, such as Universal Serial Bus (better known as USB) ports and the Ethernet local area networking protocols.

Two important concepts emerge when we consider these three types of standards in the context of communication networks. The first is what economists refer to as network externalities. Standards (especially compatibility standards) facilitate the connection of components into networks that provide electrical power, telephone service, and computer communication. In general, networks become more valuable as more people use them. In successful networks, externalities grow and are sustained by "positive feedback" (or "bandwagon effects"), which make large and valuable networks even larger and more valuable. Numerous strategic implications flow from this economic concept, and many books and articles have examined strategies for generating and capturing value from network externalities, as well as the process by which consumers get "locked in" to specific networks and the high "switching costs" they sometimes face

when moving to a competing network.[3] Further, some scholars argue that communication networks can be fruitfully understood as "information platforms" or "information infrastructure." Both metaphors indicate the potential for communication networks to sustain more advanced and complex social and economic activity.[4]

The second concept is actually a puzzle about the essential character of standards: are standards static or dynamic? This question invites philosophical reflection on uniformity and diversity. In Paul David's assessment, this puzzle "may be construed as nothing more and nothing less than the fundamental issue with which all social organizations are confronted: where to position themselves on the terrain between the poles of 'order' and 'freedom.'"[5]

Is standardization the tool of order and control? Or does it facilitate innovation and creativity? Numerous critics, most notably Aldous Huxley and George Orwell, imagined the homogenous and oppressive societies that would result if the logic of

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[3] See for example Paul A. David and W. Edward Steinmueller, "Economics of Compatibility Standards and Competition in Telecommunications Networks," *Information Economics and Policy* 6 (1994): 217-241; Michael L. Katz and Carl Shapiro, "Systems Competition and Network Effects," *The Journal of Economic Perspectives* 8 (1994): 93-115; Carl Shapiro and Hal Varian, *Information Rules: A Strategic Guide to the Network Economy* (Boston: Harvard Business School, 1999); and W. Brian Arthur, *Increasing Returns and Path Dependence in the Economy* (Ann Arbor: University of Michigan Press, 1994).

[4] Philip J. Weiser, "Law and Information Platforms," *Journal of Telecommunications and High Technology Law* 1 (2002): 1-35; Steven W. Usselman, Public Policies, Private Platforms: Antitrust and American Computing," in Richard Coopey, ed., *Information Technology Policy* (New York: Oxford University Press, 2004), 97-120; Richard R. John, "Recasting the Information Infrastructure for the Industrial Age," in Alfred D. Chandler, Jr. and James W. Cortada, eds., *A Nation Transformed By Information: How Information Has Shaped the United States from Colonial Times to the Present* (New York: Oxford University Press, 2000), 55-106; and Paul N. Edwards, Steven J. Jackson, Geoffrey C. Bowker, and Cory P. Knobel, *Understanding Infrastructure: Dynamics, Tensions, and Designs*, Report of a Workshop on "History & Theory of Infrastructure: Lessons for New Scientific Cyberinfrastructures," National Science Foundation, January 2007.

[5] Paul A. David, "Standardization Policies for Network Technologies: the Flux Between Freedom and Order Revisited," in Richard Hawkins, Robin Mansell, and Jim Skea, eds., *Standards, Innovation and Competitiveness* (Aldershot: Edward Elgar, 1995), 15-35.

standardization was left unchecked.[6] On the other hand, advocates of standardization argued that variation and standardization were the two processes that drove evolution and thus progress in both nature and society. In a 1924 essay, the safety advocate Albert Whitney suggested that

> Variation is creative, it pioneers the advance; standardization is conservational, it seizes the advance and establishes it as an actual concrete fact… Standardization is thus the liberator that relegates the problems that have already been solved to their proper place, namely to the field of routine, and leaves the creative faculties free for the problems that are still unsolved. Standardization from this point of view is thus an indispensable ally of the creative genius.[7]

