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THEME 1:

INFORMATION AND COMMUNICATIONS TECHNOLOGIES FOR ECONOMIC DEVELOPMENT

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INFORMATION AND COMMUNICATIONS TECHNOLOGIES
FOR ECONOMIC DEVELOPMENT

Information and communications technologies have clearly reached star-status on every developed country's economic agenda. By the products and industries they directly generate, through the structural transformation they permit and provoke, electronics have become a powerful agent of economic development. Clearly however, the current transformation, based on the diffusion of electronics-based systems, will not rejuvenate all economies automatically, nor will it affect all countries equally. Differences in national industrial legacies, economic structures, and governmental policies will matter greatly to the implementation of the technologies' potential.

The purpose of this note is not to prescribe specific policies, but rather to propose a framework and to outline issues for discussions that can inform policy development. Rather than attempting to spell out all-encompassing --and necessarily limited-- theories, we relie extensively upon examples and sector studies. Their stories provide concrete evidence of the constraints and implications of various policy choices.

The major economic development potential of information and communications technologies lies in the diffusion of their products and processes throughout the economic fabric. Ultimately, diffusion is a market process. Therefore, it cannot be imposed, nor prescribed by policies. Policies aimed at the diffusion of electronics will be one element, not always a major one, of the environment within which firms make decisions about production technologies, production processes, and product design. Policy development must therefore procede from an understanding of this environment and its internal dynamics.

If technology diffusion is to be the overarching policy goal, governments have an important role to play in facilitating access to the technology, in preparing the grounds for its diffusion, in stimulating its implementation. We chose here to organize the discussion around five major issues. Each one of these five issues is analyzed through a particular segment of the electronics industry, or a particular feature of the technologies.

The diversity and pervasiveness of electronics applications point at the first issue. The range of electronics sectors is so wide that few countries can control all of them. Choices have to be made about which specific sectors to support, and how to promote them, based on policy assessments of the strategic linkages that tie them together and to the economy as a whole. Because the economies of individual countries increasingly depend upon each other, national policy choices must be evaluated in light of their international trade and security consequences.

The second issue centers around the importance of final demand for electronic products. Market demand plays a critical role in guiding technological development and providing the resources to foster and sustain high technology sectors. The case of the semiconductor industry illustrates this issue. It underscores the importance of market processes in channelling technology diffusion.

The third issue is about compatibility and connectivity in a world where information systems increasingly need to communicate. The story is told through the case of the computer industry. It stresses the role policy can play in helping to diffuse the benefits of computer technologies by promoting the emergence of common standards.

The fourth issue follows the emergence of digital integrated communications networks. These new networks constitute the infrastructure of economies increasingly built around electronics-based information technologies. National policies and regulations will powerfully shape the development of this electronic infrastructure, and thereby affect the diffusion of the products and services it supports.

The fifth issue is about the skills required to carry out the electronics transformation. It is illustrated through the case of manufacturing automation. Machines will not eliminate labor, but their development, implementation, and operation will require new skills. Technology diffusion will rest on the training and education provided not only to a few scientists and engineers, but to the large population of those who implement the transformation.

The choice of these five themes is not arbitrary. They correspond to the fundamental dynamics driving the development of the electronics sectors, and the diffusion of their products and processes. Neither is each dynamic specific to the particular case we use as an illustration. Final demand is as critical to the computer industry as it is to the semiconductor sector, and skills matter as much in telecommunications as in robotics. Indeed, each of the five issues runs through all facets of the electronics transformation, and invariably underscores diffusion as the ultimate policy goal.

I. THE DIVERSITY OF INFORMATION TECHNOLOGY STRATEGIC LINKAGES AND POLICY CHOICES1

A. The Electronics Sector: from Microchips to Robots and Computers

1. Enabling technologies: Semiconductors and Software

The entire electronic industry --from computers to digital watches and robots-- rests upon two basic technologies: the integrated circuit (IC), and software. They constitute the essential building blocks of any electronic system. Importantly, the two technologies are intricately related and interdependent.

The IC is singlehandedly responsible for the dramatic cost decrease and performance increase of electronic systems over the past decades: following the law Gordon Moore spelled out in 1964, the number of components (transistors) integrated in a single circuit is roughly doubling every year. A memory chip capable of storing 4,000 bits of information used to cost $4 in 1978 ; today one that can store 64 times more information (256K dRAM) costs less than $2. Without the IC, many products (such as radiotelephones, compact disc players or personal computers) would simply not exist today.

But most importantly, ICs have added tremendous capabilities to innumerable traditional products. Whether they regulate the performance of an automobile engine, control the routing of a telephone call, fine-tune the sails of an America's Cup yacht, or guide the work of a machine tool, they underlie the single most important transformation of products and processes in recent times.

Software is the other indispensable element. For one thing, integrated circuits are useless without the programs and instructions that guide and regulate their operations. However, the interdependence of ICs and software goes far deeper. Without sophisticated Computer Aided Design (CAD) programs, engineers could not design and test today's increasingly complex microchips. In turn CAD programs can only run on powerful computers built around the mighty chips they have helped to design.

Complex chips, such as microprocessors and some custom ICs, offer perhaps the best illustration of this truly synergistic relationship between software and silicon. To a large extent, the software that instructs them is built into their circuit architecture, embodied within their physical design. Furthermore the programs they are able to process depend largely upon their logic and physical layout. Hardware and software have become so inextricably entangled that success in electronics requires both the manufacturing expertise to etch ever smaller lines on ever smaller silicon chips, and the software skills to conceive the design, testing, and application programs.

Beyond its intricate role in the IC industry, software is becoming an increasingly critical enabling technology. Like ICs, software pervades all sectors of the electronic industry. Whether it is an Operating System that controls a computer's inner workings or an application program used for word processing, the instructions that guide a robot arm or the complex rules that manage public telephone switches and keep track of phone bills, software is an integral part of all electronic products. The performance of these products, their development costs, and their ability to answer their users' needs depend critically on the software they use.

2. Systems and Applications

The possible combinations of these two basic ingredients, chips and software, are endless. Most electronic products are basically built of ICs cleverly arranged on printed circuit boards and stuffed into some kind of box (today increasingly arranged in various types of packages), ruled by a series of programming instructions. The number of different systems and applications they represent is staggering. Following is a list of the major segments of the electronics industry.

Consumer Electronics: An increasing number of everyday products relies on electronics to operate. A short list includes: Video Cassette

Recorders (VCRs), electronic watches, kitchen appliances, pocket calculators, burglar alarms, hi-fi systems, thermostats, television, etc.

Telecommunications: Electronic technologies have deeply transformed the telecommunications industry. Public and private switches, the network nodes that route phone calls and manage network operations, increasingly relie on digital technologies. Transmission links, whether copper cables, fiber optics or microwaves, integrate advanced ICs in their repeaters, multiplexers and satellite transponders. The terminals attached to the telecom networks, telephone handsets, facsimile machines or videotex terminals, are now built around specially developped microchips.

