Semiconductor Developments in the Dresden Region

Final Report

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1 Introduction

This study is part of the so-called *Tigers* project. The most general background to the objectives of the Tigers project can be seen in the so-called "Lisbon objectives." At the European Council held in Lisbon in March 2000, the EU15 set a goal for Europe:

"The Union has today set itself a new strategic goal for the next decade: to become the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion. Achieving this goal requires an overall strategy aimed at:

- preparing the transition to a knowledge-based economy and society by better policies for the information society and R&D, as well as by stepping up the process of structural reform for competitiveness and innovation and by completing the internal market;
- modernising the European social model, investing in people and combating social exclusion;
- sustaining the healthy economic outlook and favourable growth prospects by applying an appropriate macro-economic policy mix.

… The shift to a digital, knowledge-based economy, prompted by new goods and services, will be a powerful engine for growth, competitiveness and jobs. In addition, it will be capable of improving citizens' quality of life and the environment."

These objectives address the economic, the social as well as the ecological dimensions of change which will therefore also be dealt with in this document. The *Tigers* project has the ultimate objective of learning from IT-related development in Western Europe, to develop policies for the EU Candidate Countries. It was felt that analysing IT-related developments in Eastern Germany would make sense, as one would thus investigate change in a former communist society. It did not appear attractive to analyse – with limited resources of 35 days – the whole of Eastern Germany, possibly even including Berlin with its special characteristic as a formerly divided capital and its high subsidies. Rather, it was felt that it would make sense to investigate a smaller cluster in which IT-related developments play a special role.

In Eastern Germany, except for the special case of Berlin, there is a limited number of areas with above-average economic performance. These are Erfurt, Jena, and Dresden (Ragnitz et al. 2002, p. 322). The development of Erfurt is linked to engineering and electronics, Jena is linked to Jenoptik, formerly "Carl Zeiss" in Jena (as opposed to the West German "Zeiss" company), and Dresden is linked to semiconductor production, with the first post-1989 investment made by Siemens. Economists also mention Eisenach and Zwickau as major clusters of development, focusing on the car industry (Opel and Volkswagen respectively), as well as Chemnitz (Volkswagen, other machinery), Leipzig (trade, car and media industries), Plauen, focusing on machine production, and Halle with major chemical plants (Ragnitz et al. 2002, p. 61). In the framework of the *Tigers* project, Dresden was selected as being IT-related. Issues to be addressed, according to the Lisbon summit objectives, and thus according to the objectives of the *Tigers* project, are therefore:

- How can ICT-production provide employment?
- What are the social and ecological effects?
- How can government influence the development?

The methods used to address these questions were, given the limited resources available, to review the most important studies, and to conduct a limited number of expert interviews. Regarding the studies, it turned out that except for limited information on the WWW, the most important studies about Dresden are only available in German, so this study may have added interest for the non-German reader. Regarding the interviews, it was possible to conduct 8 semi-structured in-person interviews with representatives of companies, regional government, research, political parties, trade unions, and environmentalists, in Dresden. Some of the interviews were recorded on tape. Evaluation took place using hermeneutic methods as developed by Kade (1983) and Oevermann (1980).

This document is structured as follows. In Section 2, a statistical overview of general developments in Saxony and in Dresden, as well as on related information society and semiconductor developments is provided. Thereafter, in Section 3 the development of the Dresden semiconductor cluster is described. In that section, early roots of industrial development are mentioned, as they are deemed to be important for understanding how such a cluster can develop (3.1). Subsequently, in Section 4 an assessment of the developments is provided, analysing inputs and outputs and their causes. Thereafter, some open questions are formulated and an attempt is made at drawing conclusions (Section 5). Section 6 provides a summary.

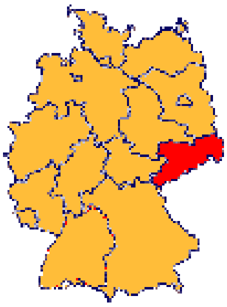
The *Tigers* project took place within the framework of the *European Science and Technology Observatory* (ESTO). It was sponsored by the ICT unit of the *Institute for Prospective Technological Studies* (IPTS) in Seville, Spain, which is part of the European Union's *Joint Research Centre*. The project was led by MERIT, the Maastricht Economic Research Institute on Innovation and Technology (The Netherlands). Other partners were the Austrian Research Centers, Atlantis Consulting (Greece), The Circa Group (Ireland), and ITAS. The project started in 2002 and was completed in 2003. ITAS was responsible for the analysis of the development of the semiconductor production firms in the Dresden region (cf. http://tigers.infonomics.nl).

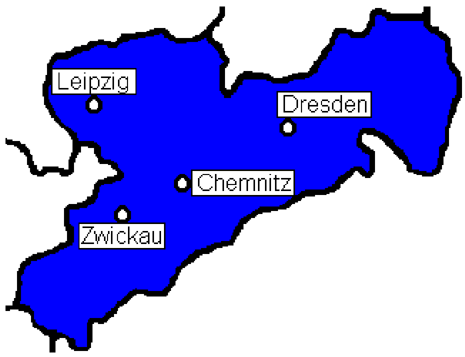
The author wishes to express thanks to the interviewed experts, to the reviewers, and to all colleagues of ITAS, IPTS and the *Tigers* project partners for help and critical comments on earlier versions of this work, in particular to Marc Bogdanowicz, Waltraud Bruch-Krumbein, Jens Drews, Dietmar Edler, Werner Esswein, Thomas Hänseroth, Hermann Härtig, Torben Heinemann, Karin Jeltsch, Inka Klotsche, Jürgen Krake, Gabriele Müller-Datz, Peter Nothnagel, Michael Rader, and Jörg Urban.

2 Statistical Overview

In this section, a mainly statistical overview of general developments in Saxony and in Dresden, as well as on related information society and semiconductor developments is provided.

Location, population: We start with general information about the location, and show in Figures #1 and #2 that Saxony is located in Eastern Germany; its capital Dresden has a relatively Eastern position. Saxony borders on Poland and the Czech Republic.





Figures #1 and #2: Germany, Saxony (source: European Commission 2002).

After re-unification in 1989, about 120,000 people left Saxony in 1990. During the following years that figure of emigrants became smaller. In 2001, Saxony had the highest absolute shrinkage of population among all German states (Statistisches Landesamt Baden-Württemberg 2002). In 2002, the city of Dresden had about 470,000 inhabitants, down from 518,000 inhabitants in 1988 (Röhl 2001, p. 245). Table #1 shows how the population of Saxony developed. After 1989, there was a sharp decrease in births, due to the new economic situation. The number of births has recovered somewhat since.

Saxony	1989	1995	2001
Population, millions	5.0	4.6	4.4
Births	55,857	24,004	31,943

Table #1: Source: Statistisches Landesamt des Freistaates Sachsen, 2002.

Employment: Some key facts and figures for the former GDR (German Democratic Republic), Saxony and Dresden are, at the end of GRD-times:

- In Saxony, 1.136 million employees worked in manufacturing in 1988 (Röhl 2001, p. 28).
- In the whole GDR, 120,000 employees worked in microelectronics (European Commission 2002, p. 18). The centre of microelectronics research was Dresden.
- The major semiconductor research centre was Forschungszentrum Mikroelektronik with about 3,300 employees, who were, e.g., piloting the 1 Mbit memory chip in 1988 (Specht 1999, p. 208).
- Major Dresden industrial companies, including the Forschungszentrum Mikroelektronik, had a total of about 30,000 employees in 1989 (Niemann 1996).

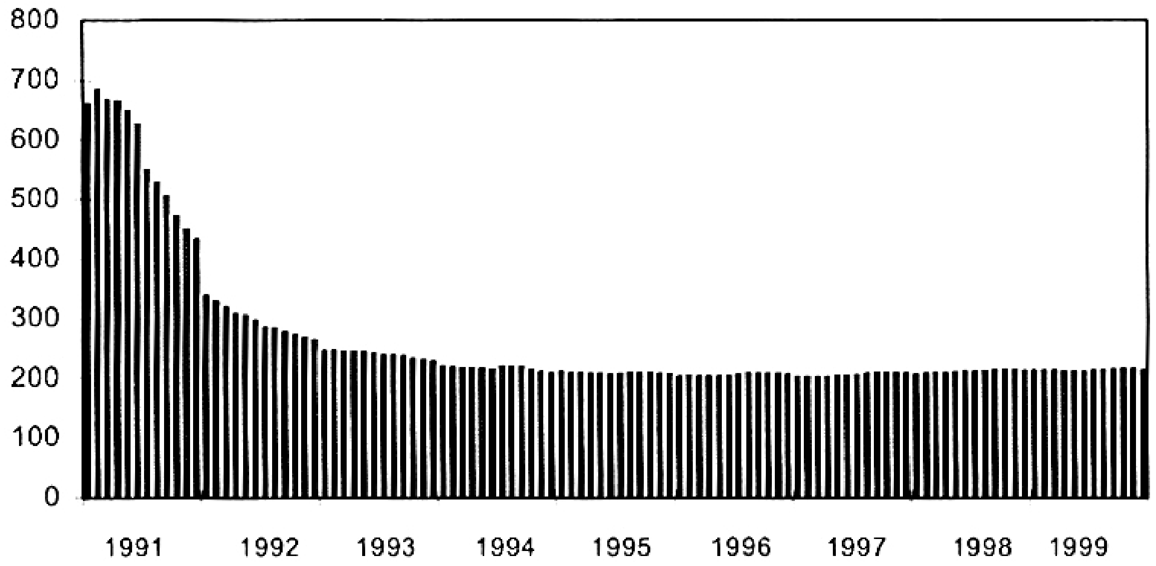


Figure #3: Employees in manufacturing in Saxony, in thousand, monthly values (Röhl 2001, p. 249).

Some key facts and figures from after 1989 are presented below:

- In 1994, only 216,000 employees worked in Saxonian manufacturing (Röhl p. 28, cf. Figure #3).
- By 1992, 25,000 of the 30,000 jobs in Dresden industrial companies had been abolished (Niemann 1996).
- In Eastern Germany, employment shrank to about 65 % of its GDR level.
- The semiconductor companies AMD (Advanced Micro Devices), Infineon (formerly Siemens) and ZMD (Zentrum Mikroelektronik Dresden, formerly Forschungszentrum Mikroelektronik) in late 2002 employed about 7,100 people in Dresden. Their partners and other semiconductor companies employed about 3,500 people in the region, including about 1,000 in nearby Freiberg.
- In Saxony, the general unemployment rate in October 2002 was 17.8 % (in Dresden it was 15.1% and in Germany as a whole 10.5%).
- In Saxony, 44.587 people worked in ICT including the printing industry, in the year 2000 (Freistaat Sachsen, Telematikbericht, 2001, p. 55, below quoted as "Telematikbericht 2001") .

Employment in Saxony	1989	1995	2001
Economically active (million)	2.24 (1991)	2.00	1.94
Unemployment rate	0 %	14.4%	19.0%

Table #2: Source: Statistisches Landesamt des Freistaates Sachsen, 2002.

Employment in Dresden	1993	1999
Economically active	241.000	216.000
Unemployment rate	11.6 %	15.6 %

Table #3: Source: Blien et al. 2001, p. 65; Landeshauptstadt Dresden 1999, p. 53

GDP, Wages: Though difficult to measure in a period of significant transition, GDP grew considerably after 1989, see Table #4 and Figure #4. The Figure does, however, also show that growth rates in Eastern Germany had become much smaller after 1995 and approached the relatively low West German levels. However, in 2001, East German *manufacturing* industries increased their output by 5% (Ragnitz et al. 2002, p. 12). *Saxonian manufacturing* is developing particularly well, with a growth of 8.4% in 2001, in particular for the production of vehicles and machine tools (Schommer 2002).

GDP and Wages in Saxony	1989	1995	2001
GDP bn €	34.8	67.0	74.3
GDP bn € (1995 prices)	47.1 (1991)	67.0	71.5
Wages €	13,179 (1991)	23,306	25,580

Table #4: Source: Statistisches Landesamt des Freistaates Sachsen, 2002. Wages = remuneration of employees.

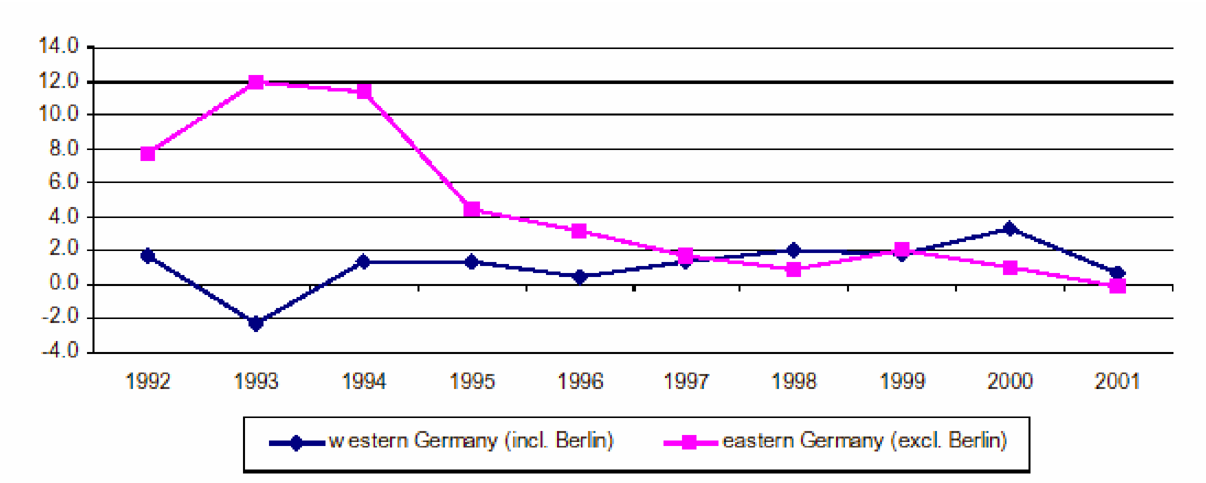


Figure #4: Annual change in real GDP in East and West Germany, in percent (1995 prices; source: European Commission 2002, p. 17).