On the whole, I am most convinced by Whitney's interpretation—that standardization is part of a dynamic and arguably evolutionary process that consists in part of the codification of existing knowledge.[8] However, critics are right to point out that authority figures can use standards to stifle innovation that does not suit their purposes. The three types of standards listed above—performance, measurement, and compatibility—help us to think more concretely about these philosophical dilemmas. All standards attempt to create a certain permanency, especially measurement standards. However, upon closer consideration it becomes clear that all standards—even measurement standards such as the meter or the kilogram—can be updated, revised, or overthrown as time passes and conditions change. This process of change, even for

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[6] Aldous Huxley, *Brave New World: A Novel* (Garden City, NY: Doubleday & Company, 1932); George Orwell, *Nineteen Eighty-Four: A Novel* (New York: Harcourt, Brace and Company, 1949).
[7] Albert Whitney, *The Place of Standardization in Modern Life* (Washington, DC: Central Executive Council, Inter American High Commission, 1924), 5.
[8] J.S. Metcalfe and Ian Miles, "Standards, Selection and Variety: An Evolutionary Approach," *Information Economics and Policy* 6 (1994): 243-268.

standards that are designed to be permanent, reminds us that standards are products of power structures that also change over time.

The second fundamental question posed above—who makes standards?—also reminds us that standardization is a power-laden process. On whose authority does something become "standard"? How are different types of standards created and enforced? In response to these questions, theorists have identified three different institutional origins of standards: *de facto*, *de jure*, and voluntary consensus.

1. *De facto* standards arise from common usage or market adoption. Individual people or single firms often generate these standards, which spread either through the efforts of a sponsor or in a more organic way. Two examples of *de facto* standards include Microsoft's word processing software and the QWERTY keyboard.

2. *De jure* standards are mandated by regulators at the local, state, federal, or international level. Governments commonly test *conformance* with mandated standards, and can legally (and at times severely) punish non-compliance. Two examples of *de jure* standards are the European GSM transmission standards for cellular telephones, and the American Federal Communications Commission Part 68 rules that govern the telephone terminal equipment.

3. *Voluntary consensus* standards are specified within a range of private institutions, including engineering societies, trade associations, accredited standards setting organizations, and industry consortia. *Consensus* refers to the collaborative and non-coercive process in which these standards are developed; *voluntary* indicates that nobody is legally compelled to adopt these standards. However, there can be strong economic incentives that encourage conformance with voluntary standards, and many parties involved in developing these standards make *a priori* commitments to adopt them. Two examples of consensus standards include the TCP/IP networking protocols and the HTML language for the World Wide Web. This is the central subject of my dissertation, and further examples will be provided in chapters 1-6.

In practice, these three styles of standardization co-exist, and have porous boundaries: for example, *de facto* standards frequently gain wider approval through voluntary consensus bodies, and consensus standards can be either referenced in government regulations or codified through government procurement specifications. Of these three styles, the voluntary consensus process is the most complicated and perhaps most important—a vital component of the American system of standardization that embodies the characteristically American preference for voluntarism, local control, and private control over commercial activity.[9]

Historians, sociologists, and economists all have studied standards that were created through a consensus process. This literature demonstrates that consensus standardization is a fundamentally *political* process, one where different stakeholders seek to exercise control over the direction and shape of technological change. Our technological world, therefore, needs to be understood as a consequence of the power negotiations and social tensions inherent in the creation of technical knowledge and artifacts, and we must not forget that "consensus" is as much about exclusion as it is about inclusion.[10]

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[9] U. S. Congress, *Global Standards: Building Blocks for the Future*, 45-50. See also Samuel Krislov, *How Nations Choose Product Standards and Standards Change Nations* (Pittsburgh: University of Pittsburgh Press, 1997), 83-133; Jay Tate, "National Varieties of Standardization," in Peter A. Hall and David Soskice, eds., *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage* (New York: Oxford University Press, 2001); and Andrew L. Russell, "Industrial Legislatures: The American System of Standardization," in *International Standardization as a Strategic Tool* (Geneva: International Electrotechnical Commission, 2006).

