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Technology and Economic Performance in the German Economy

by

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Abstract:

Germany remains Europe's largest and most diversified source of new technology, but still lags in the fastest growing areas of today's high technology. After World War II, West-German technology policy sought to rebuild the institutions which had supported Germany's leadership in the high-tech industries of the early twentieth century – automobiles, machinery, electrical engineering, chemicals and pharmaceuticals. Increasingly, however, those institutions are seen as failing to respond to new technological stimuli. In addition, Germany's bank-centered capital and inflexible labor markets have long constrained the opportunities of innovative firms for equity-based growth and the incentives for academic brains to set up in private business. Promising changes in technology policy and capital market conditions can be observed only since the mid-1990s.

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I. Performance and Policy Issues in Germany (1970–2000)

Macroeconomic Phases. Germany's macroeconomic performance over the past three decades cannot be explained as an exclusive implication of technological change alone. It has rather been shaped by a mixture of influences common to all Western industrialized countries, of developments related to the creation of Europe's common market and of events that were unique to Germany; and this means to West-Germany until 1990 and reunited Germany thereafter. After the catching-up process in the fifties and sixties, the oil-price-shock of 1973 led to stagflation, a combination of persistent inflation around five percent and mass unemployment at about four percent of the labor force, thus ending the period of extreme labor scarcity which had prevailed in West-Germany since the early sixties. The 1980s, beginning with a second massive oil price hike, saw successful monetary stabilization, crowned by an even slightly negative rate of consumer price inflation in 1986 when the counter-oil shock cut producer prices significantly. But the 1980s also saw the gradual transformation of growing numbers of unemployed into structural unemployment as the West-German economy became more service oriented and the mismatch between labor demand and the skills offered by displaced workers from declining industries became increasingly evident.

The 1990s, finally, saw a jigsaw of changing conditions. German unification and the policy of massive fiscal transfers from West to East first boosted demand and growth. But this boom was ended by a sharp recession in 1993 from which the economy has only slowly recovered in the latter half of the nineties, with annual growth rates below two percent. Unemployment even continued to climb to 4.5 million in 1997, well above eleven percent of the labor force. Moreover, the influx of labor from Eastern Germany and Eastern Europe may have slowed down West-German productivity growth in the early 1990s, but since the mid-1990s, substantial employment cuts and corporate restructuring have led to annual labor productivity gains of up to 8 percent in the manufacturing sector (OECD 1998).

Technological Phases. In the 1970s, the oil-price-shock spurred the West-German government in its drive to develop nuclear energy into a viable alternative to oil in power generation. Wage inflation at the same time prompted the private sector to search for labor saving process technologies that would help to maintain international competitiveness in the production of tradables. Because input substitution was at least partially at the expense of total factor productivity, the rising relative prices of oil and labor did play an important role in the productivity slowdown (cf. Siebert 1992). The 1980s saw a virtual cycle of booming exports, stimulated by the temporary rise of the US dollar, and of incremental technological improvements along established trajectories, which mainly benefited the export-oriented automobile, machinery and chemical industries. But several attempts by large German corporations to enter newly emerging fields of high-technology ended with disappointment, e.g. the Siemens-Nixdorf saga in computers and the early foray of Hoechst into biotechnology. With respect to computers, German producers of mainframes were at first ill-prepared for the advent of the PC, and the adoption of decentralized computerization was then slow because the required corporate restructuring, in addition to individual retraining, was delayed in Germany as many firms gave priority to meeting the booming export demand for their established product lines in the 1980s and to the eastward expansion after German unification in the early 1990s. With respect to biotechnology, public technophobia, born by many years of anti-nuclear campaigning, and a very strict law on genetic engineering circumscribed the room for experiments so narrowly that several projects were halted in the courts even after substantial investments had been made by private firms.

The 1990s brought a sea change in technological priorities: First, there was the task of upgrading the technological basis in the remnants of East Germany's industry that were not immediately closed down after re-unification. And second, there was the task of clearing the way for the entry of business start-ups into the fast growing international software and biotechnology industries, where the US example had shown lively start-up activity to hold the key to economic success at the regional and national level. Progress in the East has been hampered by excessive wage deals and surging unemployment so that labor productivity growth has merely reflected capital deepening, rather than gains in total factor productivity. However, the eventual deregulation of Germany's telecommunications industry, substantial change in Germany's capital markets and new priorities in government support policies did prepare the ground for a wave of software and biotechnology start-ups, many of which got listed on Germany's *Neuer Markt* stock market segment for technology-based growth companies after its inception in 1997.

Macroeconomic Policy. Stability has been a mainstay of West-Germany's economic policy throughout the post-war period. The persistent unemployment and inflation which characterized the years after the 1973 oil-price shock in many industrial countries had more moderate proportions in West-Germany than in any comparable continental European country, bar Switzerland and Sweden. At their respective peaks, West German inflation was at seven percent (in 1974) and unemployment was at four percent (in 1975 and 1976). Moreover, the

Bundesbank's tight monetary policy was spectacularly successful in bringing down inflation during the 1980s. At the same time, however, the cyclical unemployment of the 1970s turned into a persistent level of structural unemployment, so that total unemployment hovered around eight percent after 1982 and remained unabated by significant employment growth in the expanding service economy during the 1980s. According to OECD estimates, the share of long-term unemployment, defined by a spell of one year or more, increased from 12.8 percent in 1981 to 32.6 percent in 1988 and has since remained at one third, while the level of structural unemployment, corresponding to a non-accelerating wage rate of unemployment, increased to 9.5 percent of the labor force, or 85 percent of total unemployment, in 1997.

Despite much anti-Keynesian government rhetoric, Germany's fiscal policy of the 1980s achieved no more than a stabilization, relative to GDP, of the public debt which had accumulated as a result of expansionary policies to fight unemployment in the 1970s. So, the Bundesbank remained the main pillar of macroeconomic stability and gained considerable credibility in international markets, which in turn afforded the Bundesbank with leverage to fight off inflation without raising interest rates as much as most other central banks had to do. As a consequence, bond yields remained lower than those in most European economies and debt finance continued to carry a relatively low cost of capital for private firms in Germany. This picture of relative macroeconomic stability was complemented by large current account surpluses, exceeding four percent of GDP in the second half of the 1980s, and by a relatively modest level of public debt compared to many other European countries.

Table 1 – Key macroeconomic data for Germany (from 1991 all Germany)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Annual labor productivity change (percent)	2.9	2.1	2.7	–11.7	4.1	0.6	3.4	2.2	2.7	3.7
Gross fixed investment (percent of GDP)	20.1	20.6	21.1	23.0	23.3	22.3	22.4	22.2	21.6	21.2
Output per employee (Index for 1995 = 100)	93.1	95.0	97.6	100.0	104.1	104.7	108.3	110.6	113.6	117.7
GDP at market prices (DM billion)	2301	2384	2520	2853	2916	2882	2960	3014	3055	3121
GDP deflator	91.1	93.3	96.3	100.0	105.6	109.8	112.4	114.8	115.9	116.7
Household saving (percent of disposable income)	12.8	12.4	13.8	12.9	12.8	12.2	11.6	11.3	11.4	10.9
Labor force, total (mill.)	29.6	29.8	30.4	39.2	38.8	38.6	38.7	38.4	38.3	38.3
Unemployment rate	7.6	6.9	6.2	6.7	7.7	8.8	9.6	9.4	10.3	11.4
Monthly contractual pay rates	87.8	90.2	94.1	100.0	111.0	118.2	121.7	127.0	129.9	131.7
Balance on current account	88	107	79	–30	–30	–23	–33	–33	–21	–2
German direct investment abroad[a]				38	29	28	31	56	76	70
German portfolio investment abroad[a]	72	50	25	30	76	53	84	33	54	161
Foreign direct investment in Germany(a)				8	3	1	12	17	8	17
Foreign portfolio investment in Germany[a]	7	46	19	71	123	236	45	85	141	151
Total exports, fob (DM billion)	568	641	646	666	671	604	681	728	772	887
Chemicals exports	77	83	82	85	85	79	92	98	102	117
Manufactured materials exports	103	117	114	113	111	98	110	121	119	134
Machinery and transport equipment exports	273	312	319	326	333	299	336	361	383	440
Total R&D expenditure (percent of GDP)	2.9	2.9	2.9	2.8	2.6	2.5	2.4	2.3	2.3	2.3
R&D as percent of GDP in business enterprise sector	2.6	2.6	2.6	2.5	2.3	2.2	2.1	2.0	1.9	

(a)DM billion, from July 1990 including East Germany. Data are from the Sachverständigenrat (2000) based on German balance of payments statistics, which counts as direct investments share holdings of more than 20 percent in a foreign firm.

Source: OECD (1998).

In 1990, German unification changed this picture dramatically as both the current account and the public budget balance turned sharply negative and the public debt began to increase dramatically. Interest rates, both long and short term, shot up, yet — as another testimony to the Bundesbank's credibility — not as much as during the early 1980s, when central banks first became serious about fighting the inflationary legacy of the 1970s. The cause of the sudden current account swing in 1990 was Germany's enormous unification-induced demand for capital, an increase in absorption relative to production, which outstripped the supply of domestic savings by a wide margin. Not only was it politically inopportune at the time to raise the level of domestic savings through official measures, but also the poor state of Germany's capital markets implied that the established Western industrial corporations and financial intermediaries controlled the flow of available savings and largely channeled them into low-risk investments of the kind long practiced in West-Germany. As a consequence, reinforced by new distortionary tax credits in favor of Eastern Germany, not all socially profitable investment opportunities that arose from unification translated into appropriate signals and privately profitable openings for individual investors. Much of the limited additional savings that were mobilized from individuals went into cleverly marketed real estate developments in Eastern Germany, which promised immediate tax savings, but generated huge overcapacity and disappointing returns over the longer term.

As a further constraint, Germany's pay-as-you-go pension and health care systems already extracted so heavy a toll from the working population that the supply of private savings was bound to be inelastic with respect to rising interest rates. The current account surpluses before unification were a sign that a large portion of domestic savings went abroad, ostensibly for lack of profitable investment opportunities at home. After unification, large foreign capital inflows complemented the limited domestic supply of savings and so allowed the German government to raise huge amounts of capital in the bond market, where liquidity was and remained high. However, the extensive fiscal and social security transfer program, which was politically motivated to reduce incentives for East-West migration, meant that the larger part of Western transfer payments to Eastern Germany actually went into consumption, as well as private housing and public infrastructure renovation, while private investment in new plants and equipment remained below the optimistic expectations of many commentators in the early 1990s. To the extent that Western transfer payments inflated the prices of local resources, Eastern Germany suffered a unification-induced Dutch disease, which let the output of nontradables expand at the expense of the tradables sector.

Relatively low rates of non-residential capital formation have been a drag on the West-German (and later Pan-German) economy since the early 1980s, interrupted only by somewhat more expansionary investment during the late 1980s and early 1990s. From 1989 to 1992, gross fixed investment in relation to GDP rose by roughly three percentage points to 23.3 percent and has since declined by more than two percentage points. Germany's now endemic problem with private sector investment mainly reflects a rate of return which has since the unification boom returned almost to the abysmally low level of the early 1980s before beginning to rise slightly in the latter half of the 1990s.

In a revealing contrast, German firms have since the mid-1980s become increasingly willing to make direct investments abroad, both in other industrial and in developing countries. Although bringing the marketing and sales force closer to customers has been the dominant motive, the quest for lower labor costs and the enhancement of firms' in-house capacity to innovate have also been important considerations. In the 1990s, between 20 and 30 percent of German direct investments has shifted to the newly emerging market economies of Eastern Europe, many of which offered a sufficiently skilled labor force to be in direct locational competition with Eastern Germany. Advances in information and communication technologies appear to have been crucial in facilitating the effective management of foreign production subsidiaries and R&D laboratories in an increasing array of industries. Annual statistics on the flows of direct foreign investments, such as those provided by the Sachverständigenrat (2000), are volatile because they are often influenced by large individual transactions, like the acquisition of Rover by BMW in 1994 or the acquisiton of Mannesmann by Vodafone in 2000.

In tandem with globalization, it has been trends in technological innovation which have contributed to considerable structural change within the manufacturing sector. Via technology's role in determining comparative advantages, technological change is bound to have a larger effect on industrial structure in the German economy than in the Japanese and US economies since Germany, with its central European location, is much more open to and dependent on international trade. Yet, in terms of revealed comparative advantage, the technological position of the German economy has long been something of a paradox. At the aggregate level, Germany is not only Europe's leading producer and exporter of investment goods and consumer durables embodying new technology, but also home to a well trained labor force with one of the world's highest propensities to patent industrial innovations. In 1997, for example, Germany took out more patents from the European Patent Office in proportion to the size of the labor force than any country bar Switzerland and Sweden. At a disaggregate level, however, only a relatively small share of German exports comes from industries regarded as genuinely high-tech, like the science-based pharmaceutical, computer and software industries. Instead, the bulk of Germany's persistent export success is attributable to the technological sophistication of a broad range of continuously upgraded products from well-established industries, like automobiles, chemicals and machine tools, which may be labeled engineering-based. It is in these areas that Germany's capacity to innovate has long been a source of welfare gains from endogenous comparative advantages, which the entry of newly industrializing countries into the world market has gradually begun to erode in some of those areas.