Computers: The dramatic decrease of ICs' cost performance ratio has fueled a double evolution of the computer industry, away from mainframes which used to constitute its largest segment. At one end, mini- and micro-computers have brought computers closer to their users, and allowed the decentralization of processing capacity. At the other end, ever faster chips allow supercomputers, such as the Cray XMP, to perform 200 Million instructions per second (Mips). Computers and telecommunications together form the basis of office automation technologies.

Production automation: Electronics now control the operation of machine tools, and increasingly allow them to sense their environment. Software can instruct a machine to change from one task to another, or to work in a different way. Sensors and computer vision, coupled with artificial intelligence applications, allow robot arms to adapt to unpredictably changing tasks. Through local area networks, computer aided design (CAD) becomes progressively integrated with computer aided manufacturing (CAM) to automate the entire manufacturing process.

The distinction between these various electronic sectors is fading rapidly. New words, like "telematics" or "mechatronics", attempt to grasp the convergence of formerly distinct areas. Indeed, nothing fundamentally distinguishes a telephone switch --a computer that manages a telephone network-- from a computer that keeps track of a bank's accounts, or a computer that controls a machine-tool. Communications networks now routinely transform voices into streams of digital bits: people and computers are made to speak the same digital language, and their messages --voice, images or data-- travel alike throughout an increasingly integrated and digitized network.

The convergence of formerly distinct electronics sectors goes even further. Not only do the products look and work alike, they also increasingly rely upon one another to operate. Today's computers, because they have become smaller and decentralized, need communication networks to work together. Indeed, the network itself is so much a part of the computer's operations that is is no longer possible to tell where the computer ends and where the telecom network begins. The same is true of robots spread throughout a factory: they need a network that coordinates their operations, transmits CAD designs from the research labs, or ties them into the broader operations of the firm.

B. The economic impact of IT

The direct impact of electronic technologies on economic development first derives from the sheer size of the electronic sector. By any account, this is one of the largest industrial sectors in the developped economies, one which now rivals the largest traditional sectors, such as automobile. Such comparisons indeed provide a striking illustration of the sector's size: in 1986, the shipments of the US automotive industry totalled $162.4 billion ; that same year, the US electronics industry shipped $198.3 billion worth of products2.

Although the precise numbers depend on the definition they adopt, various sources estimate the global revenues of the world information industries around $400 billion in 1986. Moreover, whatever the cyclical variations of individual sub-sectors may be, electronics as a whole are experiencing a spectacular growth rate. The trade press calls it a bad year when, like in 1986, the global electronics markets only grow at an 8% rate. Predictions see the world electronics markets reaching the trillion dollar mark by 1990.

The economic impact of electronics reaches far beyond electronics-based sectors such as the semiconductor, computer and telecommunications industries. The diffusion of their products and the new production processes they make possible holds even greater promise for economic development. Electronic technologies and products increasingly pervade the economy, to such extent that it becomes hard to distinguish between high-tech and low-tech sectors. If microchip producers and those who build computers around these microchips clearly belong to the electronics sector, what about an automobile company which uses robots to make cars, implants microchips inside its carburators, and spends money on research ranging from programming langages for robots to the design of on-board computers?

For the entire economy, electronics are transformative technologies3: electronic industries are developing products, production processes and technologies that radically transform the structures and the organizations of production and exchange activities. Indeed, despite the popularity of home computers and video cassette recorders, most electronic products are producer goods, not consumer goods. They are bought to be integrated in the products of other industries (like microprocessors in autos, appliances, airplanes or toys) or in the production process (like robots, computers and lasers accross the range of manufacturing and services), or both.

To remain competitive, that is, to survive, traditional industries must assimilate the new technologies, design products that make use of their possibilities, develop production processes that harness their potential, and use electronics to create flexible organizations that can swiftly detect and adapt to market changes. It is not simply a question of placing new NC machine-tools in old factories, but rather of reorganizing the production process around the possibilities electronics-based technologies have opened. Beyond individual firms, the applications of electronic technologies are transforming the organization of economic activity. They help invent new ways to conduct business, tap resources, access markets, coordinate workforces and equipments, or link various organizations along the new infrastructure of information networks. Indeed the most powerful economic impacts of electronics stem from such diffusion. Economic development will go to the economies that are best at using computers, and not necessarily to those that are best at making them.

C. A strategic Technology: control of and access to electronics

Competitiveness, the degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while expanding the real income of its citizens4, rests on the capacity to diffuse electronic technologies. National and economic borders matter critically to this ability, therefore to economic development. In both the business and military sense, electronics is a strategic technology: competitive advantage lies with those who have access to and control over electronics technology, thus within nations which posess a dynamic electronics sector. The need for interactions between producers and users of electronics and the vulnerability that derives from technological dependence both account for this strategic dimension.

1. User-Producer Synergies: the required interactions

The ability to apply electronic technologies, whether to a new product or a new process, is tightly linked to the ability to develop and manufacture new electronic products. The conception and design of IC-based products requires an intimate knowledge of which ICs are available, and what their capabilities are. Conversely, IC producers need a detailed understanding of the potential applications in order to design circuits that will answer their users' requirements and find markets. Similarly, industrial robot manufacturers must collaborate tightly with their customers to grasp end-user needs ; robot users must know precisely what robots can and cannot do to integrate them efficiently within reorganized production facilities.

Such collaboration between users and producers requires sustained interaction. It rests upon a close knowledge, efficient communications, and precise understanding of what each other's needs and constraints are, all things more easily achieved within a single country. If no American robot maker offers the machine a small US textile firms needs, it will have to use a Japanese (or German) substitute, designed for and in collaboration with different users. The needs of the American user probably differ from those of foreign users who use the machine within a different industrial organization, to achieve their own specific goals. Chances are the foreign robot will not perfectly fit its application, hindering the robot user's competitiveness.

Furthermore, borders can only slow down the diffusion of a new technology. Users from its originating country will therefore be the first to use it, and thus have a chance to create a competitive advantage over foreigners who will only use it later. In the electronic sectors, where everything changes rapidly, such a delay can make all the difference between success and failure.

Clearly however, most countries cannot possibly cover the entire range of electronics sub-sectors with national firms able to remain internationally competitive at the leading edge of technology. The difficulties some faced as they attempted to foster the development of a complete electronics "filiere" underscores the danger of spreading too thin ; attempting to grab too much, countries risk to grasp too little. The question then arises for policymakers to assess the importance of specific linkages between certain segments of the electronics industry and the rest of the economy, to choose where and how governmental action should be focused.

Specifically, this raises three sets of policy questions. First, under what circumstances and in which particular sectors does the development and diffusion of technology requires such close ties between users and producers? Second, to what extent are those ties required within a single country? and third, to what extent is this a regional problem, one for example that could be resolved through interacions between French and German firms, but not between European and Japanese firms.