[10] Janet Abbate, *Inventing the Internet* (Cambridge: The MIT Press, 1999); Amy Slaton, Reinforced Concrete and the Modernization of American Building, 1900-1930 (Baltimore: The Johns Hopkins University Press, 2001); Stefan Timmermans and Marc Berg, *The Gold Standard: The Challenge of Evidence-Based Medicine* (Philadelphia: Temple University Press, 2003); Theodore Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton: Princeton University Press,

My contribution to this literature is to point out that the consensus process *is itself a product of history*. Rather than treating the consensus method as some sort of timeless organizational form or ever-present alternative to markets or laws, we need to understand that consensus standardization arose under specific historical circumstances, and in response to specific technological, organizational, and political problems. It is an idea manifest in institutions. Moreover, this organizational form faced moments of crisis in which the survival of specific consensus standards committees were called into question. Some of these committees failed; others reformed themselves and survived. At all points, the system was in flux. It was dynamic, not static—and organizations that participated in the system were no less susceptible to the gale of creative destruction than were firms in competitive markets.[11]

My history starts in the late nineteenth century, when engineers and scientists created the first consensus standards bodies as a response to the inadequacies of existing institutions. The collaborative institutions and negotiated procedures in consensus standardization bodies matured during the first three decades of the twentieth century, not only as a response to the limitations of existing forms of technological cooperation but also as a political critique of these limitations. The creation of subsequent standard-setting bodies also advanced this implicit—and at times, explicit—critique: consensus

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1995); Peter Grindley, *Standards, Strategy, and Policy: Cases and Stories* (New York: Oxford University Press, 1995); Joseph Farrell and Garth Saloner, "The Economics of Telecommunications Standards," in Robert Crandall and Kenneth Flamm, eds., *Changing the Rules: Technological Change, International Competition, and Regulation in Communications* (Washington, DC: The Brookings Institution, 1989).

[11] Joseph Schumpeter, *Capitalism, Socialism and Democracy* (New York: Harper & Row, 1976 [1942]).

standardization was a technologically and politically superior means for coordinating technological change.

These critiques were particularly sharp during the 1920s, a decade in which Secretary of Commerce Herbert Hoover advocated greater cooperation within the private sector and between private and public organizations.[12] The leading forum for consensus standardization during this era was the American Engineering Standards Committee (AESC), a federation of engineering societies, trade associations, safety groups, and government departments. Members of the AESC created consensus standards within sectional committees that consisted of experts drawn from the public, private, and non-profit sectors and fell into technological categories, such as Civil Engineering and Construction, Electrical Engineering, and Ferrous Metals and Metallurgy. Paul Gough Agnew, the longtime Secretary of the AESC, described each committee as "a miniature industrial legislature organized upon a subject basis instead of upon a geographical basis."[13]

Agnew's term "industrial legislature" is a fitting title for this dissertation because it characterizes standardization as political economy—a topic at the intersections of economics, politics, and law. Agnew was experienced in all aspects of consensus standardization, worked tirelessly to promote consensus standards and the institutions that made them, and was one of the most vocal advocates of the cause. Throughout his career, Agnew argued that self-government among technical experts was superior to the

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[12] Ellis W. Hawley, "Herbert Hoover, the Commerce Secretariat, and the Vision of an 'Associative State,' 1921–1928," *Journal of American History* 61 (1974): 116–40.
[13] P. G. Agnew, "Work of the American Engineering Standards Committee," *Annals of the American Academy of Political and Social Science* 137 (May, 1928): 13-16.

adversarial, winner-takes-all style of rulemaking as practiced in the United States Congress and judicial system. For example, in an article published in the *New Republic* in 1926 he wrote:

> Experience in diverse fields has amply shown that the [cooperative] method combines many of the advantages of the common-law and the statutory-law methods… while it avoids many of the limitations and abuses that have grown up about the legislative process."[14]

We will explore these political and cultural critiques as we consider the technical and economic aspects of standardization. First, I will explain how consensus standardization originated during the Second Industrial Revolution as a reaction to the existing political economy of engineering. Second, I will build on that foundation an examination of the history of communications networks during the twentieth century from a standardization perspective. This history illustrates how successive generations of engineers and network architects adopted and adapted consensus standardization practices. What they did was and is today important. By the end of the twentieth century, these new networks—including the Internet, digital cellular telephone networks, and the World Wide Web—emerged as the core information infrastructure of the Third Industrial Revolution.