German Technology Policy. In different guises, public debate about Germany's ability to innovate has been going on for the past three decades. It has been fed by a recurrent fear that Germany is not only losing its traditional strengths, but is also missing out on new opportunities, especially in those high-tech industries where revealed comparative advantages arise from the spatial concentration of activities subject to economies of scale — the Silicon Valley phenomenon. In some sense, the German debate is only a new verse to an old song whose historical origin has largely been forgotten. Yet, much of German technology policy still rests on the ideas of List (1841) who developed a comprehensive and highly influential strategy for economic catch-up with Britain, the undisputed technological leader of the industrial revolution in the early 19th century. After its defeat in World War II, Germany again found itself in technological backwardness, this time vis-à-vis the United States; not only had the Nazis forced many of the best academics out of their jobs and into emigration, but also research priorities of the Nazi period with potential military applications, as in aerospace, became obsolete for political reasons. Moreover, the technological paradigm of mass production arrived much later in Germany than in the US where it flourished under the uniquely favorable conditions of the 1920s, described in Rosenberg (1994). In West-Germany's post-war setting, the adoption of often superior US technology and public support for the diffusion of best practice throughout the economy were natural and complementary choices.

In the past three decades, the basic diffusion orientation of the German system of innovation has remained intact, despite several changes in official government funding priorities. While they are important, government schemes of financial support for specific new technologies do not epitomize the essence of the system. The essence is rather to be found in the institutional set-up of public research and technology transfer and in the historically prevailing conditions in Germany's capital and labor markets which determine how resources are allocated towards innovative activities and how the associated risks are shared. These conditions have helped the private sector to create the absorptive capacity which allows existing firms to adopt new technologies and build on recent findings of academic research, in line with the dual role of firms' own research and development (R&D) that was pointed out by Cohen and Levinthal (1989).

In the allocation of *capital* and in the governance of industrial corporations, public issues and stock market transactions have traditionally played a much smaller role in Germany than in the Anglo-Saxon system. The larger part of established firms' external finance has often been provided in the form of negotiated debt to a so-called *Hausbank*, to which a typical industrial firm is married for virtually all its life. However, since banks often shy away from financing intangible investments, the private sector's own contribution to R&D funding typically comes from retained earnings, a second-best solution from which most start-ups are excluded. In the *labor* market, the German system has encouraged intensive training-on-the-job and the accumulation of firm-specific human capital, which is most effectively exploited if workers stay with their employers for a long time. Back-up is provided by a diffusion-oriented education system emphasizing broad technical training at almost every level, from vocational schools to the world-famous technical universities, and by Germany's proliferating institutions for the transfer of knowledge and new technology from public research into private industry. Indeed, the established paradigm of German technology policy can be interpreted as providing public institutions to substitute for missing market transactions in the diffusion of knowledge and technology. Within the scope of these institutions, there has been ample support for incremental innovations along established trajectories, but relatively little incentive for radical moves into entirely new areas of technology.

This institutional heritage from the heyday of Germany's established industries has been slow to adapt to the changing technological opportunities and constraints, for example, in terms of the increasing codification of knowledge and in terms of the lost comparative advantage of large established firms in the most dynamic fields of high technology today. Indeed, the inertia in Germany's science and technology institutions and in its capital and labor markets appear to have been the most important reason for Germany's lack of competitive players in biotechnology and information technology until recently. Public technophobia and the overregulation of markets, which certainly did play a role in the failure of German biotechnology activities in the 1980s, appear to have been partially overcome. The application of biotechnology in pharmaceuticals is now generally welcome, but genetically modified foodstuffs are still finding few buyers when brought to market on an experimental basis, as in the case of Nestlé's „butter-finger" candy bar.

To some extent, the institutional and private sector's inertia at technological crossroads had long been recognized and the German government has repeatedly tried in the past to balance this inertia with missionary programs to develop selected technologies — like the fast breeder nuclear reactor, the Airbus family of wide-bodied aircraft and the *Transrapid* magnetic levitation train — which were thought too large, too complex or too much of a departure from existing technological paradigms to be manageable by private firms on their own. While the German government may have sought to emulate similar French initiatives with some of these programs, the German public has always shown much less enthusiasm for state-sponsored mega-technologies than the French, and sometimes even outright hostility. With hindsight, the mission-oriented elements of German technology policy have indeed done more harm than good, with the fast breeder long abandoned, the Airbus project at the center of recurrent trade disputes over subsidies and the Transrapid apparently too expensive for a viable commercial line even between Germany's two largest cities. Anyway, except as a drain on the public purse, these missionary technology projects have never had a significant impact on Germany's macroeconomic performance.

II. The Role of Technology

Technological Change — What Changes are we Talking about? Since imperial Germany's successful catch-up with British technology and productivity in the 19th century, the German innovation system has built and improved on its capacity to absorb new technology and diffuse it rapidly throughout the economy. German productivity growth has evidently not depended on a record of trailblazing domestic inventions but rather on a technological infrastructure that helps private firms to apply smoothly within the context of existing industries whatever new technology becomes available. In the 1980s, for example, West-Germany adopted computer integrated manufacturing more rapidly than most other countries. In the 1990s, the technological upgrading of old firms in Eastern Germany was swift wherever those firms were privatized and acquired by established Western firms; as a result, more than three quarters of today's industrial plants in Eastern Germany have been installed after 1990, with heavy involvement by West Germany's leading corporations in the automobile, machinery, electrical and chemical industries.

The initial development of these industries in the 19th and early 20th century was associated with a wave of fundamental innovations many of which originated in Germany's new technology-based firms of that time. Some of these, like the Otto and Diesel engines used in automobiles and the pioneering designs of Werner von Siemens in electricity generation, have defined the technological trajectories on which these industries have expanded until today. The discovery of the painkiller Aspirin by Felix Hoffmann of Bayer in 1897 established a research model subsequently applied in the synthesis of many ethical drugs. The economic success of the highly organized search for new substances in the pharmaceutical industry's laboratories has influenced patterns of innovation elsewhere, although incremental tinkering is still an important feature of the innovation process in Germany's automobile and machinery industry. Product and process innovations as well as the organization of R&D in these and other industries has increasingly taken advantage of the new information technologies since the 1980s. The absorption of these radical innovations within the context of established product lines has been aided by the long-honed excellence of many German automobile, machinery and electrical equipment manufacturers as system integrators. Only in the 1990s, however, did the search for efficient applications of the new information technology prompt the restructuring of entire businesses and industries.

One way to assess the technological position of Germany's manufacturing sector via-à-vis other countries is to look at measures of revealed comparative advantage on the basis of trade data. German exports command a share of one third in GDP and overwhelmingly go to similarly endowed economies, the EU partners and other advanced industrialized countries. For this reason, the net trade flows associated with specific industries often tend to indicate the acquired technological strengths and weaknesses which must be distinguished from comparative advantages due to Germany's more fundamental endowment with factors of production. In 1997, for example, German exports accounted for 20 percent of world trade in machinery and automobiles, but for less than seven percent in information technology, with intermediate shares for chemicals, electrical engineering products, professional instruments and aerospace (BMBF 2000).

In order to abstract from a changing overall balance of trade in intertemporal comparisons, Balassa (1965) introduced the measure of revealed comparative advantage (RCA) which is here defined for each industry as the logarithmic ratio of that industry's share of German export to its share of German imports, multiplied by 100. Positive values indicate a relative export strength, while negative values indicate a weakness in the balance of trade in a particular product category compared to Germany's overall trade balance in a given year. Table 2 highlights selected long-term trends which confirm Germany's long-standing export strength in industries making relatively *intensive* use of R&D services (see also Table 3, last column). But unlike in Japan, the US and the UK, only a relatively small share of Germany's exports comes from the *most* R&D intensive industries, including biotechnology, on which more below, and semiconductors as well as computing and telecommunications equipment where Germany has long been a net-importer, taking advantage of the innovative prowess of the US and other countries which began much earlier to liberalize their own domestic telecommunication industries.

Germany's main contribution to the international division of labor continues to lie in exports from the upper segments of mature technology, in particular from the automobile, chemical and machine tool industries, which tend to have a medium level of R&D intensity. According to a commonly used classification of manufactures, proposed by the *Fraunhofer-Institut für Systemtechnik und Innovationsforschung*, a medium R&D intensity implies a share of R&D in sales between 3.5 and 8.5 percent; whereas manufactures with an R&D intensity above 8.5 percent are considered high technology. Machinery and transport equipment together accounted for almost 50 percent of total German exports in 1997, and chemicals for another 13 percent, much of which is intra-industry trade among the advanced countries. As long established industries with substantial product differentiation, they also offer rich opportunities for exploiting economies of scale and scope, as described in Chandler (1990). Large portions of these industries are not science-based in the sense that new products and processes are a direct implication of the latest advances in academic research. Science and engineering methods have rather helped to routinize the process of incremental innovation in long established, often highly specialized R&D laboratories. Given its broad range of long-standing export strengths, Germany's most important rival on the world market is Japan, but in some of Germany's export industries, there is also strong competition from Switzerland, Sweden, France and Italy.

Table 2 — Selected Trends in Germany's Revealed Comparative Advantages

		1961	1970	1980	1990	1995	1999
53	Dyeing, tanning and coloring materials	93.2	115.1	102.3	85.9	84.7	85.9
54	Medicinal and pharmaceutical products	58.7	48.9	12.6	20.9	17.1	34.9
56	Fertilizers, manufactured	221.4	79.8	–19.7	–62.0	–27.7	3.6
57	Explosives and pyrotechnic products	82.7	40.5	5.4	–22.3	–18.1	–94.2
65	Textile yarn, fabrics, made-up articles, related products	–122.4	–51.5	–53.5	–24.2	–17.3	–12.7
67	Iron and steel	3.1	–14.5	10.0	–8.6	–10.6	–0.3
68	Non-ferrous metals	–171.0	–140.8	–65.6	–56.9	–45.4	–23.2
69	Manufactures of metal, n.e.s.	88.9	42.7	22.6	16.9	5.3	10.2
71	Power generating machinery and equipm.	45.0	63.9	58.0	33.1	33.9	3.9
72	Machinery specialized for particular ind.	75.5	89.3	94.2	95.7	106.9	97.9
73	Metalworking machinery	60.7	81.4	77.5	41.2	76.0	51.4
74	General industrial machinery and equipment, and parts	64.1	59.8	63.6	54.4	60.7	56.2
75	Office machines and automatic data processing equipment	–51.2	–39.9	–49.9	–75.4	–79.7	–90.3
76	Telecommunications and sound recording apparatus	71.8	25.5	–15.4	–56.9	–26.4	–14.7
77	Electrical machinery, apparatus and appliances n.e.s.	51.7	8.5	10.0	7.4	0.0	–1.6
78	Road vehicles (incl. air-cushion vehicles)	150.2	76.0	75.4	50.8	37.0	48.7
79	Other transport equipment	48.5	–53.3	–32.4	–32.9	16.9	–6.0
87	Professional, scientific and controlling instruments	55.2	33.5	13.8	27.5	33.2	37.3
88	Photographic apparatus, optical goods, watches	48.6	8.7	–34.8	–27.4	–19.7	–17.0
95	Arms, of war and ammunition therefore	–53.4	–17.2	79.1	–42.3	15.6	–31.2

$RCA_{i,t} = \ln\left(\left(X_{i,t}/M_{i,t}\right)/\left(\sum_i X_{i,t}/\sum_i M_{i,t}\right)\right)\cdot 100$ with $X_{i,t}$ (resp. $M_{i,t}$) being Germany's exports (imports) in product category *i* and year *t*.

Source: OECD, International Trade by Commodities (ITCS), Rev. 2, own computations, West-Germany until 1990, thereafter all Germany.

Table 3 – Relative Size of R&D-intensive Manufacturing Industries, Germany

	1995–1997		1997					
	Value added	Emplo-yees	Value added	Emplo-yees	Foreign sales	Share of em-ployees	Share of total sales	Share of foreign sales
	percent(b)		percent(c)			percent		
R&D-intensive manufacturing(a)	3.7	–3.2	5.4	–3.0	14.3	45.1	45.3	65.1
thereof:								
High technology	6.8	–3.5	8.6	–4.8	22.1	7.6	8.3	11.8
therein:								
Pharamceutical specialities	–4.8	–3.5	–4.7	–5.2	12.2	1.7	1.8	1.9
Computing equipment	17.9	–6.9	20.7	–4.3	24.3	0.5	1.1	1.2
Telecommunications equipment	14.2	–3.2	11.4	–7.2	25.9	1.1	1.5	2.3
Aerospace	–2.5	–4.9	0.5	–2.1	40.3	0.9	1.0	1.9
Medium technology	2.8	–3.2	4.5	–2.6	12.7	37.5	37.1	53.2
therein:								
Plastics	5.7	–3.4	10.0	–5.3	15.9	1.1	1.7	2.9
Machine tools	1.7	–3.1	1.2	–4.0	–0.1	1.9	1.4	2.0
Electrical switches	1.9	–4.0	2.1	–4.1	9.5	3.0	2.6	2.6
Automobile	4.8	0.7	5.3	3.2	16.4	6.2	9.9	17.2
Non-R&D-intensive manufacturing(a)	0.7	–3.5	3.3	–3.2	10.1	54.9	54.7	34.9
Total manufacturing	2.2	–3.4	4.4	–3.1	12.8	100	100	100

(a)Classification of industries according to Niedersächsisches Institut für Wirtschaftsforschung. — (b)Average annual percentage change. — (c)One year percentage change.

Source: Sachverständigenrat (1998).