Access to Information Technologies: A few figures will provide a very rough idea of the availability of information technologies.

- In 1989, there were about 500,000 telephone lines in Saxony, in 1997 already more than 2 million. In 1989 25% of all households had telephone access, in 1998 the figure was 93 % (Röhl 2001, p. 62).
- The mobile telephony infrastructure also grew significantly: in 2001 75% of all Saxonian households had a mobile phone (Telematikbericht 2001, p. 30f).
- In 2001, 36 % of Saxonian households, i.e. 740,000, had Internet access. Almost 90% of companies[1] had Internet access in 2001 (Telematikbericht 2001, p. 20 and 82f). In 1998, only 4% of companies had access (IRIS-I 1998).[2]

[1] The State of Saxony's "Telematikbericht" (2001) states on page 82 that "almost 90%" of SMEs have online access, no precise figure is provided. Assuming that the relatively few large companies are all connected, the statement in the text above should be justified.

[2] The Telematikbericht (2001) provides a comprehensive overview of ICT-related developments, but includes industries such as printing in many of its statistics, therefore its figures are not readily comparable to other ICT-related figures used in the *Tigers* project.

3 The Development of the Dresden Semiconductor Cluster

3.1 Saxony and its Capital from the Middle Ages to 1989

3.1.1 The Origins of the Saxonian Industry

The historical development of Dresden must be seen in the framework of the development of the state of Saxony. Saxons inhabit the northern slopes of the Erzgebirge – the “Ore Mountains“ – where Chemnitz (called Karl-Marx-Stadt during GDR times) and Zwickau are situated, and some less mountainous areas to the north (with Leipzig) and the east (with Dresden).[3]

The Ore Mountains are basically a relatively cold and humid area, and thus, by nature, a poor area. This changed, slowly, with the development of industries. Metal crafts started to develop around 1100 (Keller 2002). Most famous is the discovery of silver in Freiberg, which is situated between Dresden and Chemnitz. Many other mines sprang up all over the Ore Mountains. Also the glass industry developed, e.g. at the site of Glashütte, just south of Dresden. Furthermore, the wood industry developed, including the production of relatively small and precious items, such as toys and violins, in family-owned enterprises. Last but not least a textile industry developed. All these industries required trade, and allowed some economic development of the area.

At the end of the medieval ages, Saxony and Thuringia were home to the protestant movement. Prior to that movement, there had been only few professions or vocations, mainly those of the priest and of the physician. With Protestantism, activities to the benefit of other humans were ranked equally. I.e. vocational work in a certain field was highly ranked as a valuable human activity, conducted in order to live in a religious way. This appreciation is in line with the increasing importance of the different trades mentioned above. The emergence of the vocation as a core element of human life is part of the same cultural change which took place in the Italian renaissance. In Florence and elsewhere, life on earth, with craftsmanship and science, was put into the centre of living. It has been said that with Luther “vocational work appears as the outward expression of brotherly love“ (Weber 1905, p. 68; cf. Jaeger et al. 1987). This attitude means that doing one’s work perfectly is to the benefit of others. The idea which developed is that if everybody behaves like this, this will be to the benefit of all.

Modern scientific mineralogy was developed in the Ore Mountains. Georgius Agricola (Georg Bauer) published *de re Metallica*, a treatise on mineralogy and mining technology, in the 16th century[4]. During the 19th and 20th century, Saxony became Germany’s leading industrial centre. In 1799, a water-power driven spinning mill was operated by the Bernhard Brothers. Machine industries started in the 1820s (Feldkamp 2000), only little later than in the United Kingdom. Initially, the continental blockade imposed against the UK by Napoleon in 1806 provided favourable conditions. The first German Jacquard looms and steam locomotives were built in Chemnitz, in 1828, and in 1848, respectively.

In 1904, August Horch built cars in Zwickau, in a company later to become Audi. Leipzig became an effective marketplace for selling Saxonian goods. The result of engineering, hard work and trade was that the area between Chemnitz, Freiberg and Zwickau became the most industrialised in Germany from the first half of the 19th century until World War II. In 1936,

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[3] Actually the history of the Saxons is more complicated, with the Anglo-Saxons living now in the British area, and Slavic origins of part of the people in today’s area of Saxony, but this is not relevant in our context.

[4] Agricola was born in the 15th century, in the author’s hometown of Glauchau, Saxony.

East Germany (in today's boundaries) had a per capita income of 27% above that of West Germany (Richter 2000; Sinn, Westermann 2000).

3.1.2 Origins of Dresden

Dresden has a tradition as a residence for Electors (Kurfürsten), Kings and other nobles. In the middle ages, it had already become a city with many local craftsmen, working to a significant degree for the nobles. Under the rule of Friedrich August I. ("Augustus the Strong"), 1694-1733, Dresden was turned into a beautiful baroque city. A famous example of the production of luxury goods is that of porcelain, which had been produced in China since the 13th century. Augustus the Strong ordered to uncover the secret of its production. In 1707/08, Johann Friedrich Böttger and Walther von Tschirnhaus (re-)invented the white, European hard porcelain in Meißen, 20 km north-west of Dresden. Dresden is still full of precious remainders from that era, such as Raffael's Sistine Madonna which was acquired from Italian priests. Most of the buildings were destroyed in 1945, but the Baroque panorama is still visible (Figure #5).[5]

Figure #5: View of the Baroque city centre of Dresden: Ständehaus, Hofkirche, Schloß, Semperoper (from left to right, October 2002; photo: Arnd Weber).

[5] See http://www.dresden-congresscenter.de/eng/eng_1.htm for a nice interactive map of the cultural highlights.

3.1.3 Dresden Industries from the Beginning to 1945

The Dresden area was, compared to Chemnitz, relatively late with industrial development, starting around 1870, though its Technical University was founded in 1828 (Königlich Technische Bildungsanstalt). Since 1878, Burkhardt built computing machines (originally invented in Colmar) in near-by Glashütte, where also watches were built. In Dresden, industries developed such as the glass industry. “Through the Siemens brothers, Dresden became one of the originating points for the industrial revolution in the glass industry”, producing, e.g., bottles (Mauerhoff 2002). Also the camera and optical industries developed. In this report, the latter industries will be addressed in a kind of side-track, for three reasons:

(1) Their large relevance in Dresden until 1989.

(2) Their relevance for the production of semiconductors.

(3) Their relevance in recent global developments such as video cameras, digital cameras and cameras in mobile phones, key technologies for creating data on mobile networks.

Examples of early achievements of these industries in Dresden are:

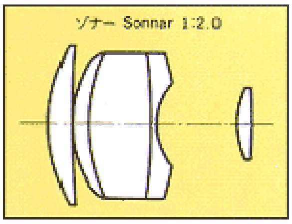
(1) The development of industrialised camera production in the Ernemann factories, which after mergers became the Zeiss-Ikon AG, second only to Kodak in the 1920s (Gerber 1998).

(2) The production of leading-edge lenses. For example, a high speed lens of f/1.8 was created by Ludwig Bertele in 1924, at a time when neither Zeiss nor Leitz were able to build similar lenses. Bertele later contributed to the Biogon wide angle lens, a design which was used for making pictures on the moon during the Apollo flights, and is still produced by Carl Zeiss, West Germany. He also contributed to the Sonnar lens, which has very few reflection-producing elements, variants of which are used in Sony digital cameras (Vario-Sonnar).

(3) The production of the first single lens reflex camera for 35mm cine film, the Kine Exakta, built by Exacta in 1936 (Hummel 1997), and the production of the first camera with a pentaprism, providing a life-size, upright image, the Contax S, in 1948 (Zeiss Ikon 1948, see Box #1).

The Dresden area was also home to a significant electrical industry. Examples are the production of electrical motors at the Sachsenwerk, and of high voltage equipment at Koch & Sterzel. In 1923 Koch & Sterzel built the world's first 1 MV transformer (Highvolt Prüftechnik Dresden 2002). In the early 20s, they also built crystal detectors used for radios (Schwarz 2002[6]), which functioned like later diodes. The successor company is now owned by Siemens. Widely known are also Mende radios, e.g. the Third Reich “Volksempfänger”.

[6] With thanks to Peter Nothnagel of the State Ministry of Economy and Labour for an email of Peter Schwarz of *Technische Sammlungen der Stadt Dresden* of October 7, 2002.

 Ernemann Ermanox 1924	 Ihagee Kine Exakta, 1936
 Zeiss Sonnar 1:2.0, Bertele 1929	 Zeiss Contax S, 1948

Box #1: Dresden optical inventions (sources: http://www.pacificrimcamera.com ; http://www.kyocera.co.jp/; http://www.big.or.jp/~kita2/ECC/PENTACONFBM/CONTAXHIS.html).

Dresden also became a place for manufacturing aircraft such as the Junkers aircraft since 1924 in the area of the Klotzsche airfield. Prior to, and during, World War II, military goods were also produced, such as tanks and targetry equipment. Below a description of Dresden by the British Bomber Command is provided, giving an overview of the state of the industry in 1944:

“Dresden is the historical capital of Saxony, its present administrative centre of considerable importance. It is one of the finest residential cities in Germany. With a population of 650,000 it is the chief centre of a populous belt which extends from north-west to south-east along the river Elbe from Meissen to Pirna. Based upon the number of persons employed in peace time, the largest single group of industries is the food and luxury trade (tobacco, confectionery etc.), with about 25,000 workers, but the manufacture of machinery and vehicles occupied 17,000 persons, regardless of the manufacture of iron and metal wares, and optical and electrical apparatus, the last occupying 10,000 persons. Other peace-time industries, in addition to light luxury industries, include textiles, glass, paper, rubber and photographic apparatus. The heavier industries are located in the W. and S.W. suburbs of Dresden, and further out in Radebeul (38,000 inhabitants), (engineering, rubber); Freital (37,000), (coal, glass machinery); Radeburg (16,000), (electrical apparatus, glass, engineering); Pirna (36,000), (artificial silk, glass, machinery); Heidenau (18,000), between Dresden and Pirna (paper, machinery, glass etc.). The industries of Dresden are mainly light industries carried on in small factories, and are not very obtrusive in the aspect of the town except in its Western half.” (National Archives 2002)

In 1945, large parts of Dresden, with the exception of certain suburbs and industrial areas such as the Klotzsche airport, were destroyed with more than 600,000 bombs. The number of casualties is unknown as the city was full of refugees. The severity of the allied air strikes is believed to have been in retaliation for the earlier German air attacks on Coventry and London.

3.1.4 Dresden Industries from 1945 to 1989

After 1945, the Soviet government picked the country clean of many valuable assets, even many rails from the railways (Stahl 1996). Later, they took a quarter of the eastern zone's annual economic output as a reparation. Nevertheless, with considerable problems – such as the 1953 revolt – the communists managed the reconstruction of large parts of Dresden, frequently with large pre-fabricated houses, so-called *Plattenbauten*. In this subsection, we essentially only look at industries which are of some relevance for the later semiconductor production, with the exception of our side-track on optics.

Aircraft

Many industries were re-built. Particularly surprising is that in the 1950s, the design of a civilian aircraft was started. The East Germans built a four-engine jet airliner, the Model 152, and flew it in 1959, less than five years after they had begun work. The headquarters of VEB Flugzeugwerk Dresden was at the airfield in Klotzsche on the outskirts of Dresden. VEB means *Volkseigener Betrieb*, literally "business owned by the people". Eventually 25,000 East Germans would be committed to the project. After a crash of the second flight, and no interest from the Soviets in buying, building aircraft was stopped in 1961 (Stahl 1996).

Cameras

Another important industry was the camera industry. VEB Pentacon, named after the pentaprisms in its cameras, had its headquarters in Dresden. In 1989 6,000 employees worked there. VEB Carl Zeiss, headquartered in Jena in the state of Thuringia, became the most important producer of optical equipment.

Electronics and Semiconductors Industries

After its closure, VEB Flugzeugwerk Dresden was split up into several smaller companies. One of these was VEB Elektromat Dresden, which started building equipment for the electrotechnical and electronics industries, such as machinery for manufacturing components, bonding machines, optical equipment, equipment for measurement, etc. (Freydank 2002).

In 1961, also the "Arbeitsstelle für Molekularelektronik Dresden (AMD) as the nucleus of a centre for microelectronics research, development and production [was established; A.W.], to serve the entire Warsaw Pact region. It began as a subsidiary of Dresden Technical University" (Bruner 2001). The AMD was founded in Dresden-Klotzsche. It should not be confused with the US-based AMD company, which became an investor in 1995.

AMD grew and became VEB Forschungszentrum Mikroelektronik. In 1967, the first integrated circuits were developed. Their production started in Frankfurt (Oder), east of Berlin, in 1970. Semiconductor production took also place at Erfurt, Thuringia. Forschungszentrum Mikroelektronik's only task was to conduct research and development and pilot production of semiconductors (Specht 1999).

In 1969, the Kombinat Robotron was founded, a *Kombinat* or combine being a large amalgamated industrial complex, consisting of 5 or more VEBs or factories. Robotron had several locations, one of which was the Zentrum für Forschung und Technik (ZFT) at Dresden. Robotron sold, among other things, complete computing centres, with computers, air conditioning, etc. in the GDR as well as in other countries of the Comecon area. In 1989 it had 4,000 employees.

In 1980 Elektromat Dresden and the Institut für Mikroelektronik Dresden were merged to form the Zentrum für Forschung und Technologie Mikroelektronik (ZFTM). In 1987 the ZFTM was integrated into Kombinat Carl Zeiss Jena. On that occasion, Elektromat Dresden and Institut für Mikroelektronik Dresden were separated again, and the latter formed VEB Forschungszentrum Mikroelektronik.

Also relevant for the semiconductor industry was VEB Spurenmetalle "Albert Funk", founded in 1957 in Freiberg, 30 km west of Dresden. It developed and manufactured high-purity semiconducting materials, particularly germanium, silicon, gallium, arsenic, and similar materials and compounds. In 1989, it had 1,860 employees (according to Sachsen LB [State Bank] 2002; according to Heidtmann (1998) it had 6,500 employees).