In Chapters One and Two I discuss the origins of the organizational form of consensus standardization. Chapter One contains a literature review built around three themes in the historiography of standardization: efficiency, power, and trust. In the late nineteenth century, scientists and engineers in the electrical and chemical industries

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[14] P. G. Agnew, "A Step Toward Industrial Self-Government," *The New Republic* (March 17, 1926), 95. Albert Whitney advanced a similar critique in "The Place of Standardization in Modern Life."

created the first consensus standards committees to solve technical problems that threatened the efficient development of telegraph and railroad networks. In the United States, the first consensus standardization committees brought together producers and consumers of technologies (such as steel rails) who came from different firms and industries. During this era, respected engineer/scientists such as Charles Dudley and Elihu Thomson leveraged their status in order to construct these committees as trusted and impartial forums. By considering standardization itself—instead of the internal dynamics of a particular firm or technology—as the primary category of analysis, I am able to emphasize the cooperative relations that sustained the American style of competitive managerial capitalism during the Second Industrial Revolution.

In Chapter Two I discuss the creation and growth of the American Engineering Standards Committee (AESC). The AESC was a national federation of standards setting organizations, created in 1918 through the joint effort of five professional engineering societies. During the 1920s, the AESC aligned its practice of consensus standardization with Herbert Hoover's "associative" vision, in which efficiency and cooperation between the public and private sectors were promoted as the keys to progress and prosperity. The AESC attracted significant interest from engineering societies as well as trade associations and safety groups: by 1928, individuals from over 350 organizations were participating in AESC "industrial legislatures." The AESC experienced growing pains during this period of rapid expansion. In response to demands that it work with greater speed and more flexibility, it reconstituted itself into the American Standards Association in 1929. The conspicuous omission of the word "engineering" from the group's new title

indicates the extent to which control over standardization had spread from the domain of scientists and engineers into the domain of corporate executives and trade associations.

In the remaining four chapters I examine the processes of network architecture and standardization in the creation of new communications networks during the twentieth century. These chapters discuss four examples: AT&T's monopoly telephone network, the Internet, digital cellular telephone networks, and the World Wide Web. I do not treat these examples as isolated networks, or merely as sites to compare and contrast divergent strategies for developing new standards. Instead, I link these four examples within a longer historical narrative, one that shows how individuals adapted and changed the practice of consensus standardization in ways that suited their needs in a particular time and place. When viewed in historical succession, these examples reveal a process of "learning by doing" in which we can see refinements to and permutations of the core ideas and institutions of consensus standardization.[15] These examples also illustrate the variety of organizational forms in the "middle ground" between *de facto* and *de jure* standardization, as well as the instability and tensions that scientists and engineers confronted within consensus standard-setting bodies.

Further, each of these examples illustrates a central argument of this dissertation: that new networks were designed as critiques of their predecessor networks. These critiques are visible both in the technological design of networks as well as in the design of the institutions created to sustain the standardization process. In each chapter, I shed light on these critiques, which were always implicit but frequently explicit. These

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[15] Naomi R. Lamoreaux, Daniel M. G. Raff, and Peter Temin, eds., *Learning by Doing in Markets, Firms, and Countries* (Chicago: University of Chicago Press, 1999).

critiques reflected the ideological convictions of their network architects, who were responding to the specific challenges and opportunities of their own historical situations.