Over time, the pattern of Germany's export specialization has remained rather stable. Germany's most important export industries, automobiles and industrial machinery, have held their world market shares and in the late 1990s even increased them; particularly impressive has been the rising export strength in specialized machinery. By contrast, there has been a gradual erosion of Germany's traditional strengths in chemicals and electrical machinery. With respect to high technology, the following *changes* are notable. Germany's relative export share in the telecommunications equipment industry, which had been in long-term decline for many years, has slightly increased since the mid-1990s. A comparison of changes in labor input and added value between R&D intensive industries and non-R&D intensive manufacturing, provided in Table 3, indicates that the computing and telecommunications industries have seen the largest productivity advances, despite their persistent export weakness, in the late 1990s. In pharmaceuticals and agrochemicals, the most R&D intensive sectors within the chemical industry, Germany has lost much of its traditional strength in exports — a loss which is closely related to Germany's protracted entry into the modern biotechnology industry. In addition, the German pharmaceutical industry, once considered the world's pharmacy, has suffered from increased competition in generica. Germany's former export strength in photographic apparatus, optical goods and watches was already lost during the ascend of Japan's industry on the world market in the 1960s and 1970s, but Germany held on to its strong export position in scientific instruments. Not reflected in the official trade data is the rise of a more competitive German software industry in the 1990s, which seems to be growing out of its former niche markets and is beginning to compete successfully in the global market for business applications.

How Technical Change is Created: a Bird's Eye View. Several empirical studies have suggested that the research productivity of the German innovation system is high in comparison with most European countries. In one recent econometric study, using data on R&D workers and patenting from 21 OECD countries during the 1988—1990 period, Eaton et al. (1998) estimate that West-German research productivity was exceeded only by some of the relatively small countries in Scandinavia as well as by Switzerland and Austria. Moreover, they argue that not only the German, but also the European income elasticity with respect to the employment of additional R&D scientists and engineers is largest if these are employed in Germany, because technological innovation in Germany tends to create the largest knowledge spillovers for other European economies.

Thus, the overall technological strength which is suggested by Germany's large share of world exports in R&D intensive manufacturing goods is confirmed when innovative activities are measured more directly, with a focus on the resources devoted to formal R&D and on its output in terms of patents. A summary of statistical evidence is provided in BMBF (2000). Of the approximately 500 billion US dollars spent on R&D in all OECD countries in 1997, Germany held a share of 8.5 percent and fell in third place behind the US and Japan. But in proportion to GDP, Germany's relative position vis-à-vis the other OECD countries has declined during the 1990s. With total R&D expenditures at almost 3 percent of GDP, West Germany was still one of the most R&D intensive OECD economies in 1989. But since unification, the Pan-German R&D intensity has declined to less than 2.4 percent while that of most other OECD countries has either increased or stayed constant. The decline in the R&D intensity of Germany's private business sector from 2.9 percent in 1989 to 1.9 in

1996 was even more pronounced; only in the final years of the 1990s has the private business sector's R&D expenditure return to an expansionary path.

In spite of changes in R&D intensity, the mixture of funding sources has long been rather stable and reflects Germany's fiscal federalism and distributed responsibilities for science and technology policy. Almost two thirds of total R&D expenditures in Germany in the 1990s was funded by the private sector, the remaining third by the government sector, within which the federal government held a share of two thirds again. The other third of public sector funds is spent by the 16 federal states which are constitutionally responsible for the institutional funding of Germany's public universities. The Federal Minister for Research and Education spends about 20 percent of his funding on research in universities and public sector research institutes, about 29 percent in the private business sector, and more than 40 percent in private non-profit, often para-public research institutions. 10 percent of federal funds flow to international institutions, including the European Union and the European Space Agency.

Within Germany, the federal government uses three main channels to distribute the funds: institutional funding, direct project grants and indirect as well as the so-called indirect-specific funding. The latter is targeted at certain preselected areas of technology, like computer integrated manufacturing, or socio-economic tasks, like health care and renewable energy sources, and funds within such programs are awarded on the merits of pertinent research proposals from eligible parties in the public and private sectors. Institutional support for public research institutes and private non-profit organizations accounted for 40 percent, direct grants towards selected research proposals for 42 percent and the indirect and indirect-specific programs for four percent of federal R&D spending in 1996 (cf. Klodt 1998). Most project support for private R&D is thus granted upon application, conditional on the evaluation of research proposals and progress reports. Only a relatively small share of federal R&D expenditure is distributed as indirect and indirect-specific project support, in spite of the fact that these channels are especially tailored for Germany's many small and medium sized enterprises seeking to innovate in a targeted, albeit sometimes rather narrow, field of technology. And despite the variety of channels used for the distribution of federal funds, it has been estimated that only about 20 percent of private R&D projects receive any federal co-financing at all (Klodt 1998).

Table 4 – Federal R&D Funds by Type of Expenditure

	1981		1990		1996	
	Mill. DM	percent	Mill. DM	percent	Mill. DM	percent
1. Institutional support	3563	34.0	5161	33.6	6813	40.9
1.1 Research-funding institutions			1346	8.8	2184	12.4
1.2 National research centers			2396	15.7	2615	14.8
1.3 Federal research agencies			966	6.3	1363	7.7
1.4 Other institutions			496	3.1	913	5.2
2. Project support	5940	56.7	8321	54.2	7470	44.8
2.1 Direct			7930	52.1	7425	42.2
thereof:						
Minister of Science and Technology			3309	21.7	3559	20.2
Minister of Defense			3090	20.3	2894	16.4
Minister of Economics			699	4.6	357	2.0
2.2 Indirect and indirect-specific			353	2.3	677	3.8
3. International cooperation	708	6.8	1459	8.8	1566	9.6
Total	10484	100.0	15361	100.0	16272	100.0

Source: BMBF (1996, 1998) and Klodt (1998).

Of all the R&D expenditure incurred by Germany’s business enterprise sector in 1993, government funding accounted for only eleven percent. But the federal share was much larger in some industries and smaller in others: While the federal share was a staggering 68 percent in aerospace, it was only one percent in the chemical industry and even below one percent in the automobile industry. Also notable among the recipients of above average support for their R&D activities are the professional instruments, fabricated metal products, iron and steel industries as well as the textile and apparel industry. Outside the manufacturing sector, the share of government funding in total business R&D expenditures has also been high, namely about 16 percent in energy, 34 percent in mining, and 28 percent in other non-manufacturing industries. There is thus a sharp contrast between government priorities and the private sector distribution of R&D expenditures in Germany. The main performers of business sector R&D, the chemical industry, electrical and non-electrical machinery as well as the automobile industry, which together account for almost three quarters of all business sector R&D expenditures, received only 20 percent of federal government funding in 1993. As Klodt (1998) notes, it is probably due to bureaucratic inertia and vested interests in the administration and distribution of government funds that the sectoral structure of public R&D subsidies has remained rather stable over time, regardless of changes in the *official* priorities of technology policy which have been announced every few years.

Table 5 – R&D Expenditures of German Business Enerprises by Industry 1993

	Total		Government funded	
	mill. DM	percent(a)	mill. DM	percent(b)
Energy	177	0.2	29	16.4
Mining	322	1.0	109	33.9
Manufacturing	48194	4.3	4446	9.2
of which:				
Chemical industry	9664	6.1	98	1.0
Rubber and plastics	728	2.5	29	4.0
Stone and clay	474	1.6	42	8.9
Iron and steel	329	1.1	42	12.8
Non-electrical machinery	5135	3.1	219	4.3
Motorcar industry	10467	5.2	93	0.9
Aircraft and space	3259	24.4	2789	85.6
Electrical machinery	12439	6.5	717	5.8
Instruments	778	4.9	102	13.1
Fabricated metal products	877	1.2	97	11.1
Wood, paper and printing	229	1.1	25	10.9
Textiles and apparel	279	2.0	57	20.4
Food and beverages	317	0.6	21	6.6
Other industries	2028	1.1	560	27.6
Total	51236	3.6	5658	11.0

(a)Share in sales of R&D-peforming companies. — (b)Share in total R&D expenditures.

Source: Stifterverband für die Deutsche Wissenschaft (1995) and Klodt (1998).

While the level of aggregate *inputs* has seen a relative decline, Germany has held its relative position vis-à-vis the other large industrial countries with respect to *output*, if that is measured in terms of patenting activity. Indeed, Germany has fully participated in the upsurge of patenting which has been observed throughout the OED countries since the mid-1990s. That patenting has risen much faster in the second half of the 1990s than industrial R&D budgets has probably had several causes. First, regulatory reforms in a number of countries have lowered the costs of international patenting. Second, firms whose shares are traded in the stock market have discovered that systematic patenting can serve as a defense against hostile takeovers by increasing shareholder value. Third, organizational restructuring and the growing use of information and communication technologies may have increased the efficiency of formal R&D activities in the business enterprise sector. This latter view is supported by the observation that the share of academically trained scientists and engineers among all R&D workers in the German business sector has increased since 1989 (BMBF 2000).

Since many manufacturing industries display a stable relationship between their aggregate R&D activities and patent counts in the fields of technology to which they contribute, patenting trends have been widely used to assess structural changes in the output of innovation in the business enterprise sector. In these studies, patent count data are used to compute an indicator of revealed technological advantage (RTA), similar to the RCA indicator introduced by Balassa (1965), across different fields of technology in which patent applications are classified by the patent offices. On this indicator, Germany's technological specialization is indeed closely related to its trade specialization (see, for example, Stolpe 1995, Casper et al. 1999 and BMBF 2000). While Germany can muster only a relatively weak patenting record in many of the fast-paced areas of today's high technology, especially in biotechnology, information technology, telecommunications, semiconductors and audiovisual technologies, it has a relatively strong record in many longer established and more slowly growing fields of technology, like nuclear power, civil and mechanical engineering, engine and environmental technology as well as conventional pharmaceuticals.

On the input side, Germany's private business sector has suffered from a shrinking share of R&D *investment* until the mid-1990s, whose decline was even *more* significant than the shrinking share of the private business sector's share of *current* R&D expenditure; and this trend has only gradually begun to be reversed. At the same time, structural change in the output composition of German manufacturing has favored the more R&D intensive industries. Gross capital formation has shown divergent trends across industries in the second half of the 1990s. It has increased by almost 50 percent in the R&D intensive industries and remained constant elsewhere (BMBF 2000). Notable has also been the trend towards increased outsourcing of R&D services in the business sector, which reached ten percent of total spending in 1997. Cooperative R&D ventures within the private business sector, which may include competitors, customers and suppliers, accounted for two thirds of external R&D spending in 1997. However, the share of universities and other public research institutes in the private business sector's external R&D spending has seen an ominous decline to ten percent in 1997 (BMBF 2000).

One reason for this decline appears to be a partial mismatch between the technological specialization of business sector R&D and the research specialization of the academic sector across science and engineering disciplines. In the latest government report on Germany's capacity for technological innovation (BMBF 2000), the profile of academic specialization is assessed in terms of the publication record of German research institutes in the Science Citation Index. Based on publications from the 1996-98 period, Germany’s academic research is more strongly concentrated in nuclear physics, optics, computing, medical technology, organic chemicals and biotechnology than the index of German patent specialization based on European patent applications during the 1995-97 period. At the same time, the publication record suggests weaknesses in process and environmental technology, machinery and civil engineering where Germany has a relatively strong patenting record. Certain long established areas of technological strength in terms of patent counts, like professional instruments, polymers, basic chemicals and materials science, are matched by a relatively strong academic publication record. But in some of the fastest growing areas of science-based technology, above all in pharmaceuticals and telecommunications, Germany’s record is relatively weak in terms of *both* publications and patents. However, there is one piece of evidence to suggest that public sector research may at least partially be moving closer towards technologies with potential applications in the private business enterprise sector: In the aggregate, all institutional sub-sectors within the public research system have increased their patenting activity significantly during the 1990s.

How Technical Change is Created: Public Research and Technology Transfer. Germany has developed one of the world’s most extensive infrastructures for academic research, much of which is intended to serve private industry despite falling largely in the public sector. The public research sector is subdivided between institutes oriented towards basic research and others with a more applied focus which are to facilitate the transfer of knowledge from Germany’s science base to industry. Among the former, university research in the natural sciences often plays second fiddle to the research carried out by Germany’s prestigious *Max-Planck-Institutes* and, in some other fields, to the research carried out by more than eighty other large and medium sized institutes on the so-called Blue List, now named *Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL).* Big science, which often requires an interdisciplinary approach as well as very large-scale equipment, is mainly performed by the member institutes of the *Hermann von Helmholtz Association of National Research Centers* with a combined staff of roughly 22,000. Their activities are concentrated in environmental, energy, health, materials science, information and communication and in aviation, space and other key technologies, which the private sector is thought to neglect in its drive for short-term profits. 90 percent of the total annual budget of currently about DM 4 billion is funded by the federal government, and only 10 percent on average comes from the states in which a particular institute is located.

Among the institutes with a more applied focus, the *Fraunhofer* Institutes stand out as forming the largest and most successful organizational network. The *Fraunhofer* Society currently maintains about fifty institutes across the country with a total staff of almost 5000 scientists and engineers. Each institute is focused on a clearly defined field of technology with special relevance to particular industries. Within this scope, each institute is to serve as an intermediary for the transfer of technology between Germany's science base and the business enterprise sector, a demand which is mainly met through contract research. The *Fraunhofer* Society's postwar origin, described in Trischler and vom Bruch (1999), lay in Bavaria which, after the dissection of Prussia, Bavaria's arch-rival, by the allied powers in postwar-Germany, seized the opportunity to lure research and engineering talent from Prussia's main agglomeration of science and technology activities, which was in Berlin. Bavaria's capital, Munich, which had seen little innovative activity before the war duly became one of West-Germany's preferred locations for technological innovation in a variety of industries, including in the 1960s and 1970s electrical and electronic engineering (Siemens), Germany's re-emerging aerospace industry (Messerschmidt-Bölkow-Blohm) and software and biotechnology in the 1980s and 1990s.