In 1976 the SED party convention decided to invest in semiconductor development (Specht 1999).[7] Between 1986 and 1989 27 billion Marks were planned for the production of the 1 Megabit memory chip (Specht 1999, p. 208)[8]. These expenditures amounted to about 40% of all governmental research and development spending. At the time, due to COCOM rules (a list of sensitive goods, specified by the Coordinating Committee for Multilateral Export Controls by the US and its partners), the GDR was not given the opportunity to buy important components for semiconductor production. Hence, its engineers had to re-invent much themselves. The result was relatively inefficient production. According to internal calculations, in 1989, 250 kbit-memory chips were produced at costs of 534 Marks, but they were sold for 16.80 Marks (Ministerium für Staatssicherheit, quoted in Schroeder 1998). Whatever the precise reasons were, it was apparently not possible for the GDR to have a profitable semiconductor production (cf. Barkleit 2000).

In 1988, the first lab prototype of the megabit-chip was ready. "They found themselves producing the world's largest microchip" Jens Drews, spokesman for the new AMD said. But it was the only megabit-chip produced at the time outside of Asia and America.

3.1.5 Concluding Remarks

Dresden was the largest site for industrial research and development in the GDR (Röhl 2001, p. 12[9]). In the GDR, 120,000 employees worked in microelectronics, with the research centre in Dresden.

According to common opinion, the products exported by the GDR were frequently, but not always inferior to the products available on the Western markets. While some products met world quality standards, e.g., machine tools such as those presented at the famous *Leipziger Messe* (trade fair), others met them only in some respects, e.g. Carl Zeiss Jena lenses were good but somewhat heavy. Many goods were competitive only at significantly lower prices than Western goods, e.g. textiles and toys.

The GDR had high birth rates, no hunger, and was relatively well-off compared to other Comecon states. But many factory buildings dated from before World War I, much chemical waste was simply dumped into the ground, buildings used to be brown because of unfiltered burning of brown coal, and lack of paint. In winter time, cities used to be in a yellow cloud for the same reason.

In the early eighties, the GDR ran into financial problems. The so-called "Devisenrentabilität" – cashed-in Western DM compared to spent Eastern Mark – shrank from values such as 0.3 to values of 0.2 and below during the 80s (Heidenreich 1991). In 1989, wage costs in manufacturing were 7% of the west German wage, at the existing exchange rate, according to an estimate by Sinn and Westermann (2000, p.18). Foreign debt increased. In 1989 the GDR had a foreign debt of about $ 21 billion. "In a confidential communication of May 1989 to the SED

[7] According to Sachsen LB, the state bank, it was the Zentralkomitee der SED, who made that decision in 1977.
[8] Barkleit reports that between 1977 and 1988 14 billion Marks were spent on microelectronics (2000, p. 27).
[9] According to Specht 1999, p. 208, it was second after Berlin.

Central Committee, the then Chairman of the State Planning Commission admitted that the GDR was economically finished” (according to Weber 2000, see also Schroeder 1998, p. 509-512).

In May 1989 an increasing number of citizens fled when the Hungarian government opened its borders (“Republikflucht” was a criminal offence). In October 1989 1,300 citizens of Dresden were arrested during a demonstration, but nobody was shot. Nor was anybody hurt at the demonstrations in Leipzig. In November, the SED-government in Berlin resigned and the year after, the GDR accessed the FRG (Federal Republic of Germany).

3.2 The Economic Situation in Eastern Germany after 1989

Early Developments

In theory, after November 1989, one could have turned Eastern Germany into a low wage area, taking into account that with the prevailing production methods, East German goods would only be competitive at low prices. This would have led, however, most likely to large political discontent and a significant exodus, so this was largely believed not to be a politically valid option.

After 1989, East Germans were very interested in buying Western goods, and Western companies were, of course, very willing to sell them. Similar processes took place on the GDR’s eastern markets. One immediately sees the challenge the German government faced. Which VEBs might be able to survive? Which could be sold to foreign investors (in this case including those from West Germany)? Which parts were so uncompetitive that they would simply have to be closed down as soon as possible?

Housing Situation

After re-unification in 1990, “economic growth in East Germany was dominated by developments in the construction sector.” (European Commission 2002, p. 17). Subsidisation of investments in construction took place by, among other things, a special 50% write-off in private income tax returns of investors, and additionally a subsidy for private homes (Ragnitz et al. 2002, p. 419). This led to a massive construction of new flats and houses, and other infrastructure developments such as industrial parks for attracting investors. Due to the oversupply, rents diminished, and it became uneconomic to renovate the old houses. An estimated 1 million apartments are now deserted (European Commission 2002, p. 46), to a large degree apartments from before World War II, which typically means from the Emperor’s time. Of the latter, 30% are empty. The situation is particularly difficult in Saxony because of its large number of houses from the Emperor’s time (Ragnitz et al. 2002, pp. 371, 378, 381). Economists today criticise the “very generous fiscal incentives for both business and housing construction” (European Commission 2002, p. 1; Ragnitz et al. 2002, p. 393) and the current “amply dimensioned flat travelling rate for commuters” (Ragnitz et al. 2002, p. 457) which provides a tax reduction typically requested by those commuting from a new house to a remote workplace.

Employment

In 1990, with the currency union, East German marks were converted one to one into West German marks (with exceptions). Economically, this was regarded to be too high, as it meant a significant increase in costs of production, with wages in East Germany about one third of those in the West. The high exchange rate also lead to significant debts for those East German companies owing money. In 1991, West German employers negotiated with the unions a five-year contract with a specified path to wage equalisation (Sinn, Westermann 2000). After 1989 there was also hope that GDR-companies could continue to export to Eastern Europe, but due to the dissolution of Comecon and the following increase of competition on these markets, sales to the East shrank considerably. These developments led to a significant reduction of employment in Eastern Germany. The German Trust Agency (Treuhandanstalt) was set up with the objective to privatise the state-owned companies. Difficulties of privatisation contributed significantly to today's German government indebtedness. It has been estimated that about DM 500 billion of DM 2,300 billion total government debts in the year 2000 are due to reunification (Mai 2002).

As an incentive to invest, subsidies to investments were then given, and still are, by the government. These ranged from 15% up to 50%, depending on circumstances such as location.

Economists observe that areas close to the West, close to Berlin, and in Saxony develop relatively well, in particular areas around large Western investment, such as Berlin, Eisenach, Erfurt, Dresden, Jena and Zwickau (Volkswagen in Mosel, next to Zwickau; Ragnitz et al. 2002, pp. 140, 142, 322). These form "beacons" of development, which must also be described, however, as different from the remainder of the regions. Actual compensation per employee is about 77% of Western level (European Commission 2002, p. 82). Compared to GDR times, employment has fallen to about 65%. 90% of all job losses occurred in manufacturing (European Commission 2002, p. 31). Many new jobs demanded new qualifications, such as acquaintance with Western technology, marketing skills, etc., which employees did not readily have.
The situation has also been described as a development of a "second Mezzogiorno", with GDP per population at working age remaining around 60% relative to rest of country, from 1995 onwards (Sinn, Westermann 2000, p. 5, see Figure #6). This figure shows a threat: despite all policy support such regions may not "catch up". Reasons for this productivity gap in Eastern Germany are seen in the number of small companies, which are generally less productive, and in the weak position of many East German companies in the market (DIW et al. 1999, p. 128). Yet, these subsidised companies with relatively low wages provide competition to West German employers.

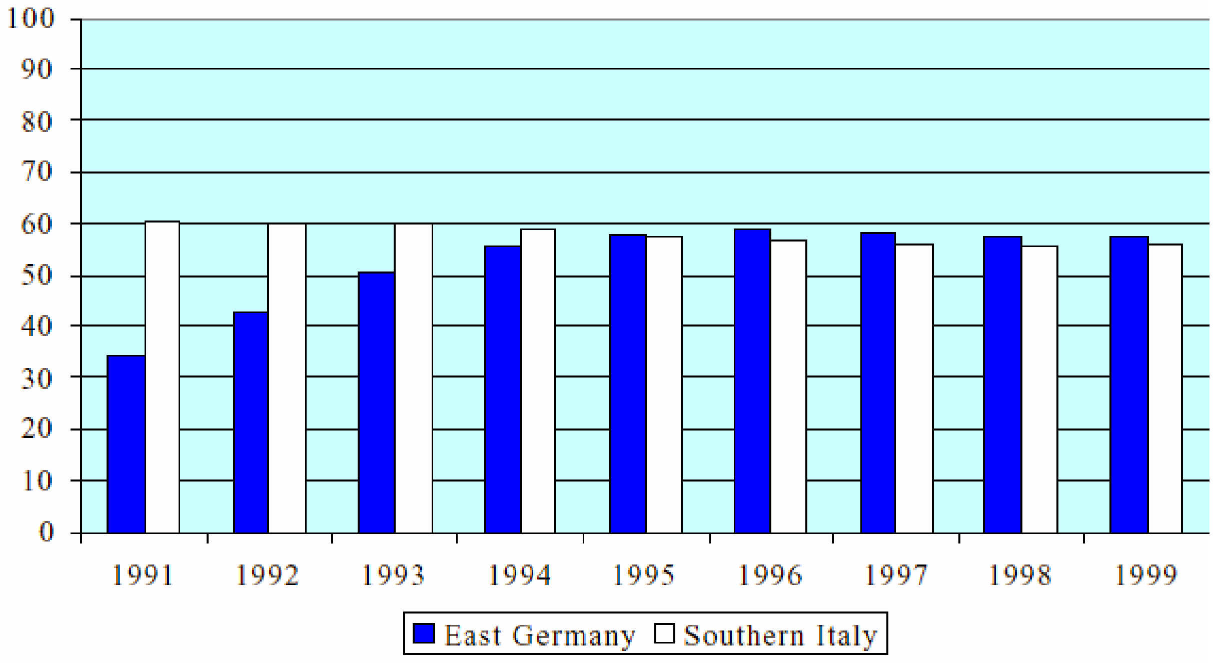


Figure #6: GDP/population at working age, relative to rest of country, in percent (source: Sinn, Westermann 2000).

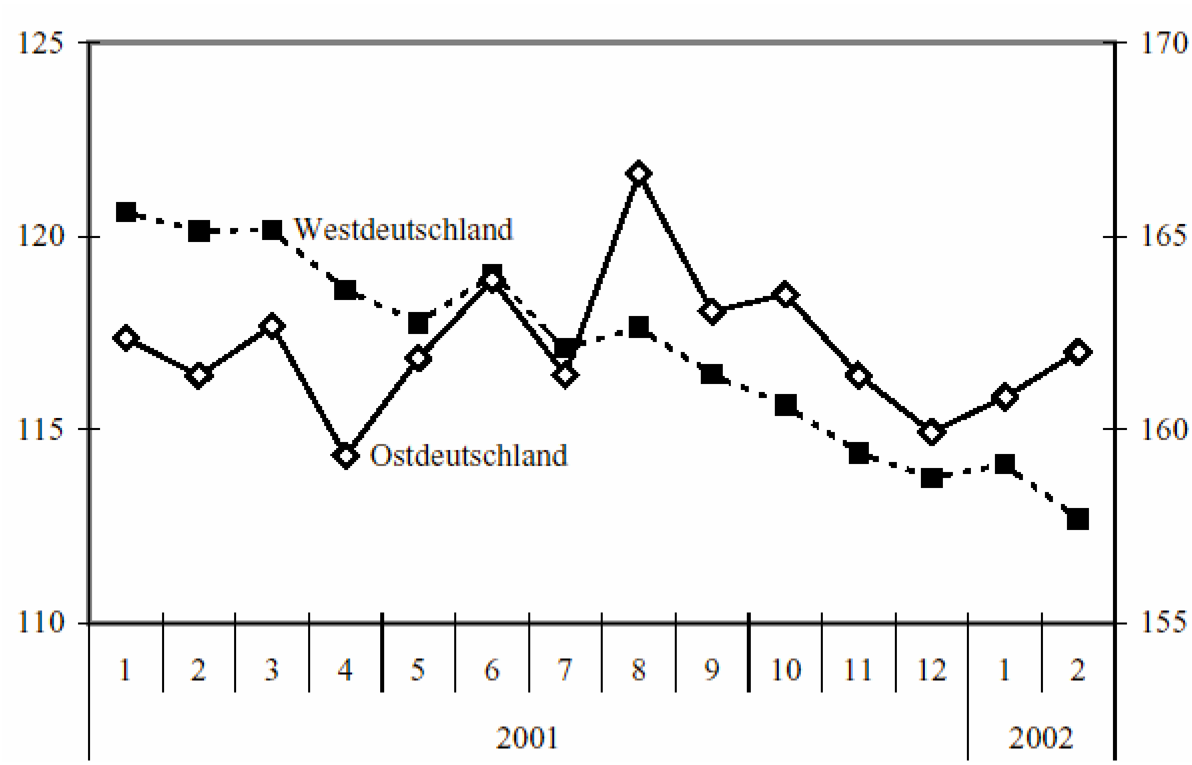


Figure #7: Net production in manufacturing. 1995 = 100. Right hand scale = East Germany (Ostdeutschland); left hand scale = West Germany (Westdeutschland). Source: Ragnitz et al. 2002, p. 16.

In 2001 the manufacturing industries increased their output by 5% (Ragnitz et al. p. 12) and have since doing comparatively better than West Germany (see Figure #7). Most production is done by SMEs (Belitz, Fleischer 2000). Also export from Eastern Germany is starting to develop, essentially from sites of the large investors Infineon, AMD and Volkswagen (Ragnitz et al. 2002 12, p. 107). Economists observe that such major foreign or West German investments prosper above average. These investors typically are big players on the world market. Figure #7 shows that there is a possible trend against the threat of developing a "second Mezzogiorno". While the construction industry is declining, manufacturing is developing above average.