In Chapter Three, I examine standardization within the archetypical regulated monopoly, the American Telephone and Telegraph Company (AT&T). From the very beginning, American telephone networks were designed as a political critique of Western Union's telegraph network. Gardiner Hubbard, who backed Alexander Graham Bell's initial telephone patents and created the Bell Telephone Company in 1877, believed that Western Union's telegraph monopoly concentrated too much power among business elites. Telephones, in Hubbard's view, presented opportunities for middle-class Americans to gain access to the information they needed to be prosperous citizens and to make American democracy successful.[16] In the late nineteenth and early twentieth centuries, AT&T executives such as Edward J. Hall and Theodore N. Vail rejected the notion that the telephone industry should be divided between competitors. Instead, they sought to create a standardized national network over which they would exercise monopoly control—"One System, One Policy, Universal Service."[17] AT&T engineers were obsessed with standardization as they assimilated local and regional systems into a national network. Beginning in the 1920s, AT&T engineers, led by their Vice President and Chief Engineer Bancroft Gherardi, also began to participate in consensus standards

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[16] W. Bernard. Carlson, "The Telephone as Political Instrument: Gardiner Hubbard and the Political Construction of the Telephone, 1875-1880," in Michael Thad Allen and Gabrielle Hecht, eds., *Technologies of Power: Essays in Honor of Thomas Parke Hughes and Agatha Chipley Hughes* (Cambridge, MA: The MIT Press, 2001), 25-55.

[17] Theodore N. Vail, *Annual Report of the Directors of American Telephone and Telegraph Company to the Stockholders for the Year Ending December 31, 1909* (Boston: Geo. H. Ellis, Co., Printers, 1910), 18.

bodies and learned to use these bodies to attack critical problems that they could not resolve inside the Bell monopoly.

In Chapter Four I examine the development of a new global communications infrastructure that used electronic computers as communication devices. In the second half of the twentieth century, researchers in the United States and Europe designed new networks that, in stark contrast to the circuit-switched networks ruled by the national telephone monopolies, utilized electronic computers and digital packet-switched transmission. The American effort, led by Robert Kahn and Vinton Cerf, was at first funded by the Department of Defense, and eventually developed into the Internet. The European effort was coordinated by the International Organization for Standardization (ISO), a standard-setting body that consisted of representatives of national governments around the world. Although most experts assumed that the ISO network architecture would become the global standard, users found that they could adopt Internet standards more quickly and easily. The Internet's victory in this "standards war" was a function of its informal methods for creating standards. On the other hand, ISO's effort failed because its consensus-building efforts suffered from excessive bureaucracy: too much consensus, it seems, can hinder the speedy production of standards.[18]

In Chapter Five I again contrast American and European efforts to build new communications networks—in this case, digital cellular networks. In both places, fundamental changes in regulation shaped the technological and strategic choices that engineers made. With the demise of regulated monopoly control in both settings,

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[18] Roy Rada, "Consensus Versus Speed," *Communications of the ACM* 38 (1995): 21-23.

engineers and regulators were forced to create new institutions to coordinate the production of new standards and new networks. European engineers designed their network—the Global System for Mobile Communications (GSM)—to enable users to stay in touch while they "roamed" across national borders. Unlike the ISO effort to create a computer network architecture (discussed in Chapter Four), pan-European technical cooperation for digital cellular standards was a successful diplomatic initiative to establish a common European market.

In the United States, political change influenced the standardization process in a completely different manner. American regulators, having dismantled the AT&T telephone monopoly in the early 1980s, refused to mandate a digital cellular standard or network architecture. Instead, they decided that market forces were the best means for creating new digital cellular standards—an implicit critique of the conditions of regulated monopoly that had prevailed in the American telecommunications industry since the early twentieth century. This regulatory restraint, combined with the divestiture of AT&T, created a temporary leadership vacuum in the nascent cellular industry that was soon filled by a number of trade associations and technical bodies. The resulting delay allowed the European GSM standard to become the global leader over the short term. However, by refusing to lock all American firms into the development of a single standard, the American decision provided venues for continued radical innovation, a process which seems likely to generate greater technological and economic benefits—as well as a new generation of legal problems—over the long term.

In Chapter Six I examine the creation and growth of a new institutional form to coordinate consensus standardization—industry consortia—during the 1980s and 1990s. Because they limited participation and focused narrowly on specific technologies, consortia provided opportunities for firms to create standards much more quickly than could traditional consensus bodies—an important feature for fast-moving markets for information and communication technologies. These advantages, however, were accompanied by claims that standards violated existing patents or so-called "submarine patents" disclosed late in the standardization process or after the process was completed.