2. The Vulnerability of Dependence

To depend upon someone else's technology for one's own competitiveness can generate vulnerability, or at least the fear of vulnerability. This is true both for countries and companies, and has international as well as domestic policy implications. The question is one of industrial structure: firms unable to produce the critical components they need for their systems will have to buy them either from merchant suppliers or from integrated suppliers. Nationally, this can represent a difficulty when the best components are produced by an integrated domestic firm that makes them for its own use, and relies upon their superiority for its competitveness in the final systems markets. Internationally, trade issues complicate the problem: firms from countries unable to produce the critical components they need for their systems will have to buy them elsewhere. Whether the foreign suppliers are merchant firms or integrated producers, trade policies often impose further restrictions, making it even more difficult for user firms to obtain the latest generation components.

The two related questions of industrial mix and structure compound each other both at the domestic and internatinal level, because most electronic products are primarily intermediate products. Access to state-of-the-art electronics critically determine the competitiveness of the firms who ultimately use them in their products (like the microchips used in a VCR) or their production processes (like the numerical controls of an assembly line). Companies may be denied such access because of trade restrictions when only foreign firms make the product they need ; or because the domestic integrated firms making them also make the final products that use them (IBM will of course not sell the proprietary ICs that embody the advances of its latest Personel System/2 computer, even to US firms) ; or because the supplier is both foreign and an ultimate competitor (the same Japanese companies make VCRs and the components that make their VCRs superior ; understandably, they won't sell those components to european VCR producers). In all cases, products designed around inferior components or manufactured with older processes will be at a disadvantage in international competition.

To this purely economic logic, governments must also add an inseparable military dimension. Today's weapons and intelligence systems relie on technologies essentially similar to those of commercial electronics5. The new COCOM rules on technology export imposed by the United States in February 1985 stress the link, as they restrict exports of the so-called "dual technologies". The US strictly controls sales of primarily commercial electronic products which have potential military applications, not only to Eastern Block countries but also to its allies. Whether the reasons behind these restrictions are purely military or combined with more commercial purposes, the consequences remain the same: they underscore the strategic necessity to secure a reliable access to advanced electronic technologies.

Yet among today's open economies, international sales must, and will, occur. Foreign markets are not simply tempting opportunities, but generate the necessary resources to sustain domestic growth. Foreign sources of capital, technology and know-how have become indispensable to development in all countries. Indeed, because national economies have grown so increasingly interdependant, a balance needs to be struck between commercial, strategic and trade imperatives. In this balancing act however, it is important to understand the stakes.

Issues for discussion

* If single countries cannot support the entire range of electronics sectors, how should they assess their relative importance to select those they should promote?

* What are the trade-offs implied by specific national market access restrictions and promotion strategies? In particular, how do one country's choices affect the options of other countries, and how can domestic policy decisions be reconciled with the imperatives of an open trading system, and of national security?

II.SEMICONDUCTORS
THE IMPORTANCE OF FINAL DEMAND6

Studies of the electronics industry always make a special place for the semiconductor industry. In large part, as pointed out earlier, this is due to the critical importance of ICs as a fundamental enabling technology, to the fact that ICs are the basic building blocks of any electronic system. In other words, what products can be made and how efficiently they can be produced is largely shaped by one's mastery of integrated circuits technology.

Final demand has been one of the most important factors in the evolution of the semiconductor industry: its volume determines the market resources available to IC makers for research and development, and, most importantly, its character has shaped dramatically distinct technological and commercial strenghs in various countries. Success stories and failures in the semiconductor industry highlight the determinants of success and failure in electronics as a whole. Intersectoral similarities stem from the fact that electronics products are intermediary goods. Access to the best components determines the users competitiveness, and they will strive to secure an adequate supply. Their success in doing so will be largely constrained by the structure of the national merchant industry, and by policy restrictions on international trade. Similarly, integrated IC producers need to generate market revenues without giving up their strategic technologies. Here again, domestic and international policy issues interplay, industry structure and industry mix jointly shape the impact of final demand through the market. The resulting dynamics are not easy to unravel, but ultimately determine both a country's access to the enabling microelectronics technologies, and its ability to diffuse them.

From the inception of electronics up until very recently, the United States was without contest the world leader in the semiconductor industry. This superiority rested upon a solid foundation of advanced technology, developed in response to strong demand for advanced circuits, first from the Department of Defense, then from the computer industry. The size of this considerable final demand was decisive in fostering the development and growth of the US merchant semiconductor industry.

During these formative years, AT&T's Bell Labs also played a critical role. Because of antitrust controls imposed on AT&T, the Bell Labs were obligated to license cheaply all the technologies they discovered and developed. Pulled by growing demand from DoD and the computer industry, pushed by rapid technology improvements financed by the market or bought cheaply from AT&T, the American IC industry made spectacular progress in integration and cost reduction.

However, these very sucesses induced new problems. With the advent of large and very large scale integration, new manufacturing technologies make it possible to produce increasingly complex circuits at very low unit cost. However, those circuits must be manufactured in ever larger quantities to spread the growing costs of research and development . At the same time, because circuits become more complex, they tend to become more specialized and can fit fewer specific applications. IC producers risk being squeezed between these two trends, having to produce ever larger quantities of chips at ever smaller unit costs for ever narrower niche markets.

This vicious cycle fuels the double evolution of the IC industry, where two related but distinct technological trends co-exist. The first trend pushes the industry towards a more "mature" phase, where the game is to produce large quantities --at low unit price-- of relatively simple and standard components. By contrast the second trend emphasizes innovation, characterized by the growing number of new niche markets for complex custom ICs designed to answer the needs of specific users. Business strategies and industrial policies in the IC industry must be developped around these two trends. Although both avenues --standard and custom-- rest on tightly related fundamental technologies, success in each of them requires distinctly different sets of skills, organizations, research and manufacturing decisions.

A. Maturity: Commodity products in an adult industry

Traditionally, memories have been the largest product segment of the IC industry, accounting for over 20% of the world semiconductor market7. This has made the memory markets important for two reasons. First, they have traditionally generated the bulk of the industry's profits to be reinvested in research and development. Second, the volume production technology RAMs required, stimulated (and funded) the development of advanced IC manufacturing technologies, that could in turn be applied to the production of all other ICs.

As the memory industry matured, manufacturing expertise, the capacity to produce large volumes at low unit-cost, and the commercial ability to sell to a mass market became essential. In such a mature sector, production strategy and capital investment matter more directly than product innovation. This advantages large diversified industrial groups, such as many Japanese companies, which can draw resources from other divisions (consumer electronics for example) to invest in IC production. They can therefore afford the highly automated production lines mass IC production requires well before they control the mass markets that will justify and support such expense. By contrast, most American merchant semiconductor producers, who specialize in IC manufacturing, could not afford such a strategy. The few integrated US firms, such as IBM, only manufacture ICs for their own consumption, and therefore do not directly intervene in those markets. Thus, Japanese producers gained control over the most advanced mass manufacturing technology, that later enabled them to produce larger quantities of standard circuits at lower unit cost than their US competitors.