Other industries are supported by substantial transfers from Western Germany to a significant degree, such as retail or finance, and therefore it is unlikely that they will develop into an engine of growth; the construction industry already has a diminishing role. Blien et al. conducted an econometric analysis based on regional data and concluded that relatively high wages contribute negatively to employment (p. 28). It would be desirable to show how this actually took place, e.g. in the chemical and machine tool industries which appear to have been discouraged significantly, according to Blien et al. Their own data show, however, that the region of Dresden with above average wages (p. 65) is among those which is developing best, as they write in their editorial.

With employment at 65% of its former level, and wages at about 77% of the Western level, discontent among the population can be noticed, and around 20% and sometimes more of the electorate vote for the PDS, the successor to the former communist SED party. Birth rates have decreased, and some regions in particular in the north of the GDR are losing most young people.

Concluding Remarks

Much property in Eastern Germany has been given back to its former owners, who typically live in the West. Also, of course, the "foreign" investments from Western Germany or abroad are not owned by locals. Due to the tax incentives to build apartments many of the new apartments also belong to fairly affluent people from Western Germany. Though the East German subsidiaries are not simply "extended work benches " as there is also research and development as in Dresden, there are hardly any headquarters of larger companies. A well-known exception is Jenoptik (formerly Carl Zeiss in Jena, Thuringia). Thus, a large share of East German property is owned by people living in the West. This does not only mean some frustration on the part of the locals, it also means that certain segments of the GDP (spending of profits for luxury goods, domestic services etc.) are underdeveloped. The West German corporations also did not move their headquarters to Eastern Germany. For instance, Siemens who, after the war, reportedly were afraid of Soviet expansionism and had moved to Munich, did not go back to Berlin (which had been nicknamed "Elektropolis" at the beginning of the 20^{th} century). The headquarters of many German companies were, after World War II, moved to different regions of Western Germany, and they have remained there.

The lack of economic activity leads to an annual net transfer of money from taxes and social insurances of about € 65-70 billion, which is about 1/3 of GDP of Eastern Germany, or about € 5,000 per inhabitant (European Commission 2002). About half of these payments are support for unemployed and pensioners (Röhl 2001, p. 31). East German pensioners receive higher pensions from public schemes than West German pensioners (Czada 1998, p. 61). Economists today recommend that the location conditions in Eastern Germany should be improved, such as the transport infrastructure. Subsidies provided to industry should be reduced (Ragnitz et al. 2002, p. 4). It has also been argued that welfare payments to the unemployed should be reduced to make them accept low paid jobs (Sinn, Westermann 2000). Also the European Commission writes that the wages of the low-skilled workers are above their productivity without showing how this was measured (p. 81). It is not discussed, however, whether dismissed persons or young unemployed could pay for rents, food and heating etc., which have approached West German levels, with lower social aid.

"The total consumption of resources by households, companies and the state in 1999 … amounted to 90% of the per capita consumption in the 'old' Federal States. Only two thirds of this was covered by the results of own economic performance." (Weber 2000, p. 10) The difference is paid for by transfers from government and private investors. Given the challenges which emerged after 1989, it can be regarded as a success that employment reached a level of about two thirds of the GDR employment. And even a catching-up process is taking place, as the decline in the construction industries is apparently being offset by a growth in manufacturing (Blum, Scharfe 2000).

3.3 The Development of the Dresden Semiconductor Region after 1989

3.3.1 The General Situation in Dresden

In December 1992, 25,848 persons were still employed on the 168 sites of the manufacturing companies in Dresden employing more than 20 people. This corresponds to about 27% of the November 1990 rate (Niemann 1996). Table #5 shows the change in employment for formerly leading Dresden VEBs.
In Dresden there are plans for the development of several nodes of manufacturing, such as mechanical engineering (Ragnitz 2002, p. 153). Famous is the Volkswagen transparent fac-

tory in the „Großer Garten“ in which its luxury model Phaeton is assembled (http://www.glaesernemanufaktur.de/). Pentacon was the first large VEB to be closed down by the Trust Agency, stating it had no economic future (Gerber 1998). Only small successor companies emerged, such as the Noble camera company, producing in the small niche of professional panoramic cameras (see http://www.pentacon-dresden.de/english/kontakt/index.html and http://www.kamera-werk-dresden.de/index.htm). Asta Medica and Smith Kline Beecham took over the city’s two pharmaceutical plants, Gruner&Jahr’s subsidiary Planeta in Radebeul is active in designing printing machinery, and the Elbeflugzeugwerke are converting passenger aircraft to transport aircraft (DIW et al. 1999, Röhl 2000, p. 17).
Regarding research, many institutes of the GDR’s Academy of Sciences were turned into institutes of the Fraunhofer or Max-Planck-Gesellschaften. In 1994, 4,900 people were employed in public research, more than in industrial research and development at the time (Specht 1999).

Many jobs were created in services, last but not least because Dresden is a significant place for tourism with 6 million visitors per year (Niemann 1996).

Company	Products	Employees 1989	Employees early 1992
Robotron Elektronik	Computing equipment	3000	800
Robotron Projekt	Software	1100	430
Zentrum Mikroelektronik	Microelectronic components	3300	1000
Meßelektronik	Electronic instruments	2500	340
Elektromat	Radio equipment	1200	0
Mikromat	Precision machine tools	2000	400
Elektroschaltgeräte/ Elektronik Dresden	Electrotechnical and electronic components	2000	0
Vakuumtechnik	Surface treatment	2000	400
Elektromotorenwerke (Sachsenwerk)	Electric motors	2600	640
Lufttechnische Anlagen	Airconditioning	2500	200
Luft- und Kältetechnik	Airconditioning	1800	700
Pentacon	Cameras	6000	190
Total		*30000*	*5100*

Table #5: Change in employment of formerly leading Dresden companies (source: Niemann 1996, p. 298, according to press articles).

As mentioned above, today Dresden has about 470,000 inhabitants. The region from Pirna to Meißen comprises about 900,000 inhabitants (Niemann 1996). Migration had its maximum in 1989/1990. In 1996, about 52 km^2 land were earmarked for construction (Niemann 1996)[10]. After 1990, the number of enterprises grew from 12,000 to almost 39,000 (www.Dresden.de). Currently, Dresden is one of the few East German areas with a positive net effect of migration (Ragnitz p. 2002, 49). 70,000 new dwellings were built. As a consequence, rents in older apartments in the city recently decreased sharply and many of these old city houses are derelict (Ragnitz, pp. 376, 385). Due to costs of knocking them down, owners typically leave them standing. Between 1990 and 2001, € 54 bn were invested in Dresden, of which € 28 bn in industry (www.dresden.de).

[10] In the Dresden region [likely from Pirna to Meißen; A.W.], plans were made for: „Potentielles Bauland in Flächennutzungsplanentwürfen: 2833 ha. Als Bauland in Bebauungs- sowie Vorhaben und Erschließungsplänen beplant: 1615 ha. Von der höheren Baubehörde als Bauland genehmigt: 827 ha.“ (Niemann 1996, p. 301)

3.3.2 Initial Semiconductor Activities in the Region

In this section the semiconductor activities after 1989 are described in some detail. This description is accompanied by some technical information providing an overview of the production processes involved. As a start, Figure #8 provides an overview of the overall process flow in semiconductor manufacturing.

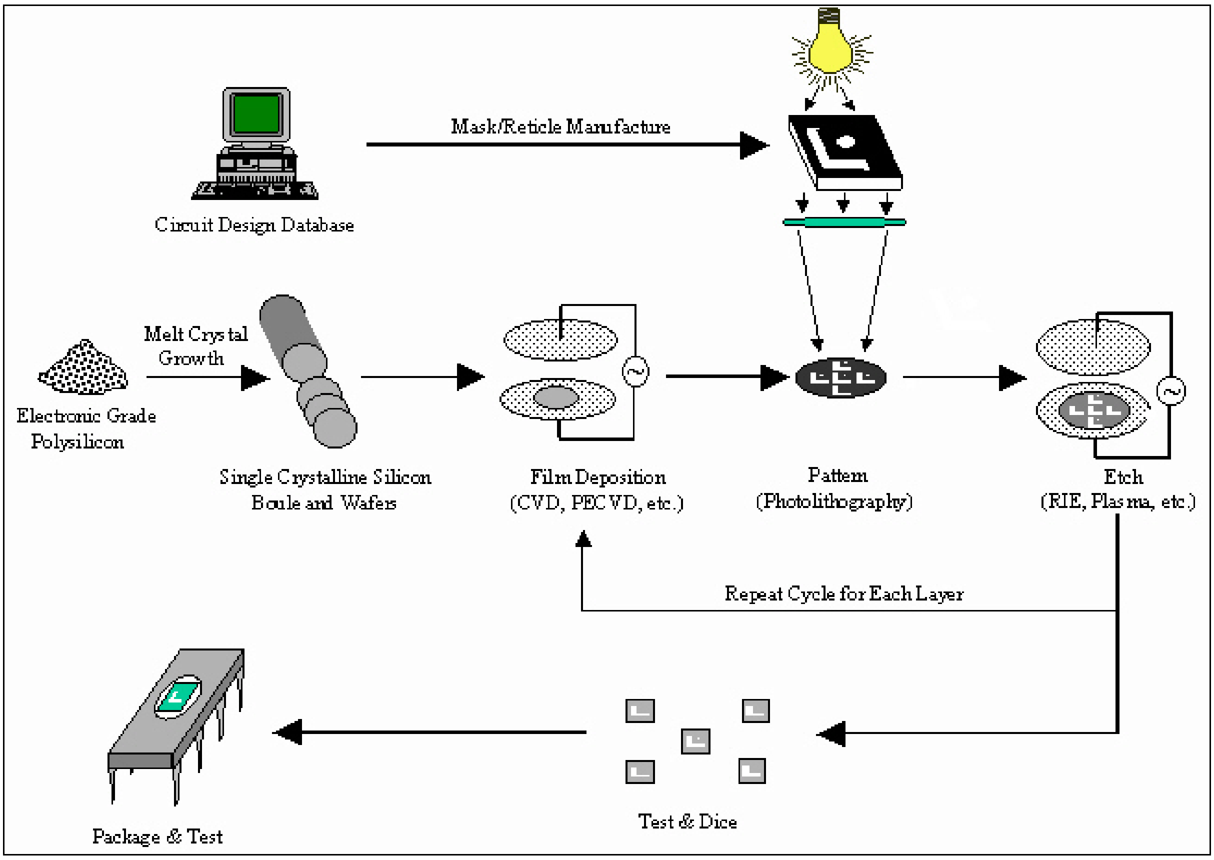


Figure #8: Simplified overall process flow for the manufacture of semiconductor integrated devices. Photolithography is the science of printing the circuit element patterns used for the construction of semiconductor devices. The figure shows a schematic representation of the overall process flow. Single crystalline silicon wafers are manufactured from raw polysilicon. The integrated circuits are then manufactured by repeatedly processing the substrates through a cycle of three basic unit operations: film deposition, lithography, and etch. This cycle builds up the patterned layers (semiconductors, conductors, and insulators) required to make a final device. The overall cycle may be repeated as many as 20 to 30 times. In general, each material, such as metallic conductors or insulators, is deposited as a blanket film over the entire substrate. The substrate is then covered with a protective polymeric material, the photoresist, that can be patterned in the lithographic step to provide patterned access to the underlying film. The patterned photoresist layer is used as a protective mask for an etch process that selectively removes undesired areas of the underlying film. After the etch process is complete, the photoresist layer is stripped away and the process is repeated to build up the various layers (adapted after Henderson Research Group 2002).

ZMD

In 1990, civil servants of the Saxonian Ministry of Economics and Labour had daily responsibility for former companies in the field. They were wondering what to do with ZMD (Zentrum Mikroelektronik Dresden, former Forschungszentrum Mikroelektronik Dresden). On the one hand, it appeared to be almost hopeless to keep it alive: their products were inferior to others on the World market, e.g. the chips were larger and more expensive to produce. Their former main market, the Soviet Union, had shrunk. On the other hand, they had many highly qualified employees, such as researchers, engineers and operators in a field which appeared to have a future. There was the danger the that best people could start working elsewhere. The state of Saxony then decided, together with the German Trust Agency, to try to keep ZMD alive. The privatisation of ZMD, which was owned by the German Trust Agency, turned out to be difficult. Investors were hesitant. In 1993, ZMD was a company with 600 employees, not profitable, though employment was down from the original 3,300. “An important signal sent from the state policy was no doubt the 1993 decision to buy the Zentrum Mikroelektronik Dresden GmbH (ZMD) company from the Trust Agency and thus to contribute to retaining specialist qualified human capital in the region.” (Edler et al. 2002, p. 57) Today, ZMD is controlled by Westdeutsche Genossenschafts-Beteiligungs Gesellschaft mbH and ZMD produces ASICs (Application Specific Integrated Circuits) for cars and medical purposes (Sachsen LB 2002). ZMD says they are world market leaders in the segments of infrared- and hearing aid-chips (Heise 2002a).

Today, ZMD operates a US subsidiary in Melville, New York. In 2001, the company turned over € 68 mio. (<http://www.zmd.de/>).[11] ZMD expected to become profitable during the year 2002 (Heise 2002b). At the end of 2002, it had 600 employees.

Siemens/Infineon (Part I)

After World War II, the Siemens headquarters were moved from Berlin to Munich, significantly contributing to turning Bavaria from an agricultural state to a German high tech region (Die Zeit 2002). Already in 1952, Siemens started the production of transistors (Schumacher 2002). The transistor had been invented by William Shockley and colleagues in the Bell Laboratories, in 1947 (Mackintosh 1986).

In 1992, Siemens was still hesitating to invest in Dresden. Texas Instruments had withdrawn their interest to invest (Hendel, Spiller 2001). In December 1993, Siemens decided to invest the equivalent of € bn 1.38 into a semiconductor plant (Edler et al. 2002, p. 57). In 1994, the Siemens Microelectronics Center Dresden was founded. Reasons to invest were:

Skills and unemployment: The availability of skilled labour, of both engineering scientists and operators, was a core advantage of the region. Siemens employed many people who had formerly worked for ZMD (expert interview).