The history of one such consortium, the World Wide Web Consortium (W3C), illustrates some of these problems. In 1994, Tim Berners-Lee, the inventor of the World Wide Web, created the W3C in order to maintain his authority in the rapidly expanding Web community and prevent the balkanization of new Web standards. The Web grew successfully during the 1990s because Berners-Lee built the Web based on non-proprietary and freely available standards, but in 2001 the W3C proposed to change this tradition and allow patents into Web standards. Open source Web developers protested furiously. They threatened to look for new venues to develop their own non-proprietary Web standards. Faced with this renewed danger of balkanization, the W3C responded by forging a patent policy consistent with its founding values and the patent-free convictions of open source programmers. The W3C was able to maintain its legitimacy during this crisis, but its leading position in the market for Web standards remained under constant attack from competing standards organizations—each operating with its own definition of "consensus" and most willing to accept patents in its standards.

Seen as part of a common history, these examples illustrate a striking trend in the political economy of technological systems. In the Second Industrial Revolution, systems such as electrical power networks and telephone networks were developed within individual firms, led by entrepreneurial "system-builders" such as Thomas Edison and Theodore Vail.[19] By the late twentieth century, the combined effects of technological and regulatory change presented fundamental challenges to this centralized style of system architecture. The design of computer systems that utilized electronic components occurred within an increasingly decentralized and highly competitive industry structure. The firms that had once exercised complete control over system architecture—AT&T and IBM—were hindered by antitrust and agency regulations that strove to facilitate competitive entry. They now missed opportunities to pursue radical innovations. The locus of control over compatibility standards changed from the domain of the dominant single firm to the domain of industry standards bodies, thus facilitating the emergence of a new style of global "alliance capitalism."[20]

This change—from systems innovation to modular innovation—not only occurred within a broader trend of social and economic globalization. It was, in fact, one of the

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[19] Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: The Johns Hopkins University Press, 1983).

[20] Thomas McCraw, ed., *Creating Modern Capitalism: How Entrepreneurs, Companies, and Countries Triumphed in Three Industrial Revolutions* (Cambridge: Harvard University Press, 1995); and Alfred D. Chandler, Jr., "The Information Age in Historical Perspective: Introduction," in Alfred D. Chandler, Jr. and James W. Cortada, eds., *A Nation Transformed By Information: How Information Has Shaped the United States from Colonial Times to the Present* (New York: Oxford University Press, 2000), 3-38; and Louis Galambos and Eric John Abrahamson, *Anytime, Anywhere: Entrepreneurship and the Creation of a Wireless World* (New York: Cambridge University Press, 2002).

drivers of globalization, and it created the information infrastructure upon which a newly globalized economy and society—the "Network Society"—could grow.[21]

The networks described in this dissertation were thus turning points in the century-long growth of an organizational form that was responsible for fundamental changes in the history of the twentieth century. The networks were simultaneously extensions and critiques of the Industrial Age. Viewed together, they tell the story of how consensus-based institutions became the dominant form for setting standards in the Third Industrial Revolution. They reveal the growth of a political economy within a political economy, designed to accomplish what existing forms of governance and engineering could not. These network architectures—and the institutions created to sustain them—were political statements, critiques of the existing order, and innovations that articulated a different vision of the future and new means of getting there.

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[21] Richard N. Langlois, "Modularity in Technology and Organization," *Journal of Economic Behavior and Organization* 49 (2002): 19-37; Manuel Castells, *The Rise of the Network Society* (Cambridge: Blackwell Publishers, 1996); Akira Iriye, *Global Community: The Role of International Organizations in the Making of the Contemporary World* (Berkeley: University of California Press, 2002); Louis Galambos, "Recasting the Organizational Synthesis: Structure and Process in the Twentieth and Twenty-First Centuries," *Business History Review* 79 (2005): 1-37; and Louis Galambos, "Globalization, Competition, and *The Information Age* of Manuel Castells," unpublished manuscript, courtesy of the author.