B. Innovation: Components become systems

Faced with declining margins on commodity ICs and the Japanese penetration of the mass markets, the US response centered around new complex components. The challenge was to find a way to satisfy the specific needs of a range of niche markets, while producing large enough quantities of each circuit to benefit from scale economies. Increasing integration made it possible to place a growing number of a system's components on a single silicon chip. A chip that used to be simply a component within a larger system became capable of containing a complete system itself.

The solution was to manufacture large quantities of complex circuits which can in some way be adapted, customized to specific uses. Micro-processors, EPROMs and EEPROMs*, as well as Programmable Logic Devices (PLD) offer such a solution because they can be programmed after manufacture to execute various tasks. Semi-custom, standard cell, gate arrays and full-custom chips offer another type of solution, as they permit customization at diverse stages of the manufacturing process.

Critically, the very nature of these complex circuits tends to represent a considerable obstacle for foreign suppliers. Indeed, because the components have become systems, their physical design increasingly embodies information and concepts that are essential to the final systems that will use them: a personal computer's capabilities are more or less those of the microprocessor and supporting circuitry it centers around. It then becomes dangerous to entrust their manufacture to a foreign company, which could use the strategic information they contain to successfully compete in the final systems markets.

C. Final Demand Shapes IC Strenghs

The respective strenghs of American and Japanese IC producers owe little to chance, nor to genetic or cultural differences that would make the Americans more inventive, and the Japanese better at technological imitation and mass production. First and foremost, they reflect differences in the nature of the final markets that induced and sustained the development of each national industry. Early Japanese inroads into semiconductor markets were unequivocally tied to final demand from the consumer electronics sector: portable radios, color TVs, pocket calculators, digital watches or VCRs provided markets and revenues for the development of relatively simple microelectronic circuits. By contrast, used to supplying complex circuits to their major client --the computer industry-- the American IC makers were well positioned for the transition towards complex, application specific circuits.

Obviously, the structure of final demand creates clear economic and market incentives for the national IC industry to design and develop the kinds of circuits that national system manufacturers will buy. Beyond this however, the character of final demand further fashions the IC industry through the sustained interaction it requires between IC users and producers. Indeed the recent Japanese inroads in IC markets traditionally controlled by US producers can be traced to the changing structure of Japanese final demand for ICs, progressively resembling its American counterpart. In 1980, consumer electronics used 58% of the semiconductors sold in Japan, while industrial electronics, computers and communications only used 42%. In 1985, the share of consumer electronics had dropped to about 40% 9. Similarly, the European weakness in IC largely results from the fact that European firms, from Swiss watchmakers to French TV producers or German telecom equipment providers, generally ignored the potential of microelectronics, and failed to generate a strong European demand for integrated circuits and the revenues European IC makers would have needed to invest.

When they tried to address these problems, European governments typically subsidized the IC suppliers. Never did they explicitely try to foster an independant European demand for ICs. In fact, they only promoted IC demand through National Champions (such as Thomson, ICL or Siemens) who had to buy preferentially from their country's IC manufucturers. Such protection compounded the lack of demand pressure on European IC producers. It further isolated European chip makers from international competition, in striking opposition with their American and Japanese counterparts.

Issues for Discussion:

* How can governments stimulate final demand in ways that will both stimulate development of the electronics industry and the diffusion of their products?

* If choices have to be made, should governments support the users or the suppliers of electronics, given their specific character as intermediary goods?

III. COMPUTER INTERCONNECTION THE IMPORTANCE OF STANDARDS

Interconnectability and compatibility, based on common standards, are now critical. As more powerful mini- and micro-computers decentralize information processing, they increasingly need to be connected. Electronic data processing systems are no longer stand-alone machines, but intelligent networks linking decentralized processing capabilities. The issue of standards is therefore of central importance, not only for the development of the computer industry itself, but most importantly for the diffusion of computer products and technologies to the entire economic fabric.

This view considers computers as constituent elements of an integrated system of production. Such network systems are characterized by network externalities: the benefits derived by one user of the system increase with the number of other users. Conversely, the users excluded from using a system because it follows a different standard suffer a direct efficiency loss ; such is the case of the owners of Apple micro-computers who are denied access to the vast library of IBM-compatible software.

Indeed, users of computer technologies are largely at the mercy of the social mechanisms entrusted with providing compatibility between the various components of the systems they use. Moreover, analysts widely recognize that markets left to their own devices usually result in an insufficient degree of standardization, and induce losses of efficiency from an overall economic point of view. Governments therefore have an opportunity to affect the global welfare of the economies that produce and use these computer systems by indirectly channelling the market-driven processes that shape standards in emerging technologies, or by directly specifying the characteristics of technological products. They can design policies that promote cooperative standard setting among firms, or more simply mandate compliance with government defined standards.

In these efforts however, policy makers face three dilemmas. The first, to use Paul David's terminology10, is the "Narrow Policy Window Paradox": policy intervention is most effective at the beginning of the technological evolution, and this only during "narrow windows", or very short periods. The second dilemma results from the "Blind Giant Quandary": public agencies, those entrusted with developing the standards, are most powerful when they know the least about the technology.

To escape from these first two dilemmas, policy makers can only strive to keep the policy windows open as long as possible, while the blind giants try to learn more about what will make a "good" standard. At this stage, any government action which prevents the industry from locking in on a particular standard will be beneficial, even though the early indecisive period may result in short term inneficiencies. Usually however, one standard will soon become dominant, and confront policy makers with a third dilemma as they need to cope with "Angry Orphans", those who had selected the now abandonned standard. So as to maintain credibility for future policy, and not to compound the risks users face when they must choose among various emerging technologies, governments should favor the development of ex post facto integration technologies -- various types of adapters and translators may help. As much as possible, standards should be developed that do not completely exclude alternatives to the dominant solution.

The evolution of the computer industry provides a good illustration of this framework, and helps outline the policy options that exist to promote interconnectability. To a large extent, computer compatibility and interconnectability are software issues. They underlie IBM's dominance over the computer industry. By introducing the 360 series architecture in the 1960s, the company was the first to provide a range of compatible computers, that could accomodate its clients' growing needs without forcing them to re-write their programs or re-encode their data. A self-reinforcing market process was then unleashed. More (IBM) computers were able to run similar programs, creating enormous opportunities for software engineers to write IBM-compatible programs. In turn, the growing number of applications written to IBM's specifications made it compelling for users to buy IBM machines, increasing the installed base of IBM computers, thus the market for compatible software, and so on... Critically for the users, the costs of "translating" their programs and files to another computer standard, and the cost of renouncing access to the IBM-compatible world, far outweigh the costs of remaining faithful to IBM, even when other manufacturers offer more advanced machines. Thus, IBM keeps its clients firmly "locked-in".