Germany's public system of research and technology transfer features a variety of other players with a special mandate to support technological innovation in small and medium sized *Mittelstand* firms, which often cannot afford to maintain their own in-house R&D departments. The most widely dispersed of these players is the *Arbeitsgemeinschaft industrieller Forschungsvereinigungen* (AiF), a network of industrial research associations which support and carry out *cooperative* research by small and medium-sized enterprises. Moreover, Germany's many regional universities and *Fachhochschulen* (polytechnics) offer and seek opportunities for collaborative R&D under contract with private firms at the periphery of the science and technology landscape. Probably the most successful regional model is the *Steinbeiss*-Foundation which maintains a network of technology transfer and consulting centers based in Baden-Württemberg's *Fachhochschulen*.

The division of labor between basic research and applied research is reflected in the mix of funding sources for the different branches of Germany's innovation system (cf. Mason and Wagner 1999). For example, the Helmholtz-, Max-Planck- and Blue-List-Institutes are predominantly financed via institutional support from the federal and state governments. But this source of funding has accounted for no more than one third of the income of a typical *Fraunhofer* Institute. Before recent cuts in government grants, another third of *Fraunhofer's* income came from government sponsored projects, usually carried out in collaboration with private business partners, and the remaining third was raised through commercial contract research for private sector clients. With this balanced mix of funding sources, the Fraunhofer society has maintained a degree of flexibility that is unusual for a bureaucracy of its size and has often been able to mobilize resources for new institutes in surprisingly short time. And what is more, the Fraunhofer Society has also demonstrated its flexibility in closing down institutes whose area of research had become obsolete. It is for these virtues that the federal government has decided to incorporate the *Gesellschaft für Mathematik und Datenverarbeitung* (GMD), the Helmholtz center for research in information technology with a total staff of more than 1,300, into the Fraunhofer Society, whose own software savviness recently led to the invention of the MP3 data compression format now widely used for music distribution on the Internet. However, the government plan has met with considerable resistance among the research staff at the GMD who fear for their autonomy in setting research priorities and do not want to taint their academic reputation by more research with commercial applications.

It is part of a more general problem that the management of individual *Fraunhofer* institutes remains constrained not only by Germany's general labor market rigidities and by the many specific employment rules which the government imposes as implicit and explicit conditions for its institutional funding of *Fraunhofer's* basic research activities. Mason and Wagner (1999), among others, have therefore voiced doubts whether Germany's applied research institutes will be able to keep up with the speed at which research priorities change in today's fastest growing areas of high technology, software and biotechnology in particular. They may thus become less attractive research partners for private firms and also lose their attractiveness as partners for university based researchers as the constraints of public funding rules no longer keep up with the rapidly rising private sector wages for the best scientists and engineers in some of the most dynamic fields of technology. Thus, Germany's applied research institutes ironically appear least likely to succeed in those fields of technology where the relative advantage of in-house R&D may be declining fastest, because the codification of an ever increasing portion of technological knowledge and falling communication costs in electronic networks have made new modes of research feasible which rely on rapid diffusion and on a deeper division of labor, including the outsourcing of R&D services (cf. David and Foray 1995).

How Technical Change is Created: Established Industries. Germany's largest technology-based industries, electrical engineering, chemicals, machinery and automobiles, were formed in the late 19th and early 20th century. Their subsequent growth and development has been closely linked to the making of Germany's national system of industrial innovation, whose elements are not only the institutions of public research or the official funding priorities in technology policy, but include the entire set of market and non-market institutions which determine the opportunities for innovation as well as the conditions for the diffusion of knowledge and the application of new technology throughout the economy.

Market structure in all of Germany's established industries has been quite stable over long periods of time and has effectively supported a pattern of cooperative research and innovation which often helped to internalize knowledge spillovers of the kind identified by the new growth theory (Grubel and Weder 1993). Many small and medium sized supplier firms, often privately held, are securely placed in niche markets around dominant players, such as Siemens in electrical engineering, Daimler-Benz and Volkswagen in the automobile industry (see Casper 1997), BASF, Bayer and Hoechst in chemicals — the latter recently merged with Rhône-Poulenc of France into Aventis — and Linde, Mannesmann and a number of others in machinery. Historically, this stable pattern of industrial organization has provided an important source of distributive strength in the diffusion of new knowledge and process innovations as long as these were complementary and not disruptive to an industry's technological trajectory. Only where disruption was forced on a firm through path-breaking technological innovation or unraveling changes in its business environment, as in the case of Hoechst's failure to manage the transition to biotechnology in two of its core businesses, agrochemicals and pharmaceuticals, did the merger with an equal-sized and even foreign firm become desirable.

On closer inspection, there are important differences between Germany's large established industries. In the electrical industry, Siemens is the giant survivor of a historic rivalry with AEG dating back to the beginnings of electric power generation, transmission and lighting in the second half of the 19th century. Siemens' scope today extends to applications of electrical technology as diverse as solar power, computer chips, medical equipment, household appliances and automotive engineering. Although Siemens is no longer the ground-breaking technological pioneer in its current areas of business that it was in its early days, it has nevertheless defended a position among the leaders in many markets through the introduction of countless incremental innovations, an efficient production system and the globalization of its operations. In the late 1990s, the

Siemens management began to take advantage of improved capital market conditions for partial spin-offs in Siemens' more dynamic areas of business — creating the separately listed Epcos and Infineon subsidiaries in telecommunications components and chip technology — in an effort to accelerate restructuring, improve managerial incentives and raise additional equity capital.

In the German chemical industry, two of the three pioneering firms of the late 19th century, Bayer and BASF, still dominate alongside the German operations of Aventis. And this is in spite of the limitations which the wars and financial crises of the early 20th century placed on the scope for the German chemical industry's diversification. Many technological opportunities were missed. World War I cut Germany off from overseas supplies of oil and the expropriation of foreign assets effectively ended the prospect of an internationally competitive oil and petrochemical industry, which had been nascent before that war (cf. Chandler 1990). The 1920s saw the comprehensive cartelization of Germany's chemical industry under the ominous roof of I.G. Farben and, as a consequence, the rapid bureaucratization of decision making. In the 1930s, the Nazi regime made autarky a political priority and enlisted the chemical industry in the search for alternative fuels from coal as well as in other technological dead ends for military purposes. Hoechst's decision in the late 1990s to spin off its industrial and consumer chemical units and merge its core business in agrochemicals and pharmaceuticals with Rhône-Poulenc of France, in the hope of exploiting more effectively the opportunities in modern biotechnology, must be seen as a radical break with Hoechst's history as an unfocused conglomerate. And so must the decision of BASF in 2000 to sell its pharmaceutical business to Abbott Laboratories in the US.

Germany's most spectacular success story of the post-war period was written by the automobile industry, which ascended to technological leadership in Europe while preserving a unique diversity of organizational models. At one end, there is Volkswagen, Europe's largest volume producer with production plants around the world. At the other end, there is Porsche, an engineering specialist, best characterized as a designer of luxury goods rather than a mere car producer. In between are the craft-based producers of performance cars, BMW and Mercedes. A somewhat less important role is played by the German subsidiaries of GM and Ford, volume producers which have rarely been in the vanguard of product technology but have often displayed the benefits of imported process and organizational innovations.

The post-war success of the German automobile industry is in striking contrast to Germany's pre-war failure to capitalize on its early lead in engine technology from the pioneering days before World War I. The early German automobile manufacturers fell behind soon after Henry Ford introduced mass production in the US, and Germany in the 1920s went through a decade of financial crises, inflation, political instability, stagnant incomes and eventual mass unemployment. This persistent war burden prevented the emergence of an affluent middle class with the ability to pay for automotive mobility and also crippled the German capital market so that raising sufficient amounts of equity to finance the manufacturing capacities for mass motorization was ruled out for Germany's domestic producers. Indeed, mass production techniques made their appearance only when foreign direct investment, as in the case of Opel's takeover by GM in the late 1920s, began to flow in. However, it was a domestic government initiative on which Germany's largest volume producer to this date, Volkswagen, was founded in the 1930s, when Hitler revived plans from the 1920s, providing also for public investment in the necessary infrastructure, including the *Autobahnen*, to make the automobile a popular means of transport. Henry Ford supplied the production equipment for Volkswagen's first plant on a greenfield site halfway between Hannover and Berlin, mainly used to produce military vehicles until the end of World War II. It was after the war that Volkswagen's Beetle, designed in the 1930s by Ferdinand Porsche, became a symbol of West-Germany's reconstruction and eventually even outsold Ford's Model T to become the world's best-selling car by the early 1970s.

In West-Germany, the automobile industry soon became a driving force of export-led growth and technological catch-up with the US. Reliance on foreign technologies was gradually reduced as German producers themselves began to pioneer important product innovations, like the anti-lock braking system in the 1970s. Many of these innovations were the result of close cooperation with component suppliers, like Bosch. Also in the 1970s, Volkswagen and leading players in the component industry began to globalize their own production through direct foreign investments, largely financed from retained earnings in the German market where a variety of non-tariff barriers to trade kept prices high.

A different strategy was pursued by Germany's luxury producers, Daimler-Benz, BMW and Porsche, which continued until the 1990s to serve foreign markets only through exports. The internationalization of production, it was thought, would compromize technological leadership or its perceived basis in Germany's uniquely skilled labor force. Instead, Daimler-Benz was in the 1980s fooled into an expensive diversification creating an unfocused technology champion, along the lines of Japanese conglomerates, when the firm acquired the bankrupt electrical giant AEG as well as several aerospace firms. But this strategy of increasing scope failed, and Daimler-Benz also eventually sought to expand the *scale* of its automobile production through direct foreign investment, building its Alabama plant in 1996, merging with Chrysler in 1998 and acquiring a large minority stake in Mitsubishi of Japan in 2000. In a similar vein, BMW sought to combine its own internationalization of production with a corporate transformation from a small-scale luxury producer into a European volume producer when it acquired Britain's Rover in 1994. However, that takeover failed because BMW was ostensibly unable to implement its superior know-how of high-quality, flexible and efficient production techniques fast enough at Rover, where workers lacked the appropriate training and experience, to overcome the disadvantage of a rising exchange rate for the British pound. Porsche, finally, chose to build its first foreign production plant in Finland, a member of Europe's Monetary Union, and has since benefited from the Euro's depreciation vis-à-vis the currency of its main export market, the US.

Germany's diversified machinery industry provides yet another example of how the national system of industrial organization and corporate governance played an important role in shaping the country's dominant pattern of incremental innovation along established technology trajectories (cf. Casper et al. 1999, Tylecote and Conesa 1999). Many of Germany's mostly small and medium-sized engineering firms have established themselves in market niches with significant scope for adding value. Prominent examples are Linde in refrigeration, Heidelberger in printing presses and Jungheinrich in fork-lift trucks. Indeed, the systematic exploitation of a firm's core technology in a variety of niche markets appears to be a defining feature of Germany's machinery industry, which rarely generates block buster products to create entirely new markets. The greatest risk to this niche strategy is that unforeseen technological change destroys an entire market segment and renders a wealth of very specific knowledge, accumulated by a highly trained workforce over time, obsolete. This happened, for example, to Linotype-Hell, a leader in typesetting technology until it failed to anticipate the rise of desktop publishing in the early 1990s.

Despite its inherent risks, the niche strategy has in the past proved profitable for many firms under the constraints set by Germany's labor and capital markets (Soskice 1997). Life-time employment has often helped to preserve the technology-specific knowledge accumulated by a firm's workers over many years of learning-by-doing. Works councils and codetermination, which are legal requirements depending on firm size, have often smoothed and sped up the implementation of new process technologies by forcing a consensus along a firm's established technological trajectory, although worker participation did of course sometimes slow down the initial formulation of a new business strategy and thus may have impeded any more radical change of strategy. For example, producers of household appliances faced a crisis in the late 1980s, when numerical control and fuzzy logic first made their appearance in Japanese products, but once the Germans started adopting this new technology, they did so with a vengeance and quickly regained quality leadership.

More generally, German machine tool manufacturers may have been among the first to include advanced numerical controls as product features, but often pushed the prices for their highly specialized products beyond those charged for the more standardized Japanese ware and lost market share. There is a long-standing tendency towards over-engineering in the German machinery industry, which is often attributed to insufficient communication and coordination between product designers and production engineers. Germany's bank-centered financial system, described below, has also generally been supportive of the incremental innovation model by providing the sort of long-term, low-risk external financing which the long-term strategies of many engineering firms with often rather large and specific investments in machinery and equipment required.