Public subsidies: The state of Saxony supported Siemens with a subsidy, which initially amounted to 23% of the supportable investment of the first building phase (Edler et al. 2002, p. 43).

Educational and research institutions: Experienced educational and research institutions, with a good reputation, were in the area, e.g. the Technical University. “[The GDR] had R&D facilities, including assembly and packaging techniques in R&D as well as in manufacturing.” (Johann Harter, Infineon, according to Semiconductor Magazine 2001) This item, as well as

[11] One can watch their latest plant being built at <http://194.15.148.206> and http://194.15.148.205/.

the skills mentioned above, show that pre-1989 structures, as described in section 3.1.4, played a significant role in the investment decision.

A supportive government: Regarding the planning of the Siemens semiconductor plant at the Dresden location, Edler points out that Siemens had "very positive experience during planning, construction, and ramping up production " (Edler et al. 2002, p. 58).

The latter point needs to be illustrated in some detail. The investment took place in the heath area north of Dresden ("Dresdner Heide"), an area with pine and birch trees on a sandy soil (Figure #9). Since the late 19th century time, the area used to be a military zone. At the end of GDR times, it was turned into a natural reserve zone. The Russian troops reportedly not only left buildings, but also ammunitions etc. During the course of the investment, the area was decontaminated (cf. Hendel, Spiller 2001).
To invest in the heath was controversial from the ecological side. Environmentalists feared the loss of trees and endangered species. During our interviews it turned out that the seemingly obvious idea to invest in a former industrial area was not attractive to Siemens for two reasons:

Figure #9: The Siemens/Infineon fab in the "Dresdner Heide" in the background, with a deserted industrial building in the foreground (October 2002, photo: Arnd Weber).

- Due to the privatisation policy of the Trust Agency, many large areas were no longer available, as parts had already been sold or were still operating, such as ZMD.
- It has also been said that the ground in the area of the Heide has particularly low vibrations.

Once Siemens showed firm interest, the local and state government supported the decisions very quickly. “Due to the close co-operation with officials of the state, district and the city of Dresden, the detailed planning was finished in the exceptionally short time of five months.” (Röhl 2000, p. 13)

Almost every political player supported the investment by Siemens. Only the site was somewhat controversial. A court case by environmentalists was quickly lost (Hendel, Spiller 2001). In 1995 the semiconductor wafer fabrication facility („fab“), was erected. After a fast “ramp up” of production, in 1996 the first 16-Megabit-memory chips were manufactured, in 1998 the first 64-Mbit-DRAM chips, and in 1999 the world’s first 256-Mbit-DRAM-chip.

The costs for a facility of this kind are primarily due to equipment, not to construction. The main proportion of orders for equipment went to foreign equipment manufacturers.

What is a Photomask?

Photomasks are a component in the lithographic process of semiconductor manufacturing. High-purity quartz or glass plates containing precision images of integrated circuits or chips, photomasks are used as masters by chipmakers to optically transfer these images onto semiconductor wafers. Current advanced lithographic tools, such as deepUV steppers, project light through a photomask and a high aperture lens. The intensity of the light casts an image of the device's design – the pattern on the photomask – onto a silicon wafer coated with a light sensitive material called photoresist. Using negative photoresist the unexposed, or masked, portion of this material is then removed so it can either be etched to form channels or be deposited with other materials. The process is reversed using positive photoresist.

Box #2: What is a photomask? (source: DuPont Photomasks 2002).

Below we will continue reporting about the development of Siemens, which later floated its semiconductor operations under the name of *Infineon Technologies*. The descriptions of both Siemens/Infineon and AMD (next section) are split into two parts, in order to present initial considerations related to the investment decisions, and initial results first. This will allow the review of the initial developments of both Siemens and AMD, in Section 3.3.3. Thereafter, in Section 3.3.5, subsequent developments will be analysed, including aspects of co-operation and emerging economies of scale to be enjoyed by third parties.

AMD (Part I)

AMD (Advanced Micro Devices) is a US company headquartered in Sunnyvale, California. It was founded in 1969. It is the main competitor to Intel, although significantly smaller.

In 1995, representatives of AMD talked to Siemens about their reasons to invest in Dresden. In December 1995, AMD announced its decision to build a semiconductor fab in Dresden and decided against Ireland. "Other places offer money, but to make the operation successful you need the people" Drews, spokesman for AMD, said. An interviewed company expert describes the decision to invest as follows: "Ireland was well advanced when the siting decision was taken. The infrastructure in Dresden was more modern: supply of extremely pure water, sewage, the motorway, an airfield. In Ireland taxes and labour laws are certainly simpler. Not here, but people are the value added."[12] These two statements show that people's skills are the most important factor.

Dresden was the first production plant outside the US (formally it is the AMD Saxony LLC & Co. KG). "Our AMD facility represents an investment of more than $1.9 billion... We were able to get aid from German federal and state governments. They gave AMD an outright grant of about 800 million deutsche marks." (Drews, according to Bruner 2001). Since then, the investment is expected to increase to $ 2.5 billion. (Drews 2003)

The AMD fab was built at the northern border of Dresden, about 2 km from the airport and the motorway, in a formerly rural area (Statistisches Landesamt 2001). The plant is actually placed on a big granite block which is said to be good for reducing vibrations (interview). AMD has a four-lane road leading to Dresden and the airport. A bridge for wild animals has been built across it, reportedly to the surprise of some US visitors (see Figure #10).

AMD experts were impressed by the skills the Dresden engineering scientists had when they flew them to the US. They immediately produced proposals for improvements (company experts). Details have not been made available because they touch on company secrets. The skills were high because they had a very good basic knowledge of physics etc., had learned to anticipate outcomes, and in particular were able to re-engineer Western technology. Representatives of AMD expressed that the willingness to take risks which Americans have fits well with German precision and ability to anticipate results ("passt gut zu deutscher Präzision und Vorausdenken", company expert). This points to the significance of Saxonian and Dresden traditions of metal and electric engineering, which have their roots in the medieval ages, but were still fully existing in GDR times (see sections 3.1.1 and 3.1.3).

[12] „Irland war bei der Standortentscheidung weit gediehen. Die Infrastruktur in Dresden war moderner. Reinstwasserversorgung, Kanalisation, Autobahn, Flugplatz. In Irland waren Steuern und Arbeitsrecht sicher einfacher. Hier nicht, aber der Mensch ist der value added."

Figure #10: The AMD fab in Dresden, with a bridge for wild animals to the right (October 2002, photo: Arnd Weber).

Regarding operators, AMD employs only craftsmen from related occupations: “the employee must at some time have had a job in electronics so that he knows where the plus and minus poles are” (from an interview conducted by Bruch-Krumbein (2000, p. 161)). Initially, two thirds of these had been unemployed (AMD expert), certainly many came from the former VEBs in the technical areas mentioned in Table #5, but no figures are available. The former human resources director of AMD Dresden, Martin Gillo, had previously worked with AMD in the US, but was born in Leipzig. In May 2002, he became Saxony’s Minister of Economic Affairs and Labour.

Typically, aluminium is used in semiconductor chips to conduct electricity inside the chip. In 1997, IBM announced the development of a production-worthy process using copper instead. These copper interconnects provide for a faster internal communication with less power needs. AMD decided to use the copper technology to build a very fast microprocessor. One of the problems of using copper is that it is “poison to transistors”. Furthermore, it requires different chemical processes (see Box #3 for a description of the process AMD is using). These chemical processes pose new environmental risks. For instance, electroplating and chemical mechanical polishing during the so-called “damascene process“ require large amounts of water and create large amounts of acid and heavy metal waste. These require bulk chemical distribution systems and waste water treatment facilities, which can well be built into new fabs (Semiconductor Magazine 2001). AMD had to build its own power plant to provide electricity to the fab (expert).

AMD decided to "bet the company" (Derbyshire 2001) on the copper technology and have its engineers in Dresden try to master the production process. AMD acquired a copper interconnect technology process through an alliance with Motorola. The Dresden fab was designed for the new processes. The copper approach did not only pose the challenges mentioned, it also required very close co-operation with the US engineers involved in designing the chip. It is not the case that the US engineers basically sent a blueprint of a chip to Dresden and had the Dresden engineers solve the manufacturing problems. Not only the copper process was new, but also production with technology for 130 nm features. That is shorter than the wavelength of the light used to project the structures (cf. Derbyshire 2001). This meant, according to company experts interviewed, that international teams had to be formed to re-design the chip, to re-consider the number of layers, etc.

AMD Fab 30 Production Modules

Thin Films

The "Thin Films" module is primarily responsible for the production of layers which are necessary for the "wiring" of transistors in microelectronic circuits. The alternately electrically conductive and insulating interfacial layers are deposited on the entire surface of the wafer by means of physical as well as chemical methods. Conductive layers are produced preferably by means of the so-called sputtering or physical vapour deposition (PVD). In this process, a target is bombarded with ions. This leads to metal atoms such as copper or aluminium being ejected from the target; these atoms deposit on the surface and form the conductive layer. In the chemical processes, also called chemical vapour deposition or CVD, various gases react at or on the surface of the wafers, forming the conductive or insulating layers required. These processes are controlled by factors such as pressure and gas flow and by temperature and plasma conditions. Further depositions of layers occur in the "Diffusion / Implantation / RTA" and "CMP/Cu" modules.

Photo Lithography

For the further processing of the wafers after such depositions of layers on the entire surface, it is necessary to set apart the areas to be processed further from the other areas. For this purpose, the wafers are first covered with a light-sensitive layer (photosensitive resist). This is followed by an optical process which is equivalent to the processes used in photography and in which a chrome-glass mask containing the future chip structures is exposed to the photosensitive resist chip by chip. After this "lacquer exposure", the lacquer mask which is now on the wafer releases certain areas on the layer below for further processing and covers other areas. Such further processing usually consists in the removal of material in the areas defined by the lacquer mask so that electrically conductive tracks can be created (Etch module) or the creation of a certain electrical conductivity, e.g. for implantations at certain points (Diffusion / Implantation / RTA module).

Diffusion / Implantation / RTA

The purpose of this production stage is to achieve the required good electrical conductivity of certain semiconducting areas such as source and drain areas on the transistors by implanting dopants into the wafers. This is done by means of an high-energy ion bombardment. Afterwards, the dopants must be activated electrically by means of thermal annealing. In addition, any irradiation damage to the silicon as a result of the ion bombardment is healed in this process, which, however, must occur relatively fast so that the undesired out-diffusion of the dopants is avoided ("RTA" = Rapid Thermal Annealing).

As has already been mentioned under "Thin Films", conductive and insulating layers are also created in the Diffusion / Implantation / RTA module, in particular the so-called gate oxide by means of thermal oxidation and the actual polysilicon gate by means of an LPCVD process. These are also the major process steps in the production of transistors.

Etch

The purpose of this production module is to remove material from a layer which has been created on the entire surface of the wafer before only in the areas defined by the 100 masks. This is necessary in order to create the actual circuit structures and elements such as transistors, contacts and track conductors out of these layers of different materials or to build them up gradually out of them.

Today, only dry etching processes are used in this production stage; the main principles of these processes are either of physical nature (sputtering-off, pulverization of the material using ions), of chemical nature (in an energetically strongly-excited state, highly-reactive gases create gaseous, volatile reaction products as a plasma with the material to be removed) or a combination of both. Over the plasma parameters such as energy, frequency, the reactor's geometry, the structure of gases and other reaction conditions, e.g. pressure and temperature, the etching speed, the selectivity of the material and the orientation of the material removed by etching (isotropy) can be controlled.

Nowadays, well-known wet-chemical processes involving special etchants (e.g. hydrofluoric acids) are no longer used for the actual transfer of structures but only for the so-called fine purification.

Chemical-mechanical Polishing and CU Electroplating (CMP / Cu)

The CPM module comprises two different principles:

1. Planarizing:
The repeated deposition and structuring of different kinds of layers during the entire circuit production process leads to a gradual formation of a topography on the wafer surface, which would not allow structures to be exposed repeatedly in the Photo Lithography module with the high precision required. For this reason, several polishing steps in which the wafer surface is planarized again by means of chemical or mechanical removal of material (etching or grinding), are provided for in the production process.

2. Structuring of metal tracks and connections (Damascene):
Metal is brought into etched structures. The surplus material is removed by being polished. The result is an electrical track conductor which could otherwise only be produced with difficulties - or not at all (the so-called Damascene process).

As has already been mentioned under "Thin Films", other necessary layers are also created in the CMP / Cu module - most importantly, the so-called circuit wiring is created here by means of electro-galvanic deposition of the copper multi-layer metallization. These are also the major process steps in the production of microelectronic components following the production of transistors. Finally, in a process similar to uniform-depth photogravure, electrical track conductors which could otherwise only be produced with difficulties - or not at all - are produced (Damascene process). For this purpose, materials such as wolfram or copper, which have been deposited in special trenches, are polished.

C4 (Controlled Collapsed Chip Connection)

After the completion of the production of chips on the wafer, the individual chips must be prepared for their future connections to the case. For ICs with a low number of connections, the so-called wire bond technology is still used in the industry in order to connect the ICs to the external pins, whereas for ICs with many I/Os (number of input and output signals, which is the total number of pins), the increasingly widespread flip chip technology is used. In the flip chip process, the front side of the chip is placed on carrier and, as a result, on the lead frames. In the flip chip / C4 process, the chip is prepared by installing so-called bumps on the connecting pads. The bumps are small soldering balls which can be scattered over the entire surface of the chips and which guarantee the electrical connection between the chip and the case later.