Under IBM's supremacy, other computer makers face a tough alternative: resist, like the (former) BUNCH, NEC, and most European makers who chose non-compatibility ; or surrender, like Amdhal, Fujitsu, Hitachi, and all the others who produce IBM-compatibles. Both strategies entail major risks. Those who chose not to follow the IBM de-facto standard renounce access to the major part of the market, and must fall back on specialized niches. By contrast, those who decide to be compatible loose the initiative, and restrict their options to strategies that are merely responsive, rather than aggressive.

Compatible equipment makers have repeatedly tried to force IBM to give them free access to such interface information, through antitrust suits in the US as well as in Europe. They were unsuccessful however, since in 1982 the US Justice Department ruled, in favor of IBM, that these were legitimate business practices. In 1984, the EEC followed a similar route, although for quite different reasons, as it negotiated an agreement with IBM. In essence, for those governments, the narrow policy window had already slammed shut. In their view, the benefits of going along with a firmly established standard justified sacrificing the requests of the dominated actors, and the interests of a few angry orphans.

Where legal means have failed, the technological evolution towards small decentralized computers may well succeed: it brings increased pressure for open systems, in reaction to IBM's traditionally closed systems policy. Metaphorically, economic power is following computing power as it becomes more decentralized to rest increasingly with the users. Indeed, companies and countries can no longer afford to use a multitude of electronic machines unable to talk to each others. The grounds gained by the UNIX operating system, as well as the agreement first ratified by 12 major European computer makers to support Open System Interconnection (OSI), push to unify the computer indutry behind common standards that escape IBM's control --and manipulations. UNIX was designed as a portable Operating System, so that programs written for one computer can easily be transported onto another. OSI, championed by the European Community, specifies interconnection standards that allow computers and peripherals of different makes to communicate over standardized networks.

Importantly, OSI is conceived and developed in a way that does not exclude any particular computer system. Rather, it takes an approach that fits around all of them and thus leaves no angry orphans but those who refuse to play by the common rule. As interconnection technologies evolved, the standard setting organization was able to work closely enough with various computer makers to keep the policy window open while it became less blind a giant.

Of course, it would be naive to only retain the impression of perfect harmony that results from this simplified framework. In particular, it leaves out what might be called the "political economy of standards"11: various agencies involved in the standard setting process, various governments representing the interests of different computer producer and user communities, undoubtedly need to pursue a range of goals, not all of which are compatible with global network systems efficiency. Similarly, industrial actors do not forget their own interests through this process and for example, IBM is certainly taking steps to gain more control over the definition and evolution of the OSI standards. Nevertheless, the main thrust of the argument remains. It underscores the benefits of a standard setting policy flexible enough to keep open the windows of opportunity while learning more about the technology, wide embracing enough to include those who otherwise would have become orphans and, rightly so, angry.

Issue for Discussion:

* How can governments promote the emergence of standards that will allow interconnectivity and thus help the diffusion of computer-based technologies, without precluding innovation and technological development.

IV. TELECOMMUNICATIONS
BUILDING THE INFRASTRUCTURE

A major transformation of the telecommunications infrastructures in the OECD countries is underway. Suppliers of telecommunications services, producers of communications equipment, and major users of both services and equipment are fashioning radically new, digital telecommunications networks in the industrialized countries. National phone networks are being digitized ; digital overlay data, facsimile and video networks are being built, expanded, and in some cases integrated into the existing public telephone network to form integrated services digital networks (ISDN). Large corporate and public sector users are also building private digital networks either wholly under their control or by leasing circuits from public service providers. Over both the public and private networks, new generations of telecommunications services like videotex, electronic mail, voice messaging, high-speed data transmission and videoconferencing are emerging. Complementing these changes are enormous new market opportunities for service providers and for suppliers of the telecommunications equipment which comprises the new networks and controls the delivery of new and old services.

The new telecommunications infrastructure emerging from the convergence of data processing and telecom technologies acts as a powerful agent of economic development because it opens a series of new opportunities. First, the network itself has to be built. This will induce significant growth within the equipment and service industries that supply the parts, assemble, operate and maintain the new telecommunications network. Second, the network generates a set of lucrative and expanding markets for terminal equipment and new services that can be connected to, or delivered over the new infrastructure. In 1986, telecommunications services and equipment together accounted for at least $115 million or about 5% of U.S. gross domestic product (GDP), about $65 billion in Europe, and $25 billion in Japan, or about 3% of GDP in each. Because the telecommunications sector is growing much faster than GDP, it is expected to account for between 7 and 10% of GDP in the advanced countries in the early 1990s. Third, and most importantly, the shape and characteristics of the new networks --and the pace at which they are created-- will affect business strategies in all economic sectors, structure opportunities for profit and growth, and influence who can capture these opportunities12.

Telecommunications networks constitute the infrastructure of the information economy, much like roads and railroads do for the goods economy. Because such an infrastructure determines what can be transmitted (or transported), in which conditions, between which points and at what price, it sets a new basis for economic activities : production processes, exchange mechanisms, institutions and organizations, business strategies or location decisions have to be developed and evaluated within a new set of constraints and opportunities. Because they define a new topography of opportunities, the new telecommunications networks raise important policy questions. They have the potential to profoundly transform the very structure of the economy, and redefine the basis of competitiveness. Yet the mechanisms through which this transformation will occur are still largely unknown.

Current evolution suggests that the shape, character and functionality of the new networks will substantially depend upon the national environment within which they emerge. Variations among the national regulatory arrangements, differences in the structures of national telecommunications industries, or distinctive legacies set by the traditional domestic telephone networks may result in significant differences between the telecommunications infrastructures of various countries. Here again, this is simply our presumption, based on a preliminary analysis of recent changes in international telecommunications13. The presumption, however, is strong enough, and its implications momentous enough, to warrant a thorough discussion of the policy options.

In turn, the competitiveness of domestic firms, from all economic sectors, will critically depend upon the shape and characteristics of the communication networks and services they can mobilize. Conversely, as firms strive to secure a competitive edge over their foreign (and domestic) competitors, they will attempt to shape the networks' evolution to their advantage. Indeed, businesses are clearly becoming one of the major forces driving the development of the new information infrastructure, one of the major influences upon its configuration and characteristics. These competitive forces interact powerfully with national telecommunications policy to shape the emerging network infrastructure --with critical implications for both policy and business strategy. Telecommunication policies need to be examined anew in the light of these changes. The development of these policies requires an understanding of the specificity of the telecommunications infrastructure.

The telecommunications network infrastructure is repeatedly compared with the earlier transportation infrastructures, roads and railroads. The analogy carries considerable suggestive power. Remembering how deeply roads and railroads have transformed the economy and its "geography of opportunities" suggests the profound transformation a new infrastructure will yield. The analogy however, should often be left here -- a powerful image. Attempts to evaluate telecommunications policies within a framework directly inspired by transportation networks quickly run into major problems. Indeed, the telecommunications infrastructure differs from the previous transportation infrastructure in several important ways. These differences matter to the role of policy in the process and dynamics of the networks' emergence. We focus here on five of these differences14.