Recent Experiences with High Technology: Software. Software firms, like biotechnology enterprises, have found relatively little specific support in Germany's traditional institutional environment — if measured against the institutional conditions widely thought responsible for the huge success of software firms in the US (cf. Casper et al. 1999). Managerial flexibility and speed of response is what successful innovation in software primarily requires, given that the prospect of supernormal rates of return from block buster products is marred by particularly high risks. But German institutions have long imposed a variety of constraints on the speed and flexibility of German firms. For example, most employment contracts are unlimited in duration so that the creation of new competencies has become almost like an irreversible investment making it rational to wait and see where the market moves (cf. Dixit and Pindyck 1994). Moreover, Casper et al. (1999) have argued that established firms rarely want to provide the high powered incentives for individual managers which are commonly used in US high-tech firms because the Germans fear such incentives could undermine consensus decisions and alienate important long term stake holders in their firms. Although financial market conditions for technology-based start-ups in Germany have improved in the 1990s and stock options are now legally permitted as a managerial incentive, the inter-firm mobility of mid-career scientists and engineers remains low and thus continues to constrain the ability of start-ups to move quickly into new fields of technology or to expand the scope of their operations when they grow rapidly. Many of the start-ups which have transformed Germany's software industry since the mid-1990s actually appear to have discovered market niches which are more compatible with Germany's established model of innovation than the scale-intensive market segments in which US firms continue to dominate the race for block buster products (cf. Casper et al. 1999).

Besides Germany's own institutional environment, the history of software development in Germany has of course been shaped also by the changing technological opportunities and global industry trends on which the dominant US software market has had the largest influence: In tandem with a series of revolutions in computer hardware technology, the focus of software innovation has shifted from delivering programming services for mainframe computers in the 1960s and 1970s, via churning out packaged software products for PCs in the 1980s to building client-server-applications for local networks in the 1990s and, since then, to designing software applications for global communications, the Internet and electronic commerce. German firms have made contributions to each of these phases. However, neither in programming services for mainframes, nor in mass-market software products for PCs has the German software industry played nearly as large a role as the US software industry. Most German users of mainframe computers, whether in business, government or academia, have hired their own specialist programmers so that a separate market for large-scale suppliers of such services never really took off, as it did in the US, the UK and France.

German PC users have overwhelmingly relied on the operating systems and standardized productivity software offered by dominant US firms. The only domestic publisher of office productivity software to make a noticeable impact on the German market, Hamburg based StarDivision, was recently bought by US based Sun Microsystems, which now offers StarDivision's technologically advanced, object-oriented products as a free download on the World Wide Web. In general, independent German publishers of PC software tend to be specialists for some well-defined niche market, often industry-specific business applications, in which they may enjoy a large domestic market share and considerable export revenue from other European markets. In part due to the worldwide success of SAP's enterprise resource planning software, the German software industry has played a much larger role in the era of client-server computing. And the 1990s, amid rapid change in the capital market, have seen a wave of business start-ups dedicated to developing software for the Internet and electronic commerce.

Besides conditions in capital markets, a crucial regulatory issue for the software industry has been the protection of intellectual property, which has mostly taken recourse to weakly enforced copyrights. While legal practice in the US has gradually moved towards patent protection of more and more software related inventions, software has remained unpatentable in the European Union, although this may change in the near future. In response to weak official protection of intellectual property rights, the software industry everywhere has developed its own strategies of protecting innovations against imitators and pirates (see Stolpe 2000). The most basic and most widely adopted technical strategy lies in the distinction between the software's source code, which developers write and manipulate and which most commercial publishers keep secret, and software's machine-readable compilation, which is distributed via media, like diskettes and CD-ROMs, or via the Internet.

Unfortunately, secret source codes do not only provide weaker protection than patents, but also do so without requiring the publication of all technical specifications pertaining to the innovation, which is an essential part of the bargain in patents. With hindsight, published source codes might have saved a significant share of the resources which actually went into socially wasteful parallel R&D by competing software publishers and attempts at reverse engineering the secret source code of successful software, sometimes only for the purpose of linking a new software product to a hidden interface. The widespread adoption of the open source *Linux* operating system in the late 1990s has not only demonstrated the opportunities for productive interaction in the development of this particular product, but has also suggested novel forms of cooperative development at the design stage of other kinds of software, if their publishers were to adopt the open source model. In a pioneering quantitative study of one of the oldest US repositories for the *Linux* open source project, Dempsey et al. (1999) have found that contributors' demographics reveal a strikingly strong European influence within the Linux community, with German residents being by far the most prolific group of all non-US based contributors identifiable by their email country suffix. Moreover, there is evidence to suggest that small and medium sized firms in Germany have a higher propensity to use open source software, for example on their Internet servers, than large German corporations and US firms of all sizes (Lutterbeck et al. 2000).

By helping the large established software publishers to monopolize the opportunities for upgrading and further developing their core products, secret source codes may have had a distorting influence on market structure in many segments of the software industry. It is often alleged that Microsoft has thrived on this strategy with respect to its MS-DOS and WINDOWS operating systems and has therefore come to exhibit too much vertical integration. The rule of secret source codes in most parts of the existing software industry has magnified the importance of rapid market penetration, the private returns to which lie in the appropriation of a large part of the static and dynamic economies of scale that ensue. And US based software publishers who took advantage of their huge and fast growing home market for speedy diffusion and market penetration automatically gained valuable credibility with software users and potential customers around the world. They thus won a bigger prize for early success in the most scale-intensive segments of software than any of the smaller markets in other countries could possibly offer. The prevailing intellectual property rights regime has thus combined with economic characteristics of software technology, like network externalities, in not only boosting the incentives for *early* innovators to define and conquer markets for the very scale-intensive software categories, like operating systems and standard productivity applications, but also in tilting the international playing field.

Non-US-based software publishers have faltered and failed in the most scale-intensive segments of the software market. German software publishers, for example, quickly abandoned attempts to market their own operating systems for PCs in the early 1980s. And Siemens-Nixdorf later sold most of its software business to Baan, a start-up in the Netherlands, when it dawned on Germany's electrical and computing conglomerate that it could not create the right incentives for successful in-house development of standard application software. Even today the German software industry remains highly fragmented, encompassing many thousands of firms of various sizes. They often serve niche markets which emerged after the demise of mainframe computing and the rise of the PC created a mass market for standardized software products and a separate market for computer consulting services dedicated to customizing and integrating hardware and software. As Casper et al. (1999) have pointed out the institutional requirements of the IT service segment are more compatible with conditions in Germany, where large corporations have long performed many business services in-house instead of buying them from external providers. The technology is cumulative, built on experience and providers' ability to re-use solutions, algorithms and software code from earlier projects. Indeed, the largely firm-specific knowledge, experience and networking of employees account for the major part of a firm's capital in IT services, while the financial risk is relatively low. Consulting services for decentralized PC users have therefore not only accounted for a large part of the German software industry, but have also provided the basis for many new ventures in the product-based software segment.

SAP, whose enterprise resource planning software made it one of today's most successful software publishers in the world, provides an example of the kind of technological strategy adopted by many smaller German software firms as well. In fact, *SAP*s main product, R/3, is an example of software straddling both the product and the IT service segment of the software market; for, the implementation of R/3 requires a considerable service input so as to meet the specific needs and parameters of client firms. Besides enterprise resource planning software (ERP), German publishers have also successfully marketed computer-assisted software engineering tools (CASE) and standardized software products for production planning and work flow management, for architectural graphics, for electronic commerce and for document management, both at home and in export markets, making the German software industry the strongest in Europe.

The business history of *SAP* (see Meissner 1997) highlights how Germany's institutional set-up tends to constrain the early growth of new technology-based firms, especially when compared with Microsoft, the leading US software publisher. Despite being several years older than Microsoft, *SAP's* growth was initially much slower. After its foundation in 1972 by a group of former *IBM* employees, *SAP* could not afford to purchase a (mainframe) computer of its own on which to write and test its programs under development in the 1970s. Programmers worked at night on the mainframe of *SAP's* first client, the German subsidiary of British chemical giant *ICI* to whom they sold custom programming and consulting services at day time. *SAP* bought its first computer only in 1979. The initial public offering of *SAP* shares on the German stock market came in the fall of 1988, when equity capital was sought for an international expansion. This IPO took place much later in the firm's history than Microsoft's debut on the NASDAQ in 1985.

Whereas Microsoft hit straight into the most scale-intensive opportunity in software development when the IBM PC was launched, *SAP* implicitly protected its software from imitation by making it rather complex. In fact, *SAP* pursued the initial development of a PC version of its main software, R/3, only as a sideshow to its continuing mainframe activities in the late 1980s. Nevertheless, *SAP's* R/3 software became a *de facto* standard for enterprise resource planning when the client-server model was widely adopted, not only by firms replacing mainframes, but also by a wave of first-time adopters of business computing. After passing this threshold in market growth and penetration, *SAP* has played a special platform role for the German software industry, similar to Microsoft's role in the US software industry: They both created a standardized program which opened up new opportunities for developers of auxiliary programs and other applications software, which in turn have made *SAP's* R/3 system more valuable for users, just as third-party applications increased the value of using Microsoft's WINDOWS.

Since the mid-1990s, conditions for software-based start-ups have greatly improved, venture capital has become widely available in Germany. Many start-ups now compete in scale-intensive Internet applications and e-commerce software for global markets. One of the best-known examples of this new type of firm is *Intershop*, a software publisher founded in 1992 and still largely based at Jena in Eastern Germany. With venture capital support, *Intershop* has been able to grow rapidly and establish its sell-side e-commerce software as a potential global *de facto* standard for online shops. According to industry analysts, *Intershop* held third place in terms of global market share at the beginning of 2000. Unlike *SAP* some twenty years earlier, *Intershop* used an early initial public offering on Germany's *Neuer Markt* in 1998, only six years after the firm's foundation, to break free from the dominance of its first large customer, *Deutsche Telekom*. Being a publicly held firm helped to build valuable credibility among new clients and potential strategic allies with respect to the prospect that *Intershop* would remain a potent independent supplier of e-commerce software and upgrades. Although *Intershop's* founder and CEO, Stephan Schambach, now leads the firm from its new headquarters in San Francisco, most of its operations remain in Jena where software programmers are much cheaper and more loyal, for lack of alternative employment opportunities, than those *Intershop* might find in California.

Deutsche Telekom, the former state monopoly for telecommunications services in Germany, has long been an important client for the communications equipment and software industries. Moreover, the firm has been a significant player in the German corporate venture capital market. But it did not adopt an explicit strategy to buy German software as part of an industrial policy, not even before its partial stock market flotation in 1997. Nor did other parts of Germany's vast government sector, which includes federal and state governments as well as local authorities and Germany's state-controlled universities, display any significant procurement favoritism towards German software. Regardless of whether decisions were fully decentralized at the institution actually using the software or centralized at the state government level, as in some *Länder*, procurement decisions have generally been risk averse in the sense of sticking to the market leader in the software category under consideration.

As a monopoly, *Deutsche Telekom* made an important contribution in terms of hardware investment, particularly in the provision of country-wide ISDN and cable networks. *Deutsche Telekom* also developed a proprietary online service named *BTX* in the 1980s which was technically comparable to France's *Minitel*, but never really caught on in Germany. One reason were initial problems with data security which were quickly exposed by members of Germany's ill-famed

Chaos Computer Club who gained illegal access to online bank accounts of third parties. Despite its own failure in the market, *BTX* was important as the precurser to *t-online*, now Europe’s largest Internet service provider. Apart from poor marketing and security problems, the adoption of the *BTX* service by consumers was also slowed down by the high level of *Deutsche Telekom’s* monopoly prices for telecommunications services, which exceeded those of comparable countries well into the 1990s.

After German reunification, *Deutsche Telekom’s* monopoly was maintained for longer than the former state monopolies in telecommunications elsewhere, partly for the political purpose of financing the building of a modern telecommunications infrastructure in Eastern Germany from *Deutsche Telekom’s* retained monopoly earnings. However, the delayed deregulation, which was eventually forced upon Germany by the EU, imposed a heavy toll in terms of missed opportunities. In mobile telecommunications technology, for example, Sweden and Finland appear to have gained a significant technological lead over Germany. Most recently, *Deutsche Telekom* has used its remaining monopoly power from owning the last mile of end users’ network access in pushing its own services, especially a flat rate scheme of Internet access; and there are claims of price discrimination from those rivals who, for lack of proprietary infrastructure, can only resell services purchased at wholesale prices from *Deutsche Telekom*.

Recent Experiences with High Technology: Biotechnology. Germany’s slow start in the modern biotechnology industry is not just another consequence of the country’s pattern of industrial organization and corporate governance, but in contrast to the software case, also reflects major weaknesses in Germany’s university system as well as hostile regulation. Developments in the past 20 years fall into two distinct phases in which the most immediate beneficiary of biotechnology in Germany, the country’s well-established pharmaceutical industry, played very different roles. The initial phase, in the 1980s, was driven by strategic investments of Germany’s large chemical conglomerates with pharmaceutical and agrochemical activities and was accompanied by political antagonism which culminated in the introduction of a rather restrictive law on genetic engineering in 1990, somewhat relaxed in 1993. The often irrational public hostility towards biotechnology, which informed the law and had, even before its enactment, led to a series of anti-biotechnology court decisions, amounted at least partially to a denial of property rights in private biotechnology investments. In the 1980s Hoechst, for example, struggled for many years with the authorities and the courts to take a newly built plant for artificial insulin into operation, while imports from Hoechst’s Danish and US competitors took over the German market. Towards the end of the 1980s, Germany’s large chemical and pharmaceutical firms seemed to be giving up on biotechnology made in Germany and invested directly in the US, then the undisputed biotechnology leader, where they acquired start-ups and built their own large-scale laboratories.