Box #3: AMD Fab 30 Production Modules. Source: http://www.amd-jobs.de/

The decision turned out to be a success. “Copper was an experiment. If it had failed, AMD would be dead.“ (expert) In March 2000, AMD had the first GHz-rated Athlon microprocessor available, well ahead of its competitors. In 2000, AMD made a profit of $ mio. 983, as opposed to losses in the other years from 1997 to 2002 (AMD 2003). AMD increased its market share from 13% in 1999 to 21% in 2001 (Kharif 2002). By the end of 2001 AMD had produced 20 million Athlon chips. In 2002 the Athlon (XP) was still named as the “Best Computer Product of the Year“ (PC World magazine, July 2002) and was used in PCs produced by Hewlett-Packard and Fujitsu-Siemens.

AMD's Fab 30 was awarded “Fab of the Year” for the year 2001 by Semiconductor International magazine in recognition of being the first facility in the world specifically designed to produce microprocessors with copper interconnects. The prize was awarded because of the high speed of erecting the fab, from 1996 to 1999, and because of the need to master new environmental challenges, due to the use of copper. In Dresden, AMD produces wafers; the chips are packaged in Asia.[13]

3.3.3 Summary of What Investors Appreciated

Available skills: As mentioned above, decision makers emphasised the skills of the local people. They are attributed to the German system of vocational training. “We have an old traditional system for vocational training in Germany that provides two years' education after young people leave secondary school,” Günter Metzger of Saxony Economic Development Corporation emphasises (according to Bruner 2001). He continues: “People are dedicated to the job. They don't see it simply as a way to go in and do the work and get their paycheck and then go home. They see it also as trying to 'dedicate myself and all my strengths to thinking how I can foster and contribute to the success of this workplace.'” This does not appear to be only PR. Also in our interviews, the vocational orientation to do work perfectly showed up. The motto from GDR-times seemed still to be alive: “My hand for my products” („Meine Hand für meine Produkte“, interview). It has been said to be an inner conviction (“innere Überzeugung”), rooted in culture (expert).

Regarding GRD-times, it was said: “The educational system in GDR was good. A high share of the population had university or technical college degrees” (expert). There was a “qualified education of craftsmen in GDR.” A company expert: “Qualifications in natural sciences were better in East German plants” than in West German ones. “I always bought textbooks for mathematics and natural sciences in Eastern Berlin, they were better.” “Basic research was excellent. Peoples’ education was excellent. School education was excellent, much oriented towards technology.” (another company expert)

In the early 90s, it was possible for the investors to select among top-class applicants, coming from the GDR companies. The gap between unemployment and employment was not too large. There was a “high willingness to contribute to productivity improvements. In Munich mostly only unskilled workers apply for a job. In Dresden, there has never been a shortage of applicants.“ (company expert)

Another expert: There was “an absolute urge to move things” [14]. Yet another: “Personnel was very committed and motivated. There were many excellent people in one place. They were good, motivated and had ideas.“ This led to the “very positive experience during planning, construction, and ramping up production.”

[13] At <http://www.amd-jobs.de/> a nice virtual tour through the fab is available.
[14] „Absoluter Drang, etwas zu bewegen.“

Regarding the operators it has been said: “This is boring work for bad money. But you have to work free of error. People here in Dresden did such work in the past.”

Regarding the engineering scientists, they were said to have a very good capability to anticipate possible outcomes of new technical approaches, as in the area of copper use. “No one can copy German engineers.” Others referred to “German precision engineering” and “German thoroughness.”

Summarising one can say that all experts and the literature point out that technical education in general (schools, craftsmen, engineers) was very good in Eastern Germany. In particular it has been said that much of the operators‘ work is repetitive, though it needs months of training. Many operators in Dresden are craftsmen in related electrical professions. Due to their skills, and of course also due to the unemployment in the region, they are able and willing to work very carefully, and contribute to achieving a high yield.

Public subsidies: Subsidies have been provided by the state and federal governments. Part of these funds originate from the European Union’s “European Regional Development Fund” (ERDF), under the responsibility of the Directorate-General for Regional Policy (see <http://europa.eu.int/comm/secretariat_general/sgc/aides/thema/feder_en.htm> and <http://europa.eu.int/scadplus/leg/en/lvb/l60015.htm>). The objective of these funds is to enhance “economic and social cohesion” for “catching up on structural imbalances in the regions.” According to a government expert, two thirds of the subsidies provided are ERDF-funds.

Larger subsidies require approval by the European Commission which makes sure they are in line with EU competition policy (see Official Journal, C 107 of 07/04/1998 pp. 0007-00012, according to Edler 2002, p. 43). In 2002, funding in Dresden was limited to 35%, as opposed to, e.g. the upper Ore Mountains, where rates are up to 50%.

The decisions by Siemens and AMD “cannot be explained with the massive public funding alone, as other locations like Scotland offered financial subsidies on a similar scale” (Röhl 2000, p. 13), i.e. the human factor was essential. It should be noted that the subsidies cover only a fraction of the total investment costs.

Educational and research institutions: In the Ore Mountains area, there are technical universities in Dresden, Freiberg, Chemnitz and Zwickau. All these universities contribute to supplying staff to the semiconductor industry, but of course also to other industries. A noteworthy development is the “dualer Studiengang” (dual course of studies) in Zwickau, providing a combination of practical work and theoretical education for students who are employees of Infineon. Since 1999 AMD has co-operated with the “Berufsakademie Sachsen” in various fields, e.g. Electrical Engineering, Computer Engineering, Business Administration. This co-operation combines theoretical lessons and practical phases that help students to become good engineers.
Besides the universities, there are numerous other research organisations, as mentioned above.

A supportive government: As reported in the literature, and confirmed in our interviews, the investors talked very positively about the local administrations. As mentioned above, the approval and planning for the investments took place very speedily: “The companies never had to wait for a permit” (interview). In the state parliament’s voting, only one member from the Social Democrats was against the decision to subsidise Siemens. All others, including the Green Party, agreed. Also the improvements of the motorways and the airport were appreciated and probably deemed indispensable by the US investors. Bruch-Krumbein summarised in 2000: „In all, a highly energetic policy has been pursued.“ (2000, p. 284) She mentions the consensus-oriented policy of the former Saxonian Prime Minister Kurt Biedenkopf, who aimed at obtaining support from both investors and workers.

High acceptance in the population: Another factor which is in favour of the region “seems to be the high acceptance of large scale investment in the population”, as Röhl put it (2000, p. 13).

Natural resources: Sufficient clean water from the ground was appreciated, and clean air.

3.3.4 Subsequent Semiconductor Activities in the Region

Siemens/Infineon (Part II)

In the year 2000, Siemens Halbleiter was floated and renamed *Infineon Technologies AG*. Together with Motorola and Wacker, Infineon developed, in Dresden, a technology for wafers of the size of 300 mm. The 300 mm development was supported by the German Ministry of Education and Research which had shown significant interest in economically improving semiconductor production in Germany (expert). The ministry supported the initial development with € 95 mio. (BMBF 2002, p. 11), the state of Saxony gave another € 61 mio. (Edler et al. 2002, p. 62). “Infineon had always said it would do it to drive down the cost curve.” (Semiconductor Magazine 2001). This is particularly relevant in the DRAM business, as this is a very competitive market with relatively low revenue per wafer, as opposed to, e.g., the market for specialised chips (Leachman, Leachman 2003).

The 300 mm Infineon fab costs amounted to € 1,1 bn. It will be subsidised with € 229 mio (Edler et al. 2002, p. 44). The latter subsidy was authorised by the European Commission (press release IP/02/517 of 9. April 2002, see <euo.dk/euidag/rapid/IP_02_517_0_RAPID/>). The Commission had investigated whether the market was in decline ahead of giving its approval.

M+W Zander, a subsidiary of Jenoptik, participated in the planning and construction of the 300 mm fab (http://www.jenoptik.com/). “The 300 mm production was introduced with breathtaking speed“ (expert interview). The world’s first 300 mm product was produced, a 64-Mbit-DRAM chip. Volume production of 300 mm wafers started in 2001 (Infineon 2002). Infineon was awarded the “Fab of the year prize” of the year 2000 by Semiconductor International magazine for the 300 mm pilot line.
The Siemens/Infineon investment is one of the rare cases in Eastern Germany in which “foreign” investment is combined with research (Belitz, Fleischer 2000, p. 290). Infineon Technologies has partners and co-operations in many countries. One focus are co-operation projects with smaller companies, universities and institutes in the local area. This is part of the tasks of the “Memory Development Center" (MDC) founded in 2002, which took over this responsibility from the former "Center for Development and Investigation" (CDI). The MDC is responsible for joint development projects and has the possibility to share clean room area with other companies or institutes.
In 2002, fabrication in Dresden is taking place with 200 and 300 mm. On the 300 mm-wafers, technologies with 140 nm structure and less are used, 70 nm is under preparation. Important products are logic IC´s (e.g. for communication) and DRAMs. Infineon claims cost leadership due the 300 mm production (Schwarzer, Preissner 2002). For future DRAM chips Infineon will use their “trench” technology to provide for superior storage capacitors.

Figure #11: Part of the Infineon fab (source: Infineon 2002).

In 2001, the global semiconductor market declined. In its fiscal year 2001, Infineon made a loss of € 1.02 billion. 5,000 of its 35,000 jobs were lost. Short time work was introduced in Regensburg and Munich (Infineon 2002b). Investments in Regensburg were reduced to "practically zero", as CEO Schumacher said (EE Times UK 2001). Regensburg had short time work in 2001, while Dresden had none. A new fab in North Tyneside, UK, had already been closed in 1998, representing unneeded capacity. The fab in Richmond, US, is already also using the 300 mm technology. Employees in the two 300 mm fabs compete against each other ("benchmarking").

In its fiscal year 2002, Infineon made a loss of € 1.14 billion, with a turnover of € 5.21 billion, 8% less than in the previous year. In the autumn of 2002, Infineon employed 4,600 people in Dresden. Siemens had originally planned for only 1,450 (Edler et al. p. 58). Infineon will build, together with the Taiwanese Nanya Technology Corporation, a new 300 mm fab in Taiwan (Infineon 2002[15]). Infineon believes to be able to achieve profits in the DRAM market with its 300 mm production, e.g., on the growing Chinese market. Early in 2003, they announced to have returned to profitability on their memory products (Infineon 2003).

AMD (Part II)

Dresden became AMD's only processor fab. AMD founded the Dresden Design Center as a product development centre. It is developing, e.g., chipset ICs, which connect processors with peripherals. It is also participating in developing "Personal Connectivity Solutions" such as Web tablets, mobile computing devices and automotive systems.

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[15] This does not appear to represent the concept of a foundry, which is a „fab" working for „fab-less" companies (or companies without sufficient in-house capacity). Leachman and Leachman (2003) report about Taiwanese foundries and state that they provide „excellent customer service" while compensating their workers and engineers better than almost anywhere else. However, the foundry typically does not need to have the latest technology, as it is needed in the DRAM market.
STMicroelectronics, Philips Electronics, and Motorola will jointly operate a 300 mm fab in Crolles, France, in order to share the costs of 1.4 bn $ (IEEE Spectrum 2003).

AMD's global share of the processor market decreased to 11.6 % in the autumn of 2002 (FTD 31.10.2002). AMD made substantial losses in 2002 of $ 1.3 bn, with a turnover of $ 2.7 bn, down from $ 3.9 bn in 2001. Its competitor Intel made profits of $ 3.1 bn, with a turnover of about 23 bn, in 2002.

Economic sustainability hinges on whether AMD will become profitable with new processors and products from its other businesses, e.g. the production of flash memory for phones and cameras. It intends to return to profitability with new products, such as a 64-bit processor. This "Hammer" line of products, branded "Opteron", was launched in April 2003 and will be used by server producers, e.g., by Cray, who have already published plans to deliver to the US Sandia National Laboratories, and by Newisys, founded by a former CTO of IBM (http://www.newisys.com). In Dresden, AMD plans to continue investment and reach a total of $ 2.5 billion in 2003. In October 2002, AMD employed about 2,000 people in Dresden, of whom fewer than 10% are engineers. In November 2002, AMD announced a reduction of its staff by about 2,000, or approximately 15 % of its global workforce. As of writing in early 2003, no reduction of permanent employment is planned for Dresden.

3.3.5 Contractors for Semiconductor Production

AMTC

In May 2002, AMD, Infineon and DuPont Photomasks founded AMTC, the Advanced Mask Technology Center. The next generation of lithographic masks for the exposure of silicon wafers will be developed there (see Box #2 "What is a photomask?"). This is a significant step towards establishing Dresden as a world centre of semiconductor research, a "sensation" according to one expert interviewed. According to <De.Internet.com>, it will lead to the closing of Infineon's mask production in Munich.

Figure #12: Drawing of planned AMTC plant, being under construction in 2002 (source: www.amtc-dresden.de).

Wacker Siltronic

VEB Spurenmetalle in Freiberg was bought by Wacker, Munich. In late 2002 it had about 560 employees. In October 2002 it was announced that it would open a 300 mm wafer factory in Freiberg. The quality in terms of purity, flatness and crystalline quality will be high enough for production of below 100 nm structures. The plant will cost an estimated € 430 million, it will be subsidised with € 25 million (de.internet.com) and is planned to start production in 2004. It will deliver wafers to Infineon Dresden and customers worldwide. Wacker Siltronic plans an additional 600 jobs. Wacker, Munich, was, in 2002, the only manufacturer, besides Shin-Etsu and Sumitomo Mitsubishi, who was capable of producing 300 mm wafers in large quantities.

Figure #13: Wacker Siltronic production (source: http://www.sachsen.de/de/bw/hightech/).

Freiberger Compound Materials

Freiberger Compound Materials (FCM) is another offspring of the former VEB Spurenmetalle. It continues the GaAs business and had about 200 employees in late 2002. Experts interviewed said these are faster than Silicon chips and in particular used for military purposes. "Freiberger" claims it maintains technological leadership in the world market for gallium arsenic semiconductor wafers (see Figure #14). Since 1997 it has been owned by Federman Enterprises, Israel (87.5%) and Infineon (12.5%).

Figure #14: Freiberger GaAs crystal (source: http://www.fcm-germany.com/).