First, the influence of transportation technology on distance is different in kind from that of telecommunications. Improvements in transportations merely "stretched" geography : A rubber band on a map showing the area within reach would be stretched as transportation technology improves. Suddenly with telecommunications, the accessible area so stretches that the rubber band breaks : it is exactly as fast, and soon will be equally cheap, for somebody in Berkeley to transmit voice or data to San Francisco, Paris or Tokyo. Transportation technologies yielded incremental improvements in accessibility, but telecommunications provides a quantum leap towards ubiquity. National telecommunications authorities then loose a great deal of their control: a multinational dissatisfied with the high tarriffs imposed through one country's telecom policy can demand changes and threaten to transfer instantly its telecom traffic abroad.

Second, the transportation analogy implies a false idea of homogeneity. It views telecommunications access as uniform, much like access to a road. Once laid out, the road network provides essentially the same service to anyone connected to it. Widening a two-lane country road to a four-lane freeway may reduce traffic jams, but does not inherently change transportation. By contrast, access to a wide-band optical fiber link rather than a simple telephone line makes all the qualitative difference between the ability to transmit video images and data, and being restricted to voice communications. Basic network access no longer suffices for firms seeking to take advantage of telecommunication's competitive potential: to implement their strategies, a twisted pair will not substitute for an optic fiber. Telecommunications policies, by providing (or not) access to various types of network facilities, by regulating who will have access and at what price, will therefore directly affect industrial and economic development. Fundamentally, these are society-wide, hence political decisions.

Third, in a transportation system, technological improvement is primarily embodied in the vehicles, and therefore diffuses instantly and uniformly over the entire network : faster, more efficient trucks immediately improve the whole transportation system. By contrast, technological capability in telecommunications and service applications is embodied within the network itself (software-controlled digital switches, wide band optical fibers, "intelligent" multiplexers) and benefits only those who have access to the more advanced portions of the network. With roads and rail, it was important to control the vehicles and the vehicle technology. With telecom, competitive advantage and power rest with those who control the infrastructure itself, whether they are private or public entities.

Fourth, telecommunications is a "soft" infrastructure, one built with software as much as hardware. Applications developed over the network (electronic-mail, packet switching, VANS, video conferencing,...) are critical parts of the infrastructure, and inseparable from its hardware. While ubiquitous connectivity tends to make all locations more alike, the services and applications available over the network introduce major differences: having access to the right network hardware is not enough, one needs access to the right applications. The case of American Airlines illustrates the point. With SABRE, it was first to offer travel agents on-line computer access to its data listing flight and reservations information, for all airlines. Of course American's flights were systematically displayed in a prominent position, placing competitor airlines that did not have their own system at a competitive disadvantage. Travel agents, therefore customers, were connected to all airlines, but trapped in American's application. Here again, competitive advantage will rest with those, private or public, who control the "soft" side of the infrastructure.

Fifth, a telecommunications network is a non-standard infrastructure. With minor restrictions, trucks and trains can technically travel anywhere along a continent's roads and railroad tracks. Not so with telecommunications, where standards often constitute major barriers to network access. There is not really one telecommunications network, but a series of juxtaposed sub-networks with various degrees of interconnection. Importantly, standards affect both levels of the infrastructure: hardware and software. As they decide --or let the market decide-- how to set such standards, policies will have critical economic consequences.

Recognizing that telecommunications networks are not homogeneous, universally available "public" goods, brings new questions to the attention of policy makers: Who controls the design of the networks? Who controls their construction? Who controls what applications they will support? Who has access to which networks? And what motives guide each of these actors? What objectives do they pursue through the construction and use of the networks? More than anything else, the policy answers to these questions determine the evolution of the telecommunications infrastructure, its shape and characteristics. They will in turn largely affect the growth of the economies that rely upon these infrastructures.

Telecommunications has traditionally been an important area of government involvement. In all developped countries, until recently, state-owned or state-regulated monopolies developed, built, controlled and managed the telecommunications network. With a handful of domestic equipment suppliers, the monopolies would agree on what technologies to promote, what products to design, what to sell and at what price. This had important consequences for the telecommunications infrastructure it generated. The rationale guiding network development was often that of the state administration rather than the users'. Network management practices and service offerings reflected the concerns of the monopoly network operator more often than those of clients who had nobody else to turn to. Centrally imposed standards guaranteed uniform access and equipment compatibility anywhere within a single national network, but also served to limit foreign penetration of the domestic markets, making international communications all the more complex.

This cozy relationship tying governments and the telecommunications sector is now changing rapidly and dramatically. AT&T is no longer a monopoly in the US ; British Telecom in the UK and NTT in Japan have been privatized and are facing competitors for the first time ; other traditional monopolies are today threatened. The barriers governments once erected to protect their national telecommunications industries are shattered, giving way to intense international competition. New technologies and new regulatory frameworks enable private and public organizations to build, control and manage their own communications systems, reducing the share of the network under public control.

Yet, if the role of government is being re-defined, telecommunications policies and regulations retain considerable implications for the shape and characteristics of the emerging networks. Deregulation in the United States means that by and large, the networks will be shaped by the needs of large users. Developmental re-regulation in Japan accompanies a deliberate policy decision to build an advanced integrated digital network in anticipation of its use. The European PTTs, who retain the tightest control over telecommunications, appear determined to insure that the telecom network will offer equivalent service to all, including residences and small businesses.

These policies obviously have very different implications for the future of each national telecommunications infrastructure. The trade-off they imply, in terms of who has access to the networks and who controls their evolution, are equally obvious. Their long term consequences are less clear, and it remains debatable which policy will best serve long run eonomic development. It is clear however that advanced networks will be critical and that policies should be developped around the goal of providing economies with an infrastructure able to support their development.

Issues for Discussion:

* How should governments re-define their role in the telecommunications sector to foster the emergence of the new network infrastructure?

* If the networks emerge nationally, shaped by primarily domestic dynamics, what are the implications for international trade relations?

V. MANUFACTURING AUTOMATION
LABOR RELATIONS AND SKILLS FOR FLEXIBILITY15

The diffusion of information and communications technologies in the developped economies remains at a very early stage. Potential uses of existing, not to mention future, electronics technologies, have yet to be fully explored. Earlier fantasies of automation had predicted sweeping economic reorganization, massive job displacement, tremendous productivity increases, radical and almost instantaneous lifestyle changes. Both the reality and the consequences of the applications of electronics to economic activities have emerged more slowly and differently from what was expected. Indeed the diffusion of new technology cannot be simply deducted from its purely technological potential. The technology itself merely defines a domain of possibilities. Within this domain, labor relations, business strategies, management practices, skill structures, financial channels and military strategies interact with technology decisions and policies to frame complex channels for technological diffusion, even affecting to a large extent the path of future technology development itself and shaping the technology frontier.