Since innovation continues to be driven by entrepreneurial start-ups even after more than twenty years of industry growth in the US, the development of biotechnology appears to require a set of institutions not easily reconciled with Germany's traditional system of industrial organization and corporate governance (Casper et al. 1999). The discovery of new drugs seems to require highly specialized skills and fragmented scientific knowledge of the sort which can only be obtained and maintained through close linkages with basic research (cf. Zucker et al. 1994). Hence, small start ups, especially those with their origin in academic research programs, appear not only to offer the best opportunity for university researchers to become involved in the commercial development of biotechnology, be it through employment or temporary consulting, but also to have an enduring comparative advantage with respect to innovation. Large pharmaceutical firms, by contrast, continue to hold the specialized assets for the development, clinical testing and marketing of new drugs and thus can still appropriate much of the pecuniary payoff even from innovations found in cooperation with biotechnology start-ups. Indeed, it was partly for the purpose of becoming a more potent and attractive research partner for biotechnology start ups that Hoechst and Rhône-Poulenc recently merged and concentrated their pharmaceutical and agrochemical activities in Aventis.

The late 1990s have seen a wave of biotechnology start ups in Germany. At the end of 1999, there were 279 new biotechnology firms with fewer than 500 employees (VCI 2000). As a group, they achieved annual increases in employment, patents and sales of more than 30 percent in the last two years of the 1990s. R&D expenditures even increased by more than 50 percent annually in 1998 and 1999, reaching 640 million Deutschmark. Total sales of these firms reached more than one billion Deutschmark for the first time in 1999. However, the economic significance of biotechnology start-ups still pales if compared to the situation in the US. Moreover, many of Germany's new biotech firms are even small by European standards. In 1999, 20 percent of European biotech firms with fewer than 500 employees were located in Germany, but these accounted for only 15 percent of European employees and less than ten percent of sales, according to a study of Ernst and Young (2000).

Taking a closer look at the German biotechnology scene, Casper et al. (1999) have identified two distinct market segments within biotechnology which have fared rather differently under the influence of Germany's broader innovation system. Relatively few German start ups do drug discovery research, falling into what Casper et al. (1999) call the therapeutics segment. By way of contrast, they have called the platform technology segment the activities of firms creating the research tools used in therapeutics, and this segment appears to be more in line with the German system of innovation. Indeed, the platform technology segment has given the main impetus to biotechnology's second phase in Germany, beginning in the mid-1990s, and includes start-up ventures in genetic sequencing and engineering as well as the application of information technology and automation technologies in drug screening. For example, one of Germany's most successful new biotech-firms, Qiagen, holds a strong technological lead as well as a dominant and highly profitable market position as a supplier of cheap consumable kits that replace labour intensive processes in DNA-filtration. Platform technologies of this kind are not directly targeted at consumer markets, do not themselves introduce genetically modified substances and therefore have created much less controversy and public hostility than, for example, genetically modified foods.

Casper et al. (1999) have emphasized the distinction between platform technologies and the therapeutics segment because their distinct economic characteristics can help explain the differential success of firms specializing on either development under the incentives and constraints set by Germany's innovation system. The discrete nature of technology in the therapeutics segment and the short time horizon of individual research programs makes a frequent reorientation of a firm's research strategy necessary. Research may become obsolete whenever a competitor wins a patent or an unexpected technological obstacle occurs, and biotech firms must constantly be on alert and move with speed when entering or leaving a particular field in the therapeutics segment. But this game requires a frequent turnover of employees with highly specialized human capital, which is difficult to accommodate within Germany's tightly regulated labor market. Moreover, there are also high financial risks because the failure rate of many therapeutics research programs is high, time to market tends to be long and the percentage of cost devoted to R&D can be extreme. On top of this, there is the unique risk of meeting regulatory testing and approval requirements, which is often hard to predict in terms of timing and probability.

Platform technologies, by contrast, possess the characteristic that their development usually relies on cumulative rather than discrete technologies. Research scientists and engineers therefore need much more firm-specific knowledge than is typically acquired within therapeutic firms. By improving employees' incentives to invest in firm-specific skills, the long-term employment contracts which are standard in Germany's labor market can actually give

German firms a competitive advantage over foreign rivals in the platform technology segment. Compared to the therapeutics segment, the share of R&D in total costs appears to be lower, technological failure is less likely and innovations have to meet fewer regulatory approval and testing requirements. Moreover, Casper et al. (1999) have observed that key inventions can often be leveraged into new markets through follow-up R&D and continued close interaction with users, most of which are other biotechnology or pharmaceutical firms. For all of these reasons, the financial risks of investing in platform technologies are much lower than those in the therapeutics segment, and new firms have found Germany's underdeveloped market for private equity less of a constraint. Many start-ups in the platform technology segment have actually relied on state subsidies for their initial R&D investment and used retained earnings to finance subsequent R&D, while building their standing with a *Hausbank* to prepare for an initial public offering of equity shares.

The 1990s saw some significant and novel government initiatives aimed at closing the gap vis-à-vis Britain and the US in biotechnology. In recognition of systemic interdependencies at the regional level, which had become a hot subject in academic discussions, the German government in 1995 announced a contest, named *BioRegio*, for the allocation of regionally targeted subsidies. The idea was not to award subsidies to individual firms selected on their own merit, but to select the one region with the best prospects of accommodating a vibrant biotechnology industry. Criteria for selection were the level of commercial biotechnology activity already established within the applying regions and the specific merits of a regional plan to further develop and improve conditions for the transfer of technology from universities to private firms as well as for inter-firm cooperation within the region. In the end, three regions were awarded funds totaling 150 million Deutschmark, disbursed over the course of five years. The winners include the region around Cologne, the Rhein-Neckar triangle and Munich where the Max-Planck-Institute for Biochemistry with almost 500 research scientists has been an important center of academic research. Within three years of announcing the contest, the number of biotechnology firms in Germany tripled; but, of course, even with hindsight it is hard to tell how much of this burst in activity was related to the *BioRegio* contest rather than to the creation of the *Neuer Markt* stock market segment in 1997 or to other pertinent improvements in financial market conditions in the second half of the 1990s.

III. How Germany Develops and Harnesses Technological Change

Regulatory Issues: Capital Markets. Germany's capital market, for a long time aptly described as bank-centered, has seen the development of much broader and more liquid equity markets in the 1990s. The market capitalization of shares of domestic firms traded on Germany's main stock exchange, the Deutsche Börse in Frankfurt, quadrupled between 1990 and the end of 1999, while the value of domestic bank credits and the market value of bonds barely doubled. There have been several events behind this, including Europe's monetary union, which has intensified foreign competition for Germany's financial intermediaries, and technological change, which lowered the costs of financial market transactions while increasing the demand of innovative private firms for public equity issues. In a broad historical picture, the German capital market has come almost full circle, since it was private equity provided by banks and wealthy individuals that fueled Germany's industrial revolution in the 19th century. It was no coincidence at the time that a member of the Siemens family headed the Deutsche Bank and steered the allocation of capital in the emerging electrical industry (see Gall et al. 1995). Indeed, the private banks founded during the boom years of Germany's industrial revolution after 1850 often acted much like venture capitalists and investment banks today. But that earlier emphasis on equity finance was lost during the long series of financial crises which followed in the wake of Germany's failed military ambitions in the first half of the 20th century. Hyper-inflation in 1923, the stock market crash of 1929 and the subsequent depression caused so much financial loss, economic disruption and political disaster that risk aversion did not only become widespread among the German people but also dominant in the official regulation of banks and financial markets.

Until today, the total stock market capitalization as a percentage of gross domestic product (GDP) is much smaller in Germany than in the UK or the US. According to data from the *International Federation of Stock Exchanges* (FIBV), the market capitalization of listed domestic firms was only 51 percent of GDP in Germany at the end of 1998, approximately one third of the US ratio, less than one third of the UK ratio and even less than one fifth of the ratio in Switzerland. Also the number of publicly listed domestic firms remains relatively low; at the end of 1999, shares of only 851 German firms were traded in Deutsche Börse's regulated market segments, far fewer than the 2274 British firms whose shares were traded on the main and parallel markets of the London stock exchange. The total number of domestic firms with a public listing on a German stock exchange was 966, up from 776 in 1990, according to the *Deutsches Aktieninstitut*, a private organization advocating greater political support for public equity in Germany.

Amid the 1990's booming stock markets, even the Germans have begun to take a less cautious stand on equities, and the number of German share holders reached five million in 1999, according to a survey conducted by *Infratest* on behalf of the *Deutsches Aktieninstitut*. But at the end of 1997, the private household sector's holdings of equity shares, excluding its even less significant holding of investment funds, accounted for only 8.3 percent of all liquid assets held by private households in Germany. They still held much larger shares in saving deposits (22 percent), life insurance schemes (22 percent) and fixed income securities issued by the government, by Germany's state banks or the large private banks (21 percent) (Deutsches Aktieninstitut 1998). Moreover, because Germany's compulsory pay-as-you-go pension scheme is comprehensive, only about 20 percent of the limited number of shares in circulation was held by institutional investors, such as insurance firms, pension and other investment funds, against 70 percent in the UK. And for lack of a competitive brokerage industry, most outside investors' access to the securities markets is effectively controlled by banks, even institutional investors rarely have their own trading desks. Revealingly, Germany's large private banks still own 80 percent of Deutsche Börse which runs the Frankfurt stock exchange. A number of regional stock exchanges continue to exist as relics of times long passed.

Although the stock market has greatly gained in importance during the 1990s, Germany's financial system must still be considered as basically bank-centered. It is a system, however, which has long defied a simple classification as credit-based, because German banks tend to play a dominant role not only in the allocation of credit, but in the provision of external finance in general (cf. Christensen 1992). Banks and insurance firms have also retained their traditional roles as supervisors of many publicly held firms through seats on supervisory boards and through proxy voting rights. Conversely, most German firms still rely on banks or retained earnings to finance investments. However, while banks are often willing to offer long-term financing for *tangible* capital, they do not normally finance R&D. Credit constraints for intangible investments are significant despite the ability of German industrial firms to extend long-term commitments to their own stake holders, including employees and the firm's *Hausbank*, which is seen as motivating banks' long-term commitment of credit in general (see Casper et al. 1999). Because of their long-term relationship with client firms, banks can often monitor the status of their investments more closely than other outside investors. Germany's universal banks may lack the expertise to monitor investment in new technology, but reputational monitoring has often helped to overcome that deficiency in the past.

Within the banking industry, there is a clear segmentation of markets between the big private banks, which mainly cater for large corporations, the state-owned *Landesbanken*, which have a mandate to finance regional development regardless of firm size, and last, but not least, the numerous cooperative banks and municipal savings institutes (*Sparkassen*), where most consumers keep their savings and where the small, privately held *Mittelstand* firms find the cheapest and most readily available loans. Together, the public sector banks, i.e. the *Landesbanken* and municipal savings institutes, hold a share of almost 50 percent in the German banking market, measured in terms of either balance sheet totals or business volume (Sinn 1997). While the five major private banks hold only a relatively small share of Germany's retail banking market and also neglect *Mittelstand* firms with less than five million Deutschmark in annual sales, they have long dominated the market for corporate clients and have recently been gearing up to compete in the fast growing markets for corporate restructuring, asset securitization and the underwriting of public share offerings. Yet, they are still frequently being outdone by the large US investment banks with German subsidiaries which have successfully used their own home market experience, global presence and sheer size as a leverage in the German market.

On the other hand, Germany's major private banks also face stiff competition from the *Landesbanken* which are subsidized in a variety of ways by their respective state government owners and mostly act like any universal bank, lending freely in national and international markets and holding shares in many German industrial firms. At the behest of Germany's private banks, the state subsidies, mainly in the form of unlimited government guarantees for the liabilities incurred by the *Landesbanken*, are currently under review by the European Commission. The municipally owned savings institutes still provide the backbone of external financing for Germany's numerous small and many medium-sized *Mittelstand* firms, except for high-tech start-ups which cannot offer collateral and thus do not qualify for debt finance. The municipal saving institutes are barred from holding equity in private firms and thus cannot play the venture capital game. Throughout much of the post-war period, the cost of capital for German firms has appeared to be low in comparison with other countries mainly because the obstacles for small and new firms seeking to raise external equity have defied measurement and have thus long been ignored.

The absence of effective public equity markets has probably had a decisive impact on the rate and direction of technological innovations pursued by German industry. Some of the leading technology firms, like Bosch and Carl Zeiss, are still privately held through foundations with the express purpose of keeping the firms independent from outside interference. These protected holding constructions may not only have adverse effects on the quality of corporate governance, but also effectively rule out that these firms venture into fast-growing new markets requiring large-scale investment into new technological competencies outside their traditional core technologies. However, in new technology-based industries, the lack of access to public equity markets has been hardest on newcomers so that, for example, in telecommunications Mannesmann, an old steel and engineering conglomerate, enjoyed a head start in terms of financial resources even if many of these had to be wasted in that firm's internal transformation into a telecommunications business. That it was taken over by the purebred British mobile communications operator Vodafone after a hostile battle in 1999 merely confirmed Mannesmann's lower firm value for being an anachronistic conglomerate in the high-tech world.

In the 1990s, new guidelines for regulatory harmonization within the EU, set out in the Investment Services Directive, prompted significant changes in Germany's securities market legislation and for the first time created a federal agency overseeing securities trading in Germany. Insider trading became a punishable offense in 1994. The Corporation Control and Transparency Act which took effect on May 1, 1998, allows share buybacks using distributable capital and simplifies the regulation of stock option programs for employees of private firms. Such programs are often seen as vital for liquidity-constrained start-ups in high-tech industries seeking to attract and motivate appropriately qualified and experienced managers; but also established firms have made wider use of stock option programs since their partial deregulation. Among other measures aimed at introducing best practice and international standards in German equity markets, the relief of issuers to generate consolidated financial statements under German law when they are already obliged to use foreign or international standards for their financial statements has been especially important. A law regulating corporate takeovers and mergers is currently being prepared.