Equipment Manufacturers

The total of all equipment purchases by the Dresden semiconductor companies between 1995 and 2002 was predicted to amount to approx. € 5.5 bn. (Edler et al. 2002, p. 104). 30 international equipment manufacturers opened sales and services offices in Dresden (Edler et al. 2002, p. 11). Many contractors settled in Dresden only after AMD went there. It must be noted that by far the largest share of equipment is produced abroad. An example of a foreign equipment manufacturer is Tokyo Electron (<http://www.tel.co.jp/index_e.html>), who still have their main German office in Munich (<http://www.tel-europe.com/info/ted.htm>). Other examples mentioned are KLA-Tencor, one of the largest semiconductor equipment companies of the world, which produce process control systems. They have a subsidiary in Dresden. Another example mentioned is Nikon, producing, e.g., lenses and scanners, with a subsidiary in the Frankfurt (Main) area. Yet another example is the Dutch equipment provider ASML which produces scanners for exposing wafers (www.asml.com). ASML is the fifth largest equipment producer in the world and has offices in Dresden ("An der Flutrinne"). In their scanners they use, e.g., lenses from Carl Zeiss, Oberkochen, West Germany. Zeiss in turn contracts IMEC to develop production processes, see Box #4 (cf. Carl Zeiss SMT AG 2002).

Planning and construction of fabs was done by M+W Zander, a subsidiary of Jenoptik.

Lithography

Lithographic lenses: By example, a figure of a Zeiss Starlith lens, usable for creating masks with 100 nm structures. It has a maximum aperture of f/0.45 for a wavelength of 193 nm (source: http://www.zeiss.de/de/semicon/home.nsf/Inhalt-Fra-meDHTML/67A3FE8AF0A749E041256A680035CD78). Zeiss is currently working on developing an optical system for achieving a resolution of 35 nm.

Measurement equipment: By example, a Nikon measurement system for checking exposures. Measures mask images with a low-aberration optics and achieves a precision of 2 nm, about the size of the molecules (source: Nikon 2002b).

Box #4: Lithography.

Some new equipment manufacturers who started business in the area are:

- DAS (Dünnschicht Anlagen Systeme) is a ZMD spin-off from 1991. It is one of the fastest growing regional suppliers. It invented an innovative process for the environmentally safe disposal of poisonous wastes associated with semiconductor manufacturing. They produce, e.g., systems which treat all pyrophoric, toxic and environmentally hazardous gases used or generated in semiconductor manufacturing. They employ 120 people, most of them in Dresden.

- Another example is FHR Anlagenbau (Röhl 2000, p. 17). FHR Anlagenbau was founded in 1991. It is working in the field of high-rate sputtering for microelectronics (<http://www.fhr-ab.de/html/overview.html>). By 2000, FHR had 45 employees.
- Then there is, e.g., the new company Karl Süss, founded by a former director of VEB Elektromat (Plattner 2001). The government writes about the company: "The Saxon company Karl Süss brought the world's first analytical prober for 300-mm wafer and sub-µ-processes on the market. The Karl Süss Dresden GmbH is in high demand as an equipment manufacturer for the semiconductor industry. With the PA 300, the company achieved the development of the world's first analytical prober for the 300 mm wafer technology. In its year of foundation in 1990, two employees worked at Karl Süss – today there are more than 100. This measure of success is also reflected in the continued growth of the export sector which currently amounts to more than 80 % of the total turnover. The Saxon company supplies its customers all over the world. These include such well-known names in the semiconductor industry as Siemens, IBM, Daimler Benz, Intel, Sony and Toshiba." (www.sachsen.de; cf. www.suss.com)

Edler et al. noticed that it would be desirable for the region to have more equipment development in the area. It should therefore be investigated, Edler wrote, whether pilot production such as with the Centre for Micro- and Nanotechnology Innovation (MINATEC, cf. www.minatec.com) in Grenoble should be publicly supported (p. 160f).

3.3.6 Other Semiconductor-related Companies in the Region

In this section, we mention a few more companies, for example:

- One case is a successful one, the case of KSW (see Box #5). An interviewed expert pointed out the case of KSW to illustrate not only a successful case, but also that policy makers should make more efforts to support the development of promising companies.
- Another company, Silicon Vision, ran into a shortage of cash (see Box #6).
- Then there is Systemonic (http://www.systemonic.com/). The company was founded in 1999. It produces chips for wireless communication. For instance, they produce a chipset which provides complete coverage of both IEEE 802.11a, b and g standards. Thanks to their innovative products, they have been named one of "Europe's 50 Hottest Tech Firms" by Time Magazine. One interviewed expert said "the importance of Systemonic cannot be overestimated, as they are doing world class developments there.“ The company has obtained support from Raytheon und Sony. At the end of the year 2002, they had 89 employees in Dresden and in San Jose, California. In 2003, Philips took over the company.
- Yet another company to be mentioned is Solarworld in Freiberg, which produces solar cells (http://www.solarworld.de) with about 300 employees.

It is not possible to mention the activities of all companies now active in the field. According to Gitta Haupold, of the industry club "Silicon Saxony", there are about 200 companies in the area of Dresden active in the area of semiconductors (Sachsen LB 2002). Production is concentrated in the Dresden and Freiberg areas, related training in particular in Dresden, Freiberg, Chemnitz and Zwickau. Beyond semiconductor production, there are of course other companies involved in the larger field of microelectronics. Figure #15 provides a geographical overview.

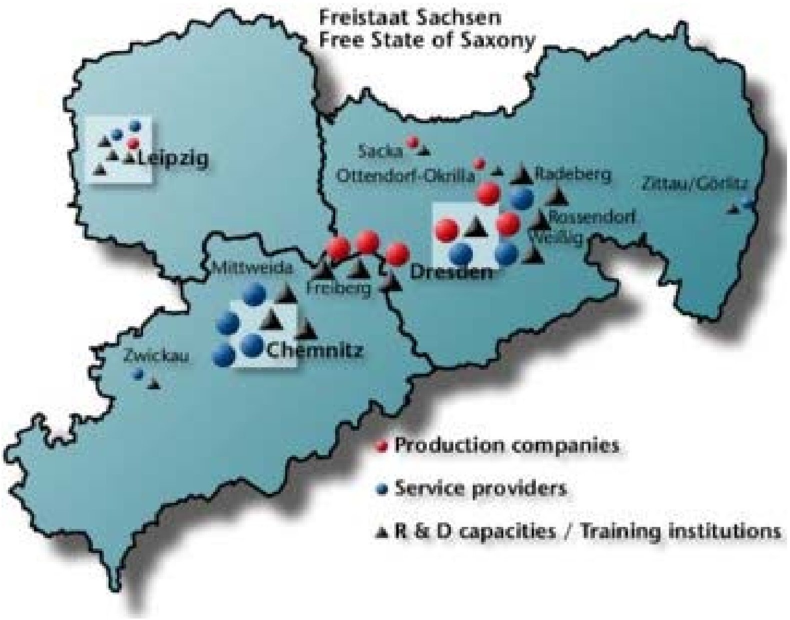


Figure #15: Microelectronics in Saxony (source: www.sachsen.de).

The Case of KSW

“In GDR times, there was a leading assistant called Mr Seidowski. In 1990 he was scheduled to be appointed professor. At their appointment, the rector told him, ‘We’re reconsidering everything. I can’t appoint you.’

When machines from the institutes were decommissioned, he stored them in his own basement. He was active in the field of packaging, where they make chips out of wafers. He then specialised on labels for transponders [KSW Microtec]. You have to think of it this way: you have a paper label with a small antenna stuck onto it, and in one corner is a tiny chip. The manufacturer sticks this thing into a suit and you can then drive a container through a gate with an antenna and can identify every single suit. In contrast to barcode you can write on the chips. Something they’ve developed lately is a novel battery which is completely flat and also soft. This has the advantage over competing products, such as one from Varta, that you can dispose of it in an environmentally friendly way in household refuse. The chip can also do such things as measuring the temperature. For instance, when transporting meat you can measure the temperature afterwards.

He didn’t get any outside capital at the time. Of course, over time he received the usual financial support for company founders and investment subsidies. About two years ago, he got venture capital. They now have a new factory with a clean room built on a meadow in Klotzsche.

The man made it, but that was luck because he’s an innovator, a workaholic with good international contacts, but he isn’t immune to advice. He almost went to Boston because they wanted to prescribe the colour of his windows here on the industrial estate.

In GDR times, the packaging department at the TU Dresden was a world wide leader. The university chairs in this area have practically been scrapped. They’re jumping on the upstream areas of chip manufacturing, but they do that everywhere. In that way, they are neglecting the areas where medium size companies have their opportunities. Capital need for chip manufacture is too large. That’s one of the deficits here. Seidowski is something of an exception, he’s the most successful. By the way, he extended his contacts to Russia. He is doing research with them, also buying from them. This is completely alien to West Germans.” (source: expert interview).

Reportedly, KSW has 40 employees (http://www.bizzcontact.com/).

Flexible Smart Label Inlays (source: Heinrich, http://www.tu-dresden.de/vd51/trabrief/012002/s22.html)

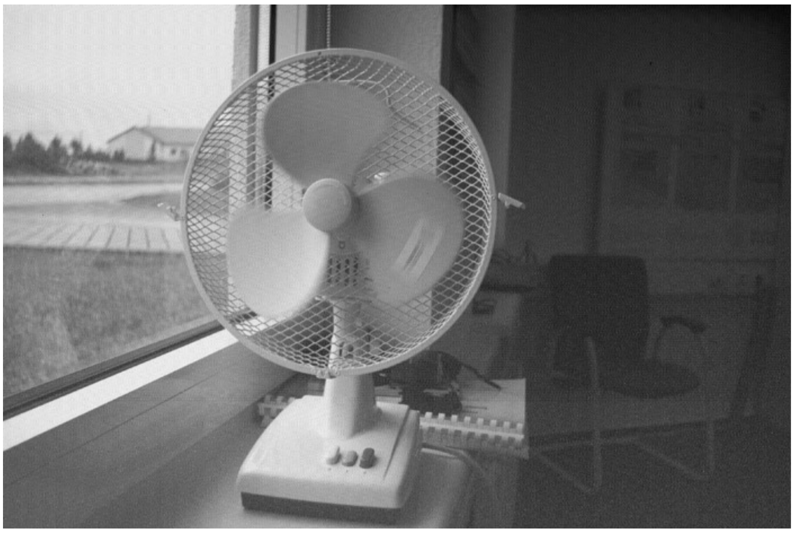
Box #5: The case of KSW.

The Case of Silicon Vision

Silicon Vision AG is engaged in the development, fabrication and marketing of powerful digital image sensors. The devices are made in Thin Film on ASIC technology (TFA). An amorphous silicon photodiode is positioned on top of a crystalline silicon ASIC (Application Specific Integrated Circuits). Compared to other CMOS or CCD image sensors this hybrid provides several advantages.

Very good Quantum Efficiency and High Sensitivity
TFA sensors employ a-Si:H thin film systems as the photosensitive devices. Amorphous silicon has a higher absorption coefficient than crystalline silicon and its spectral response is closer to that of the human eye, which is in the range of about 350 nm to 750 nm. Beginning with short wavelengths (380 nm, violet) the sensitivity of a monochrome LARS III for instance TFA/CMOS sensor reaches its maximum value of about 255mA/W at 530 nm (green). In the region of longer wavelengths the sensitivity falls again, since the photon energy decreases and a complete absorption is not possible any more.

100 % efficient Global Shutter
When confronted with the task to capture a fast moving or a rotating object CCD imagers have some limitations due to their concept. The rolling shutter read-out leads to distortion of the objects. Because the integration of the signal cannot be stopped in a standard CMOS pixel even those "Global Shutters" do not fulfil all expectations.
Only the separation of diode and ASIC and the specific design of a Silicon Vision TFA/CMOS pixel electronics provides a shutter efficiency of 100%. Because a transistor controls the integration it really stops when the electronic shutter is closed (the description so far is based on information available on the Silicon Vision server).



Sample image of a fan rotating at 1,800 rpm. There is no distortion and no background shining through the blades (source: http://www.siliconvision.de/)

In June, 2002, the company opened a new headquarter in Moritzburg / Boxdorf near Dresden with a new fab of 1,056 m². Sales, however, did not develop as expected, prices declined, partner Agfa withdrew, as well as banks (Gesco 2002). The company had to declare insolvency in August, 2002 (Finanzen.net 2002). Infineon plans a takeover of parts of the company (Heise 2003).

Box #6: The case of Silicon Vision.

4 Assessment

4.1 Assessment of Individual Dimensions

Employment

The Dresden Semiconductor Beacon

Both, expenditure by firms as well as the number of employees, increased during the last years, more than initially expected (Edler et al. 2002, p. 6 and 66). AMD, Infineon and ZMD alone employed about 5,000 people in 2000. This has been estimated to increase to 6,300 during the year 2002 (Edler et al. 2002, p. 123). In autumn 2002, however, for the big three companies we obtained figures which add up to about 7,100 (see Table #6). That does truly give the impression of a beacon.

Semiconductor Employment in the Dresden Region	
Infineon	4,600
AMD	2,000
ZMD	500
Wacker	560
FCM	200
Solarworld	300
Other related companies in the region	2,500
Total	~ 10,700

Table #6: Employment in 2002 (source: own computation, “other related companies” is the figure provided by Edler for “other suppliers” Edler et al. 2002, p. 119. It has been renamed in order to take into account of employment with companies such as KSW. Edler’s figure excludes companies in Freiberg, therefore Wacker, FCM and Solarworld are mentioned separately).[16]

Table #6 shows that a total employment of more than 10,000 persons has been achieved. It is difficult to estimate the actual figure more precisely. For instance, one expert pointed out that employees of subcontracted catering companies would have to be counted in addition, another pointed out that increasingly individuals receive the status of “self-employed”. Furthermore, the spending of income leads to additional employment which was estimated to be about 2,300 persons (Edler et al., p. 123).