Production automation is perhaps the area where the transformation seems the slowest to materialize. If it falls short of past futuristic dreams, the reorganization of the production system is nonetheless complex and powerful. The current diffusion patterns deserve careful study because they create channels, methods and habits that will condition technology diffusion in the future. We focus here on the role of labor organization and skills in the diffusion of electronics-based manufacturing technology. To understand the role of this "human element", and the broad potential of production automation, we first need to step back and to grasp two distinct elements. The first is the purpose that drives the adoption of the new technology, summarized in one word: flexibility. The second is the industrial tradition that pre-existed the introduction of the technology and that constitutes a country's legacy in responding to the transition.

Flexibility has become the slogan and the goal of today's application of electronic technologies throughout the factory, and the theme of a large literature on production automation. Firms seek both static flexibility (the ability at any time to adjust business operations to shifts in the market), and dynamic flexibility (the ability to design production lines that can quickly evolve in response to changes in either the product or production technology). Production Automation (PA) is expected to allow firms to adjust output levels and to produce several different products on a single production line (static), and to "make rapid changes in production technology to lower costs and thereby improve productivity" (dynamic)16 .

Programmable automation, and the flexibility it permits, has major advantages. First, it increases the advantages of batch production over mass production. Batch production becomes feasible in situations where costs had previouly required the rigidities of mass production. "since approximately 75% of all machined parts are produced in batches of fewer than 50, the potential uses of mechanization are widespread"17. Because the equipment is controlled by an electronic program, set up time and the cost of shifting between uses are dramatically reduced, yielding economies of scope along with economies of scale.

Second, machines can perform more sophisticated tasks than before because more advanced sensory techniques are possible. Machines will also be used in dramatically new ways. CAD speeds up and sophisticates product design, and design testing ; it reduces the cost of design and speeds the shift between design and manufacture. Introducing new products, or designing a range of related products, becomes faster and cheaper.

The challenge is not simply to replace old equipment and labor by new machines within existing production system. The new equipment is part of introducing an entirely new production system. Greater benefits will be captured if the new technology is not simply used to automate existing practices, but to permit new ones. The benefits of a single PA machine taken in isolation are nothing compared to the benefits from a new production system organized to take advantage of the PA machine. Indeed, the real potential of the new production equipment comes from its integration: fully integrated production systems linking design with manufacturing, permitting an automatic shift from one product to the next.

Because the objective of the new production organization is flexibility, it necessarily results in lower scale economies, as the cost of individual pieces of machinery rises while it can only be spread over shorter series. The integration of production automation however will result in economnies of a different kind, that we at BRIE have called systems economies. These result directly from the flexibility of a complete integrated manufacturing system, that minimizes the time lost between each step of the production process, and during the reconfiguration of this system. Importantly, the benefits of such a system cannot be fragmented, and must be understood within the production process as a whole. Such Computer Integrated Manufacturing (CIM) systems are still a long way off. But manufacturing practice and the use of manufacturing automation are evolving rapidly.

The current period of economic transition is a time when dynamic flexibility is of predominant importance. the transformation doesn't simply mean that a few "sunrise" manufacturing sectors, such as personal computers, are assuming the importance once held by traditional manufacturing sectors, such as automobile. Rather, computers and microprocessors have begun to alter the production process throughout industry. The transformation is occurring because the electronic technologies are agents of change, sources of innovation, within the traditional sectors. The critical question is how the new technologies spread throughout the economy as a part of national and corporate responses to changing competition. Neither markets nor technology will dictate the decisions. Rather, political, economic and strategic choices will determine the path of technological development. Manufacturing Matters18 builds an argument explaining why specific national development emerge out of these choices, and the legacy they constitute. Similar notions are expressed by Richard Nelson19 and Giovani Dosi20 as "technology trajectory".

The technology trajectories of different nations, as evidenced by the patterns their industries follow in adopting programmable automation, differ widely. Let us simply contrast the cases of the United States and Japan. Per capita expenditure on industrial automation is roughly similar in the two countries, with an advantage for the U.S.: $10.9 in the U.S. versus $8.1 in Japan (far ahead of Europe, with $3.2) 21. However, the picture changes completely when one looks at the specific technologies employed. Advanced automation, including CAD/CAE, manufacturing planning and control systems (MP&CS), robots, and Flexible manufacturing systems (FMS), accounts for only 12.3% of total manufacturig automation in the US in 1985, up from 4.3% in 1980. By contrast in Japan, these advanced systems account for 31%, and have represented a consistently high share of total automation since 1980, when the ratio was 36.2%.

The technologies of advanced automation are precisely those that allow manufacturing flexibility. The rest of manufacturing automation consists essentially of stand-alone numerically controlled machines. Therefore the figures highlight two very different automation trajectories: a trajectory of "rigid" automation in the US, contrasted with a trajectory of flexible automation in Japan. Critically, the two trajectories rest on very different approaches to labor. While rigid automation aims at the elimination of labor from the production process, flexible automation uses the machinery towards the different goal of swift adaptability and requires broadly skilled production workers for its implementation.

Production automation technologies can fit into a series of distinctly different economic and social settings. More importantly, the technologies will be shaped by the context in which they emerge. Automation is used to solve market, management, and labor problems, in ways that differ in each country. Therefore, policy, market structure and labor arrangements will shape the development of the technology differently in each national context. In these respects, there is a lot to learn from the contrast between American and Japanese policy. The following remarks first address government policies directly aimed at automation, then consider the implications of industry structure for diffusion, and conclude with the role of labor organization and skills.

American policy in programmable automation has been largely conducted by the Defense Department and was aimed primarily at the manufacture of sophisticated weapons , from aircraft to tanks. Japanese policy in contrast, has been aimed at the development and diffusion of commercially applicable technologies. The policy of diffusion established mechanisms to ensure that small firms could learn about the new technologies, find and develop machines appropriate to their needs, and lease them on favorable terms. The consequences are quite clear. American machine tool manufacturers dominate production of larger machines used for the most complex purposes. Japanese producers dominate the market for smaller machines used in the broadest range of industrial purposes, thereby controlling the mass market. They now sell about half of the NC machine tools used in the US. Not surprisingly, the Japanese control precisely that portion of the market that their policy addressed22.

The market structure, the mix of large and small firms in industries, will likewise shape the ways in which the new technologies are used and consequently the way they evolve. If economies of scale created a technological advantage for large firms, today's automated production technologies should permit small firms to design and develop products that can be sold in competition with large firms. But evidence suggests that fixed costs in marketing, distribution and finance are often more important obstacles to new producers than production economies.