The 1990s' reforms in the regulation of securities trading were matched by private reform initiatives at the *Deutsche Börse* which owns the all-important Frankfurt stock exchange. As elsewhere in Europe, adoption of new information and communication technologies to automate trading and settlement has had a pervasive impact on equity markets. Not only has *Deutsche Börse's* continuous, order-driven electronic trading with intermittent auctions generated huge network externalities and enhanced stock market liquidity, but also the accuracy and speed in the settlement of stock market transactions has been improved. The latter is provided by *Clearstream*, the settlement specialist owned by Germany's large private banks. The main reason that outside investors' explicit trading costs remain much higher than the implicit trading costs determined by Deutsche Börse's trading technology is that Germany's universal banks still dominate brokerage and have so far defended their position as effective gatekeepers to the stock market (cf. Domowitz and Steil 2001). Low Internet penetration rates are holding back online brokers in Germany, but the advent of *Jiway*, a Swedish online market making system, may soon change that.

In terms of impact on the wider economy, the 1990's most important achievement in Germany has been the creation of the *Neuer Markt* segment for small growth stocks in March 1997 which, in contrast to a previous attempt at creating a regulated market for small caps in the 1980s, attracted a large number of initial public offerings of shares from new technology-based firms. The total market capitalization in the *Neuer Markt* grew within three years after its start to more than 120 billion Euro, accounted for by more than 200 listed firms at the end of 1999; there were even 338 listed firms with a total market capitalization of 115 billion Euro at the end of 2000, according to a press release by Deutsche Börse. Germany's *Neuer Markt* thus accounted for 50 percent of Europe's combined market capitalization of fast growing small-caps that are listed in the various new market segments of national stock exchanges. With stringent disclosure requirements, the *Neuer Markt* has sought to replace an issuer's long-established reputation for financial stability by transparency as the main key to outside investor confidence. Moreover, each newly-listed firm is required to name two designated sponsors responsible for providing matching share offers and bids at any time, although such market making activity to maintain liquidity in thinly traded stocks would probably occur spontaneously in the continuous trading that is practiced by the *Neuer Markt*. While banks which appear to use market making as a loss leader also dominate the IPO market as underwriters, IPOs can in principle be introduced by other financial intermediaries as well. By creating an attractive option of exit via an initial public offering of shares, the *Neuer Markt* has certainly improved the refinancing conditions for venture capitalists in Germany.

In policy initiatives predating the creation of the Neuer Markt, the German government has made support of venture capital for new technology-based firms a top policy priority in the 1990s. In one scheme, for example, the *Kreditanstalt für Wiederaufbau* and the *Deutsche Ausgleichsbank*, the national development banks, guarantee 65 percent of the potential loss of equity participations which they have co-financed for a period of up to ten years. In addition, individual Länder grant targeted subsidies and subsidized loans for small and medium sized enterprises. Many obstacles to the growth of venture capital, some of which were originally introduced to avoid tax evasion, have indeed been substantially relaxed (cf. OECD 1998). For example, capital gains are now tax free after only one year of share holding, going public need no longer take place within ten years, the minimum number of shareholders has been reduced and majority holdings in individual firms are now possible for up to eight years. However, more needs to be done, especially in the tax system and with respect to inflexible labor market regulations.

While Germany's venture capital industry remains small in comparison with that of the US, it has recently grown much faster than the venture capital industries in most European countries. In 1998, approximately 30 percent of all European venture capital investment in the early stages of start-up firms was made by German venture capitalists, according to data gathered by the European Venture Capital Association. Relative to GDP, however, the German venture capital market reached only a level of 0.7 percent, including a level of 0.25 percent for early stage deals, in 1998. These levels are still small compared with the US (2.3 and 0.75 percent), the Netherlands (1.7 and 0.5 percent), Belgium (1.1 and 0.7 percent) and Finland (1.0 and 0.6 percent). Nevertheless, with a much larger emphasis on early stage investments than in the more voluminous UK venture capital market, the German venture capital industry seems to have embarked on a promising learning cycle.

Indeed, there are signs of an increasing specialization of investments in software, Internet and biotechnology related ventures —which demand a particularly large share of intangible investment and where the comparative advantage of venture capital vis-à-vis other forms of financial intermediation is greatest. This ongoing learning cycle should soon begin to raise the efficiency of the screening, selection and management support services provided by venture capitalists for new technology-based firms in Germany. Moreover, the increasing depth and improved functioning of Germany's stock market is likely to benefit new technology-based firms in a variety of other ways. In particular, by promoting the independence of small firms from dominant customers — as venture capital might have done in the case of *SAP* in the early 1970s had it been available at the time —, venture capital may also facilitate the freer flow of knowledge via more varied user-producer relationships and via enhancing the mobility of people across small, fast growing firms.

Regulatory Issues: Labor markets. The German labor market suffers from a plethora of regulations and rigidities that make life difficult for innovators who want to start a new business. Many of these regulations were originally introduced to protect workers from dismissal and unfair treatment by established employers. But many of the rigidities have an adverse effect on Germany's capacity for innovation by reducing the mobility of workers across regions and industries, by reducing workers' incentives to form human capital and by making the formation of new firms unnecessarily risky for entrepreneurs. High unemployment means that many people do not participate in the learning process. Low rates of employment among the less skilled imply inter alia an underdeveloped service sector, and thus an inefficiently low depth of the division of labor. Moreover, people do not move easily between firms, because it is risky for new firms to hire people; the opportunity costs of leaving the corporate sector or the university sector to start a new firm are exacerbated.

Wages are determined through autonomous negotiations between the trade unions and the employers associations of broadly defined industries; negotiated wages are protected by a set of legal rules. For example, it is illegal to offer a job contract to a union member that deviates from the collective wage agreement unless the deviation improves the worker's situation by paying a higher hourly wage or by granting a reduction in hours worked. But a reduced risk of losing the job is not considered as a legal improvement of a worker's situation by the German labor courts. Moreover, decentralized bargaining at the firm level is legally permissible only if it is explicitly provided for in the industry-wide wage contracts. The law thus provides strong protection of the cartelized bargaining process, not least because firms tend to apply the negotiated wage to non-union members as well. As a consequence, Germany's unemployed have effectively lost the opportunity to enter the labor market at a wage below the industry-wide negotiated wage.

As an implication of labor market rigidities, the unemployment rates of West Germany's Länder became more diverse over the period 1975 to 1990, while the regional wage structure remained largely constant (Siebert 1994, Table 7.1). Moreover, also the wage structure with respect to qualifications has remained constant during the last 20 years, although there has been a massive shift in labour demand at the expense of less qualified workers (Sachverständigenrat 2000, pp. 343). This created excess levels of unemployment among the less qualified and lowered their incentives and opportunities to build up the human capital required for a more active participation in the economy's innovation process. To the extent that the constant wage structure has followed from resistance to allow higher wages for skills in strong demand, there have also been insufficient incentives for qualified workers to extend and further improve their human capital in response to changing demand in the German labor market. In the 1990s, for example, acute scarcities have developed in the labor market for computer specialists.

In an important contrast to the rigid wage structure, Germany has achieved much more flexibility with respect to working time in the past decade. A large number of more flexible working time arrangements were negotiated at the firm level, between management and workers' councils who chose to ignore the industry-wide wage contracts on these points. In exchange for their cooperation, a firm's workers were usually given a guarantee against layoffs for some specified number of years.

Siebert (1997) provides a comprehensive description of the institutional arrangements affecting the performance of Germany's labor market. Besides the market process, layers of rules governing wage formation, the legal system and the system of nonemployment income have adversely affected labor market performance, because the cumulative effect of these rules has made the German labor market ever more rigid since the late 1960s. The tax wedge widenened, pressure on the unemployed to accept job offers was lowered as the replacement ratio rose and rules of reasonableness were introduced. Sick leave payments were raised to 100 percent of regular pay for six weeks for all workers in 1969. Employment schemes financed by the government were introduced and made to pay 90 percent of the previous net wage.

Looking at the impact of Germany's present labor market regulations on innovation, it can be argued that they tend to favor established firms seeking only to expand along well-established trajectories. The main point is that long-term commitments to firm-specific human capital are credible. People do not have to fear that they will be sacked unless the firm as a whole sinks. Moreover, codetermination can at least in principle be interpreted as a safeguard against a strategic reorientation which might devalue the sort of firm-specific human capital which employees have accumulated over time and which have made German firms competitive in some of Germany's traditional industries. But such an incentive structure comes at a high cost: fundamental changes with a new innovative path become less likely. Risks are less likely to be taken. Actually, the German government now plans to update the law relating to the rules that must be adhered to in the firms (*Betriebsverfassungsgesetz*) intending to give worker councils an even larger say. An important area to be included are retraining schemes for workers whose skills have become obsolete due to new technological developments. To what extent worker councils may try to resist retraining schemes and thus may stifle firms' innovative capacity in the future remains to be seen.

Layoff constraints represent another institutional aspect affecting technological advance. This is especially relevant for research personal. For firms these restraints are costly by forcing them either to keep research workers with low productivity or to pay high severance to make them quit voluntarily. Given that public funding generally rules out severance pay for the public and semi-public research sector and for tenured positions in the universities, there is an even worse problem of adverse selection there: the less productive researchers tend to stay within the system and reduce spontaneity and inventiveness.

The University System. A major weakness of the German innovation system is the organization of its universities. They are basically steered by administrative processes, and effectively shielded from competition. This may be at the root of many protective attitudes in the German society. Moreover, reform of the German university system has been slowed down politically by an implicit agreement that all major changes must be coordinated through committees at the federal level although the constitutional responsibility for education and science rests with the individual *Länder* (federal states). In particular, the conference of science and education ministers from the 16 states acts as an effective cartel by suppressing any unilateral change in the organization of schools and universities which might affect the accessibility of educational institutions in one state for students from another.

Lack of competition and the absence of a price mechanism in the allocation of academic resources are at least partly to blame for massive overcrowding, poor teaching quality, high withdrawal rates and prolonged study periods before a fraction of the initially enrolled students eventually graduates. In their external relations, German universities often appear sluggish and inflexible. Changing demands of the labor market tend to have little impact on the content and methods of teaching, entirely new fields of study are developed and introduced only very slowly. The system of degrees is incompatible with the US model where a first degree is regularly awarded after four years of college education. In Germany, by contrast, most students need at least five years before obtaining their first university degree, despite having spent 13 years in primary and secondary education. Another five years of study is now the rule for a doctoral degree, although that does not yet qualify for independent academic teaching. Anyone seeking a career as a university teacher needs to earn another degree, the *Habilitation,* for which no equivalent exists in the US. While a doctoral degree is primarily awarded in recognition of demonstrated originality of research, the *Habilitation* is thought to recognize precision and breadth of knowledge as well.

Many of the current deficiencies of the German university system are a legacy of political priorities in the post-war reconstruction and subsequent expansion of higher education. Due to demographic change, general economic progress and changing labor market conditions, demand for university studies began to rise rapidly in the late 1960s and state governments primarily aimed at a quantitative expansion of supply. In addition, there was some relaxation of the administrative control by state governments, but instead of using market mechanisms and competition, new rules of democratic decision making were introduced which involve students and administrative staff in many internal university decisions, thus limiting the traditional authority of academic teachers. Nonetheless, state governments retained ultimate control over budgets, the hiring of personnel and strategic choices about future directions of research as well as broad areas of teaching. Despite the expansion and democratization of the past three decades, the basic structure of the German university system still reveals its historic origin in the early 19th century.

The origin of the modern German university can be precisely dated because it was the foundation of Prussia’s Berlin reform university by Wilhelm von Humboldt in 1810 which marked a clear break from the prior practice of universities as mere teaching colleges as well as from the French model of specialized higher education where each school trained students only for a particular industry or profession. In the era of European enlightenment, research was separate from teaching and primarily conducted by individuals or private academic societies. The task of universities was merely to categorize and preserve the state of knowledge and to pass it on to the next generation of scholars. The separation between basic and applied research, which plays such a prominent role in technology policy today, only began to be practiced in the nineteenth century, after Wilhelm von Humboldt had made the unity of basic research and teaching a central tenet of his Berlin reform university. When Germany was unified under Prussia’s leadership in 1871, education and research policies remained responsibilities of individual state governments, which established a principle that continues to hold until today. At the same time, however, the imperial government in Berlin assumed responsibility for standard setting and patent legislation, and this assignment endowed the imperial government with responsibility for certain areas of technology-related research.

Germany’s first imperial research institute in the area of high technology, founded in 1878 under the name *Physikalisch-Technische Reichsanstalt*, was devoted to research in the new field of electrical engineering and led by the prominent physicist and physician Hermann von Helmholtz. At that time, the *Physikalisch-Technische Reichsanstalt* with its focus on industrial applications was a center of excellence, a playground for the best scientists and engineers, whereas university teaching was considered a suitable occupation for less qualified academics. The private industrial research laboratories which emerged in Germany's chemical and electrical industries of the late nineteenth century also acquired a high status and established a new pattern of applied research which in turn influenced the organization of research in the university sector and in publicly funded academies.