Thus, institutional supports --public or private-- are necessary to help small firms firms harness the new production technologies. First, there must be manufacturers of PA equipment suited to small firms. Second, there must be a network of service companies to maintain the equipment. Whereas large companies can provide in-house service, small firms often are not able to do so. Third, there must be marketing channels and access to credit for small firms, as well as equipment producers aiming to meet their needs. Japan's policy of financing the diffusion of programmable automation equipment to small producers creates such an environment. Similarly, studies of Italy's small producers show a particular institutional fabric that supports small firms23.

The existing pattern of labor relations, the arrangements between labor and management, and the skills of the workforce will also shape the diffusion of electronics-based production technologies throughout the industrial sectors. Management favors the development and introduction of technologies that fit its vision of how work should be organized, of how control --and whose control-- should be established. Which technologies are applied, how they are applied, is in large part a strategic response to skill availability and prices. American shopfloor organization largely reflects production strategies based on notions of economies of scale, with narrow job definitions serving a rigid mass manufacturing system. By contrast labor organization in Japan, which defines job responsibilities broadly, is better suited to the adoption of the new technologies. Moreover in Japan, the labor force is being broadly educated to understand both the technologies and their applications.

The ability to diffuse the new electronic technologies in traditional sectors is as vital as the ability to develop them in the first place. Although advanced technological development requires an elite of scientists and engineers, the diffusion of advanced technologies rests upon a broadly educated and skilled population. A skilled and involved workforce will help firms create the "dynamic flexibilities" required to sustain productivity increases. Crucially, automation strategies seeking the elimination of skilled workers directly threaten the firms dynamic flexibility: indeed, their own skilled workers, not their robots and engineers, often have the experience and know-how necessary to continuously develop, absorb, and apply new production technologies.

If the new equipment is used simply to strip labor out of production, to substitute directly capital for labor in existing production organization, then PA is likely to be ineffectively used and its potential missed. As the low-skill functions become automated, higher skills become necessary. Static flexibility
--the ability to vary product mix-- demands workers trained to perform a variety of tasks. Dynamic flexibility --the ability to fluidly introduce process innovation-- demands broadly trained workers, sufficiently well-versed for example in the fundamental principles of basic math and science that they can easily understand and adapt to the new technological regimes.

Issue for Discussion:

* The availability of a skilled workforce is critical to the adoption of innovative production strategies. How can governments develop educational reforms --broadly understood to include adult training and retraining-- that will help their country to meet this challenge?

1 The arguments of this section were first developed by BRIE with the Institut Francais de Relations Internationales (IFRI) in Rapport Annuel Mondial sur le Systeme Economique et les Strategies 85/86, Chap 3.4: "Nouvelles Technologies et Strategies Economiques", IFRI, Economica, Paris, 1985.

2 The auto industry is defined to include automotive stamping (SIC 3465), motor vehicles and car bodies (SIC 3711), truck and bus bodies (SIC 3713), parts and accessories (SIC 3714), truck trailers (SIC 3715), and motor homes (SIC 3716). The electronics sector includes computing equipment (SIC

3573), communication equipment (SIC 3651, 3661, 1662) and electronic components (SIC 3671, 3674-79). Data from the US Industrial Outlook, 1986.
3 This view that the full impact of electronics technologies stems from the structural economic transformation they provoke constitutes a central theme of our work at BRIE. The particulars of the transformation are analyzed in details in Manufacturing Matters, S. Cohen & J. Zysman, Basic Books, New York, 1987.
4 This meaning of "competitiveness" is the one adopted by the President's Commission, as defined in Volume III of the Report of the President's Commission on Industrial Competitiveness, by Stephen Cohen, David Teece, Laura Tyson and John Zysman, Washington D.C. 1985.
5 For a detailed analysis of the interrelations between civil and military technologies, and their policy implications, see : Jay Stowsky, Beating our Plowshares into Double-Edged Swords: The Impact of Pentagon Policies on the Commercialization of Advanced Technologies, BRIE Working Paper, April 1986.
6 The arguments developed in this section are taken from Michael Borrus, Responses to the Japanese Challenge in High Technology: Innovation, Maturity, and US-Japanese Competition in Electronics, 1983, and Reversing Attrition: A Strategic Response to the Erosion of US Leadership in Microelectronics, 1985, BRIE working Papers. Additional sources are cited specifically throughout the text.
7 combined markets for dRAMs, sRAMS, and ROMs, in Electronics, "1987 Market Report" 1/8/87 and 1/22/87.
* Erasable and Programmable Read Only Memories, and Electrically Erasable and Programmable Read Only Memories.
9 Data compiled by Michael Borrus (Reversing Attrition...) from various sources: Electronic Industry Association of Japan (EIAJ), Electronics Components Manufacturers Association, and Dataquest.
10 In "Narrow Windows, Blind Giants, and Angry Orphans: The Dynamics of Systems Rivalries and Dilemmas of Technology Policy" (paper presented to the International Conference on the Diffusion of Innovations, Venice, Italy, March 17-22, 1986), Paul David outlines a framework to analyze these dynamics. This section draws largely upon his model.
11 Paul David, op. cit. p. 24.
12 Michael Borrus & John Zysman, "The New Media, Telecommunications, and Development" BRIE working paper, 8/84.
13 For a more detailed analysis of these current developments, see: Borrus M., Bar F., and Warde I., The Impact of Divestiture and Deregulation: Infrastructural Change, Manufacturing Transition and Competition in the US Telecommunications Industry, BRIE Working Paper, 1984, and Borrus M. et al. Telecommunications Development in Comparative Perspective: The New Telecommunications in Europe, Japan and the US, BRIE Working Paper, 1985.
14 The original analysis is presented in: Francois Bar, "Business Users and the Emergence of the New Telecommunications Infrastructure", OECD-BRIE Telecom User Group Project, unpublished, BRIE, March 1987.
15 This section is excerpted in substantial parts from S. Cohen and J. Zysman, Manufacturing Matters: the Myth of a Post-Industrial Economy, Basic Books, New York, 1987.
16 Burton H. Klein, "Dynamic Competition and Productivity Advances", in Landau and Rosenberg, eds. Positive-Sum Stragegies. Cited in Manufacturig Matters, p.131.
17 Carol Parsons, The Diffusion of New Manufacturing Technologies in US Industry, BRIE Working Paper, Berkeley, 1985.

18 Cohen and Zysman, op. cit.
19 Nelson R. R., and Winter S. G., An Evolutionary Theory of Economic Change, The Belknop Press of Harvard University Press, Cambridge MA, 1982.
20 Dosi G., Technical Change and Industrial Transformation, Mac Millan, London, 1984.
21 These figures and the following are from: Arcangeli F., Dosi G., and Moggi M., "Patterns of Diffusion of Electronics Technologies", paper prepared for the Conference on Programmable Automation and New Work Modes, GERTTD, Paris, 2-4 April 1987. Data from various sources, including Electronics, Motorola, CBEMA, OECD (Industrial Structure Statistics), US Dept of Commerce, Reseau (Milan).
22 Manufacturing Matters, pp. 172-173
23 Manufacturing Matters, pp. 173-174

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