Prussia took the lead in devising a science policy which used private sector funds but remained under the influence of the state with respect to its strategic orientation. In line with these policies, the *Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften* was founded in 1911 as a private association controlled by the government. Within its first three years, the *Kaiser-Wilhelm-Gesellschaft* established five research institutes, devoted to chemistry, physical chemistry, coal, biology and medical science, which were directed by powerful representatives of their respective discipline who were chosen for their academic reputation. Many of the activities of the *Kaiser-Wilhelm-Gesellschaft* were directed not towards basic research but towards applied research which proved extremely useful in the chemical and electrical industries.

After World War I, Germany's academic research found itself in a serious crisis. Not only did private funding cease to flow, but also many international contacts died. In an emergency response, leading scholars founded the *Notgemeinschaft der Deutschen Wissenschaft* in 1920, which later became the *Deutsche Forschungsgemeinschaft*. Their primary purpose was to fend off the imminent exploitation of academic research for narrow political or commercial ends and to establish the principle that the scientific community should decide for itself how to distribute the funds it acquired from private and government sources. As an instrument for the acquisition of funds from private industry, the *Stifterverband der Notgemeinschaft der Deutschen Wissenschaft* was founded in December 1920, and all donations thus received were duly passed on to the *Notgemeinschaft der Deutschen Wissenschaft*. In addition, substantial funds flowed in from abroad, above all from the *Rockefeller-Foundation* in the United States. Throughout the 1920s, the appropriate influence of private industry on the priorities in academic research was the subject of intense discussions and the *Helmholtz-Gesellschaft* became a competing model with a much stronger influence of industrial financiers than were tolerated by the *Notgemeinschaft der Deutschen Wissenschaft*.

After World War II the institutes of the Kaiser-Wilhelm-Gesellschaft were transformed to become the new *Max-Planck-Gesellschaft zur Förderung der*

Wissenschaften (MPG). The Max-Planck-Institutes were now dedicated to basic research. Within the university sector, the initial post-war-decade was devoted merely to the reconstruction of teaching activities. But in the 1960s there was a public debate about the appropriate scale of university education in an advanced industrial country. Under the impression of rapidly expanding college education in the US, the numbers of enrolled students in higher education in Germany seemed totally inadequate. There was much talk about an educational crisis which would strangle efforts by the German economy to catch up with the United States. So towards the end of the 1960s and throughout the 1970s, the German university sector embarked on an ambitious quantitative expansion of teaching activities. Not only did the teaching staff at existing university expand with the opening of new faculties, but also new regional universities were built in several West-German states. Initially, that expansion aimed at creating the capacity for 200,000 in West-Germany; after a revision in the 1970s, capacities were expanded to 900,000, but in 1990, there were actually one million students in West-Germany alone.

The strong quantitative expansion came largely at the expense of high-quality research. Indeed, the university system’s transition away from applied research after World War II now appears to have been a key factor in the economic stagnation that has overtaken Germany. After the war, universities became skittish about applied research for a variety of reasons — including the ambiguous moral issues that emerged during the Nazi regime, the „brain drain“ and flight of many talented scholars to the US, and the lack of resources that accompanied a damaged infrastructure, among others. The unity of research and teaching that had defined the pre-World War II era was etched away and along with it much of the university sector’s role in Germany’s economic progress.

The neglect of research is also beginning to affect the development of Germany’s dense network of technical universities, whose name already indicates their ambition to be as comprehensive as the more established humanistic institutions. Technical universities need a critical size, which Berlin, Aachen and Munich already achieved in the 19th century. But some state governments no longer heed this lesson and have recently created small new technical faculties in old humanistic universities where the prospects for research will be very limited. In addition, the post-war period has seen the institutional innovation of Fachhochschulen — comparable to polytechnics or universities of applied science — which emphasize teaching but do almost no original research. Instead they use consultancy work to bring students into contact with business practice. Fachhochschulen thus represent an important stepping stone on the way towards an increasing separation of teaching and research.

Research within the proper university system is also thought to be hampered by statutory limits on non-academic income generating activities of a university professors (*Nebendienstverordnung*) which can make it difficult to set up in business to commercialize inventions and other findings of prior academic research. In a peculiar contrast, German professors are allowed to acquire patents on their own account even if they are based on official university research (*Hochschullehrerprivileg*). But this is now to change because in the past, many professors have not exploited their patenting opportunities efficiently, concentrating instead on furthering their academic publication record. According to current government plans, property rights in future academic research are to be held by the respective university and the share of its inventor-employees is to be limited to one third of all licence income, still much higher than in the private sector. Another factor that hinders research lies in the *Beamtenrecht* which has long prevented the employment of foreign academics as tenured professors in German universities.

One way of measuring the international competitiveness of the German university system is by looking at the number of foreign students it attracts to spend part or all of their study period at a German university. Public perception is that the numbers have been declining, and comparisons are often made with the early years of the 20th century when overall student numbers were small and a relatively large portion of privileged students from the US came to Germany for advanced studies.

Table 6: Foreign Students in Germany (percentage of beginners in parentheses)

Locus of Nationality	Winter term					
	1975/76	1980/81	1985/86	1990/91	1995/96	1998/99
Europe	22730 (24.7)	29086 (24.7)	39670 (21.4)	53151 (26.9)	87455 (30.2)	104368 (29.6)
Africa	3249 (19.9)	3884 (17.8)	4310 (16.6)	6441 (21.8)	13555 (15.9)	16500 (18.0)
Americas	5451 (39.5)	6572 (34.9)	7600 (35.4)	8455 (36.4)	9084 (34.3)	8972 (39.3)
Asia	14408 (17.1)	17056 (16.5)	21667 (14.8)	30051 (17.2)	34051 (13.8)	34390 (18.7)
Other	1460 (20.1)	1115 (18.7)	1327 (19.1)	1662 (22.0)	2326 (15.8)	1764 (18.6)
Total	47298 (23.6)	57713 (22.9)	74574 (20.6)	99760 (24.3)	146471 (25.1)	165994 (26.6)
Thereof "Bildungsinländer"					48082 (17.8)	57209 (16.5)
Percentage share of foreign students in all students	5.7	5.6	5.6	6.3	7.9	9.2
Percentage share of foreign students minus "Bildungsinländer" in all students					5.3	6.0
Percentage share of foreign beginners in all beginners	6.8	6.8	7.4	9.6	14.0	16.8
Percentage share of foreign beginners minus "Bildungsinländer" in all beginners					10.7	13.2

Note: "Bildungsinländer" are legally considered foreign, but they have graduated from a high school in Germany, in most cases because they were brought up by foreign parents living in Germany.

Source: Statistisches Bundesamt, Hochschulstatistik, own calculations.

Table 7: Major fields chosen by real foreign students* in Germany in the winter term 1998/99 (percentage of nationality group in parentheses)

Locus of Nationality (total number in parentheses)	Social sciences, law and business studies (SLB)	Humanities (HUM)	Engineer ing studies (ENG)	Sciences (SCI)	All others, including arts, sports, medicine and agriculture (OTH)
Europe (59584)	17608 (29.6)	20727 (34.9)	7644 (12.8)	6483 (10.8)	7122 (11.9)
Africa (14460)	2528 (17.4)	2033 (14.1)	5269 (36.4)	3172 (21.9)	1458 (10.1)
Americas (7555)	1501 (19.9)	3195 (42.3)	945 (12.5)	876 (11.6)	1038 (13.7)
Asia (26129)	4763 (18.2)	5730 (21.9)	5660 (21.7)	4731 (18.1)	5245 (20.1)
Other (1057)	155 (14.7)	195 (18.4)	275 (26.0)	185 (17.5)	247 (23.4)
Total (108785)	26555 (24.4)	31880 (29.3)	19793 (18.2)	15447 (14.2)	15110 (13.9)
Percentage share of real foreigners in all students	4.7	7.7	6.5	5.7	6.1

*After subtracting "Bildungsinländer", i.e. students born to foreign parents in Germany.

Source: Statistisches Bundesamt, Hochchulstatistik, own calculations.

Recent data on the number of foreign students, which is presented in Tables 6 and 7, reveal distinct patterns for source countries, depending on their location in Europe, Asia, the Americas or Africa. While most students from developing countries in Asia and Africa appear to be coming for full courses of studies, largely concentrated in engineering and the sciences, students from the Americas appear to be coming primarily as exchange students for a spell of one year or less, to study the German language and culture, in the humanities. Among European students, the proportion of temporary exchange students has declined since the opening of Eastern Europe led to an influx of students who sought to study full courses at German universities in order to obtain a German degree, with a strong preference for the humanities, social sciences, law and business studies.

One question for policy makers is whether foreign students can make up for an increasing mismatch between the qualifications of German graduates and the changing structure of labor market demand. Indeed, the steady supply of German engineering and science graduates has begun to dwindle in the 1990s under the impact of unfavorable demographics and a declining quality of high school education in mathematics and the sciences. However, unlike in the US, foreign students have neither arrived in sufficient numbers to fill these gaps, nor are those from developing countries normally allowed to compete in the German labor market after their graduation.

More general comparisons with the US and other countries are difficult for a number of reasons. Student flows are not only influenced by the expected academic quality of the chosen host university, but also by the costs of study (including the costs of living and tuition which is generally free in Germany) as well as by students' language skills. But in a revealing contrast with the US system, participation rates of foreigners are at their lowest among doctoral students in Germany, whereas in the US, the share of foreigners is at their highest among doctoral students. While this surely reflects on the strength of research in US universities, there is also a financial reason: Foreign doctoral students in Germany often cannot take up positions as teaching assistants because of language problems and legal barriers.

Other Microeconomic Issues of Innovation Policy. As an example of excessive product market regulation and mismanagement which has stifled innovation, the German railway system stands out, especially in comparison with neighboring France, a world leader in the implementation of advanced railway technology. This is not to deny that German industry has established a strong patenting record over time. But throughout the post-war period, German infrastructure investment has been biased in favor of the automobile. In sunset industries, disincentives for innovation have often been caused by massive subsidies which tend to protect long obsolete products and processes. As a general problem, low rates of capital formation, at least partially induced by the tax system, have adversely affected technology adoption in many industries. Moreover, Germany differs from many other advanced countries in refusing to grant a general R&D tax credit.

The current tax reform, which has been approved by both houses of parliament in 2000 and is to take effect in 2001, once again reveals a mistrust of capital markets as a guide for the allocation of investments in the economy. The tax reform is rightly intended to improve the private incentives for investing in physical capital, by lowering taxes on earnings. However, while tax rates are indeed lowered, the depreciation period is reduced so that the private user costs of capital may actually be increased for many firms. On balance, it appears the net effect will be improved incentives for most firms. What is clear, however, is that the tax reform discriminates against new firms by introducing a split tax rate for earnings retained in the firm and those paid out to its owners. New firms, especially those based on new technology with high fixed costs of R&D before the product launch, often do not have retained earnings and thus cannot benefit from the tax privilege to be associated with these. By the same token, the tax reforms also reduces the influence of the capital market on firms' investment decisions. Because retained earnings are to be taxed at a lower rate than distributed profits, self financing becomes relatively more attractive than raising equity externally, for example, by issuing public shares on the stock market. What is more, the tax reform will penalize investments in human capital because the returns from these are to be taxed at the much higher personal tax rate and do not benefit from the reduced tax rate on retained earnings.

IV. Summing Up

What policy lessons can be derived from the German experience?

Germany certainly has developed a set of fine institutions which have successfully supported industrial innovation in Germany's traditional areas of technological strength. Some, like the *Fraunhofer* institutes of applied research, are now being copied and adapted in many industrial countries, e.g. France, and have even been imported in the US. But outside Germany's traditional areas of strength, economic performance has probably been hampered mainly by two factors: by a failure to innovate in the university system, which has reduced the quality of teaching and research, and by over-regulation of markets in many sectors, which has distorted incentives and inhibited the free flow of knowledge. More flexibility would be needed foremost in the labor market. While heavy investment in public infrastructure to facilitate the transfer of technology may have its merits under conditions of incremental technological change in an established industry, it may impose undue inertia when new opportunities emerge in entirely new areas of technology.

Above all in industries with skill shortages, it may be counterproductive for the government to promote the technology transfer by setting up special centers that directly compete with private firms for skilled labor. A better strategy might be to set incentives for people to move between firms in the private sector and the universities. Many of the necessary reforms can be introduced in a piecemeal fashion, there is no need for central planning and coordination through political committees. In practice, however, frictions between the different interest groups in Germany's corporatist system are often invoked as an excuse for arranging round-table talks at the highest level. But such talks rarely achieve any significant reform. They rather give the participants a high-profile opportunity to present their views, and so they effectively reinforce the corporatist system that is at the root of Germany's difficulties with reform.

Our analysis suggests that Germany's problem with technological innovation are based less on market failures, but rather on missing markets. In the past, technology policy has invested in institutions that were meant to substitute for some of the missing markets. But with an accelerated pace of change in today's high-tech industries, that strategy is becoming increasingly obsolete. However, Germany has begun to move in the right direction in recent years, when it began to place greater trust on the market in allocating resources towards innovative activities. The biggest remaining problem is the labor market.

In a far cry from the infant industry argument of trade policy first formulated by List (1841), protectionism for high technology is no longer seriously considered, except in the aircraft industry. Instead, policy makers are now urged to adopt policies for greater openness and market flexibility so as to improve the capacity of an economy to seize some of the enormous opportunities in today's most dynamic industries. These urges appear to be particularly relevant for Germany which already has many of the assets needed for a leading role in knowledge-based industries, like software and biotechnology, but which — for reasons we have explored — has often been tardy in entering newly emerging fields of technology with sufficient vigor to actually establish a leading position.

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