Besides semiconductor production, there are also other microelectronics-related companies. After 1989, Kombinat Robotron was split into several firms. One example is Schäfer IT-Systems who produce PC and server housing and deliver, e.g., to IBM, Hewlett-Packard and Fujitsu Siemens. They have more than 600 employees (Sachsen LB, Saxonmail).[17]

[16] In June 2002, Edler et al. computed the employment effect of the semiconductor fabs in the Dresden region as follows: 6,300 direct jobs, 2,572 with suppliers, 401 for construction, and 2,341 as an effect of income spending (p. 123).

[17] The city of Dresden publishes a figure of 20,000 people working in the areas of microelectronics and IT (www.dresden.de). The state’s “Telematikbericht” (2001) provides a figure of 44,587 for the whole of Saxony, including the printing industry. Whether the city’s figure is a bit high cannot be judged here. There is of course

Unanimous relief about the employment development initiated by Siemens and AMD can be noticed when talking to ordinary citizens in Dresden and experts alike. There has been a five-fold increase in turnover according to the statistics for radio-, TV-, and communication technology production in Saxony between the years 1995 and 2000 (Edler et al. 2002, p. 127). According to Edler (personal communication), this is to a significant degree due to the Dresden semiconductor fabs.

However, the situation needs to be framed by regarding the total situation in Saxony. On the one hand, Dresden has so far developed better than the similarly large city of Leipzig (see Figure #16). As there is a lack of company headquarters, and a lack of large companies, it is understandable that the Saxonian government encourages large investments to address these deficits. For instance, there is the car "beacon" of the investment of Volkswagen in Mosel (Zwickau). In 2001, BMW announced its intention to invest in Leipzig. As mentioned earlier, there are reports about relatively increasing industrial production in Saxony. On the other hand, the general unemployment level remains at about 19%.

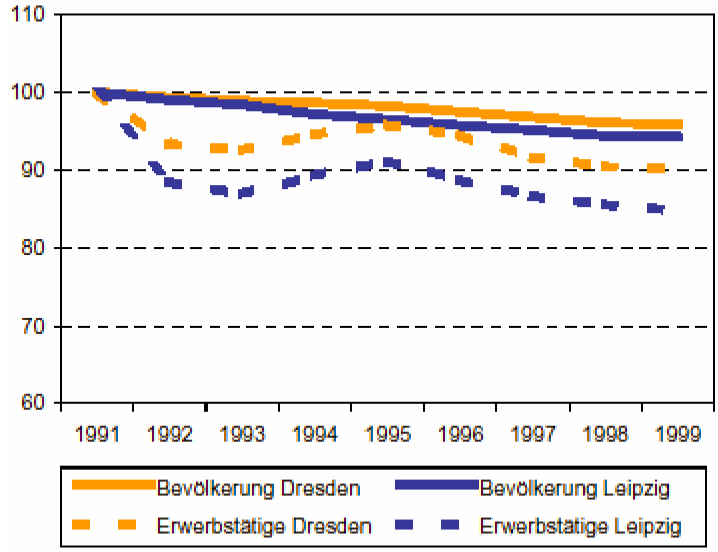


Figure #16: Population (Bevölkerung) and economically active population (Erwerbstätige) in Dresden and Leipzig, 1991 = 100 (source: Blien et al. 2001, p. 42).

Government Spending and Revenue

According to estimates by Edler et al., the government subsidies, as big as they may appear, will lead to even higher tax payments in the form of (1) income tax paid by employees, (2) social security payments, and (3) taxes paid by the companies, though the latter will likely be the smallest:

- The total government subsidies to the semiconductor companies between 1994 and 2010 will probably be € 1.2 bn.
- Total revenues to the government from the subsidised companies will be around € 2 bn in taxes and € 3.9 bn in social insurance contribution (including savings due to reduced unemployment, Edler et al. p. 141).

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considerable related employment outside Dresden, in Chemnitz, e.g., there is the IBM-subsidiary "IT-Services and Solutions" which has 1,500 employees alone.

The creation of about 10,000 jobs with about € 1 billion subsidies comes down to a subsidy of about 100,000 €/job, without taking into account effects through spending of incomes and social insurance.

In the literature, and in the interviews, the following issues arose:

1. Semiconductor production has a strategical role for Germany, as visible from projects supported by the Federal Ministry of Education and Research, e.g. the MEGA-project of the 1980s (cf. Reger et al. 1999) or the recent push of the 300 mm-technology. From that point of view, grasping the opportunity of having underemployed specialists available becomes understandable.
2. Companies with less need for equipment, e.g. a software company, should not be given similar amounts. That would not be justifiable (expert interview).
3. Large investments by solid investors show a tangible effect – "there is something substantial on the meadow to be shown by the government" – and are less risky (expert interview).
4. Supporting "enlarged workbenches", as done earlier by the Trust Agency, is not good enough. "Independent substance is more important" ("eigenständige Substanz", company expert).
5. Entitling every investor to a subsidy can lead to huge costs, and windfall gains. Too many apartments were built after 1989. Also the subsidisation of mobile investment goods in the East may have led to windfall gains at Western headquarters (see Ragnitz et al.).
6. To achieve more employment, the government may have to support more risky investments. That would be difficult for traditional civil servant thinking, but it was said to be a chance to develop more locally based industries (expert interview). Also, today only very mature proposals would be approved by the government, and the rules were said to be too complicated for some investors (company expert).

Summarising one can say that the government subsidies contributed to a positive development in terms of both employment and future government revenues. The "only" question remains whether the government could have done even better.

Job Quality

The existing studies hardly address the quality of the jobs. The burden on operators probably is not negligible, due to extensive shift work, the special behaviour needed in clean rooms, such as wearing special clothing ("bunny suits"), no make-up, the need not to smoke before work, etc. According to Edler, wages of operators are about € 29,000 per year, while wages of university degree holders are about € 56,000 (Edler et al, 2002, p. 109).

In expert interviews it turned out that due to the general situation of the global semiconductor industry, continuous productivity improvements take place, which may even lead to outplacements (Infineon galaxy June 2002). In 2002, the companies noticed that people's willingness to move has become larger, and the number of qualified unemployed jobseekers has increased (interviews). Increasingly, job contracts are of limited duration, or subcontracts are being used. The flexibility of staff to accept or invent changes in production reportedly is higher than in Munich or Regensburg. In Dresden, employees who work with one of the large semiconductor companies are clearly envied by the rest of the population. One of the investors at one time received about 1,200 applications per month.

Education and Research

The semiconductor companies in the area, in particular Infineon, are actively developing educational processes. They anticipate that future needs for well-educated engineering scientists can hardly be met in the area, e.g. because of decreasing birth rates. Therefore, they participate, e.g., in the development of new professions, such as “mechatronics”, in creating new types of tertiary studies, such as the “dualer Studiengang” (dual course of studies) mentioned above. Recently, the “Dresden Chip Academy” has been created as a framework for such vocational training (cf. Buss, Wittke 2000), offering the degree of a bachelor.

Nevertheless, it is anticipated that in the future, more engineers “will need to be recruited in the Czech Republic and in Poland” (interview). The expert who said that was pleased about the knowledge of the German language of applicants coming from these countries. Concluding one can say that the traditional education in Eastern Europe, here in Eastern Germany, in natural sciences, at ordinary schools and at universities alike, was seen as a highly important factor for the creation of the semiconductor cluster. Players see that efforts must be made to retain that level.

Ecology

The ecological aspects are not only dealt with because the EU addresses them in its official objectives. After the severe flooding of Dresden in August 2002, it was felt to be impossible to avoid checking if there is any relation between the semiconductor investments and the floods.

Floodings: The fabs were not been by the floods of the Elbe river and the smaller rivers in the area. The floods, during which the river Elbe approached 8.77 meters (normally about 2 meters), have been estimated to have caused damage of about € 6 billion or more in Saxony (Badische Zeitung 4.11.2002), which, by the way, is roughly the total value of all “fabs” (Edler et al. p. 65). With their constructions sealing the soil, the fabs contributed marginally to the floodings further down the river Elbe. Causes for the floods must on the one hand be seen to be natural, as similar floods occurred, e.g., in 1845 and 1897 (Merian 1999, Mende 2002), and on the other hand they must be seen to be man-made, as water dams, erected for protection, were used as reservoirs in the “upstream” mountainous areas of Germany and the Czech Republic and were filled for purposes of electricity generation and tourism. Further man-made causes are rivers being diverted or made navigable.

Hazardous Chemicals: The ecological effects of the semiconductor production itself are not addressed in the scientific literature about Dresden. The issues themselves are obviously dealt with, see the above remarks on AMD’s copper production and the protective equipment produced by DAS.

Water supply: Production may have an effect on the water supply, as ground water under the fabs is tapped, but it was not possible to investigate any long-run effects.

Energy consumption: This is another area not discussed in the literature about Dresden and only scratched in Mazurek (1999, p. 49).

Traffic: It is understandable that investors preferred locations in proximity to the motorway and the airport. For semiconductor production, areas with clean air, water and low vibrations are particularly attractive. The issue arises, however, why it has not be possible to construct new sites close to the city centre to avoid new traffic, i.e. in the former industrial areas. For the moment, this does not appear to be a severe issue, as we are only talking of about 10,000 jobs. But if economic activity reaches a level as in West German cities, or as in the Dublin area, car traffic may increase significantly. A major reason appears to be that the Trust Agency said it made no industrial policy and therefore did not consider to keep large scale production areas intact, or systematically reserve them for large investments. A frequent result of this are split ownerships of territories. It has also been pointed out by one environmental expert that US investors may find proximity to motorways and airports a more obvious need than to historical city centres: “They look at that on maps in America, look for motorways and airfields. They have a different idea of town centres, prefer to live close to the motorway.”[18]

Quality of Life

Is the quality of life in Dresden, the attractiveness of the city an important factor? On the one hand, one might believe unemployed skilled engineers and operators and public funding are the essential factors. On the other hand, there is evidence that the attractiveness of the area is important for two reasons:

- To attract investors in the first place: According to our interviews, investors have been shown attractive parts of Dresden, such as the Baroque scenery next to the river Elbe, the fine residential areas in the hills above the river, next to vineyards and floodplains, to make them interested in the area (see Figures #5 and #17).
- It has also been reported that a high quality of living is necessary to be able to attract specialists (Edler et al. 2002, p. 161).

Figure #17: One of the finest residential areas in Dresden (October 2002, photo: Arnd Weber).

[18] „Die gucken sich das von Amerika aus auf der Landkrate an, gucken nach Autobahn und Flughafen. Die haben eine andere Vorstellung von Innenstädten. Sie wohnen lieber in der Nähe der Autobahn.“

Neither the „Plattenbauten“ nor the large number of deserted houses contribute to making the city particularly attractive. The university with its good reputation as well as the new Dresden International School for young pupils, with already 220 pupils, certainly do (<http://www.dresden-is.de/SchoolFrameset.htm>). To give an impression, one investor at one time chartered an aircraft to fly in 25 foreign specialists and showed them the city (company expert). Nine of them remained. Another company expert reported, about the global situation: “In some areas, there are a dozen or so specialists. You won’t get these specialists to a city [on the Balkans]”.

Economic Sustainability

Arguments in Favour of Sustainability

On the one hand, the semiconductor area appears to be flourishing extremely well:

1. Large construction activities continue, such as for the Mask Centre or at ZMD’s premises.
2. Employment keeps developing better than anticipated.
3. According to one interview it can be expected that the difficulties of producing in the 100 nm range or below will make it increasingly necessary to have very close co-operation between designers of products, designers of production processes and operators of pilot production lines.
4. Well skilled, available, relatively cheap craftsmen co-operate intensively with highly skilled engineering scientists. This combination is not easily available elsewhere. Regarding operators it has been said: “They have to work free of errors. Here in Dresden, people have done such work in the past” (expert) Workers in accession countries would not necessarily be used to that.
5. Investors increasingly conduct research in the Dresden area.
6. EU enlargement will contribute to easing any shortage of engineers. Engineers from accession countries would be as good as German ones (expert).

One group of researchers even concludes that the Dresden development is unrivalled by developments in Western Germany (Blien et al. 2001, editorial). Some respondents expressed that the general level of skills of potential operators in the Candidate Countries is somewhat lower, and that sometimes local governments in these countries are less transparent and efficient. These issues have not been investigated in any detail, but it would mean that the Candidate Countries are no real rivals for the time being.

Arguments Against Sustainability

On the other hand, some critical issues may need to be watched:

1. The large investors made losses in 2002. The main reason was the global situation of the semiconductor markets, see Figure #18. The figure makes the large relative changes visible which the companies have to deal with. “The top 25's semiconductor sales dropped from more than $167 billion to just less than $112 billion [in 2001]”, according to Electronic News 2002. Regarding AMD, currently their main competitor Intel is much more profitable, with a profit of $ 3.1 bn in 2002. Yet, AMD will need to make large investments in order to remain competitive, $ 5 billion have been mentioned (interview). Regarding Infineon, due to tough competition they had also incurred losses. They compete against, e.g., Hynix (a merger of Hyundai’s and Goldstar’s semiconductor operations). Hynix has a “position [which] remains positively

dire at best, buried under a mountain of debt and desperate to raise cash. Technically bankrupt, it is being kept alive due to indirect support from the Korean government.“ (Future Horizons 2002, p. 32). Infineon has been pressing the EC to file a case with the World Trade Organization charging the Korean government with violating global trade rules through its connection to the Hynix rescue package (Robertsen 2001). Early in 2003, the EU reportedly threatened to impose a 25% import tariff as a sanction against Hynix. Infineon also competes against Samsung, who are profitable (cf. Table #7; according to iSupply, Samsung became number two semiconductor producer in 2002).

2. EU enlargement may lead to reduced public subsidies for new investments in the long run.

Ranking	Company	$ billion
1	Intel	23.9
2	Toshiba	6.8
3	STMicroelectronics	6.4
4	Texas Instruments	6.1
5	Samsung	5.8
...		
9	Infineon	4.6
...		
12	AMD	3.9
...		
18	Hynix	2.5
...		
Top 25		112

Table #7: Semiconductor sales in 2001. Source: Electronic News 2002.

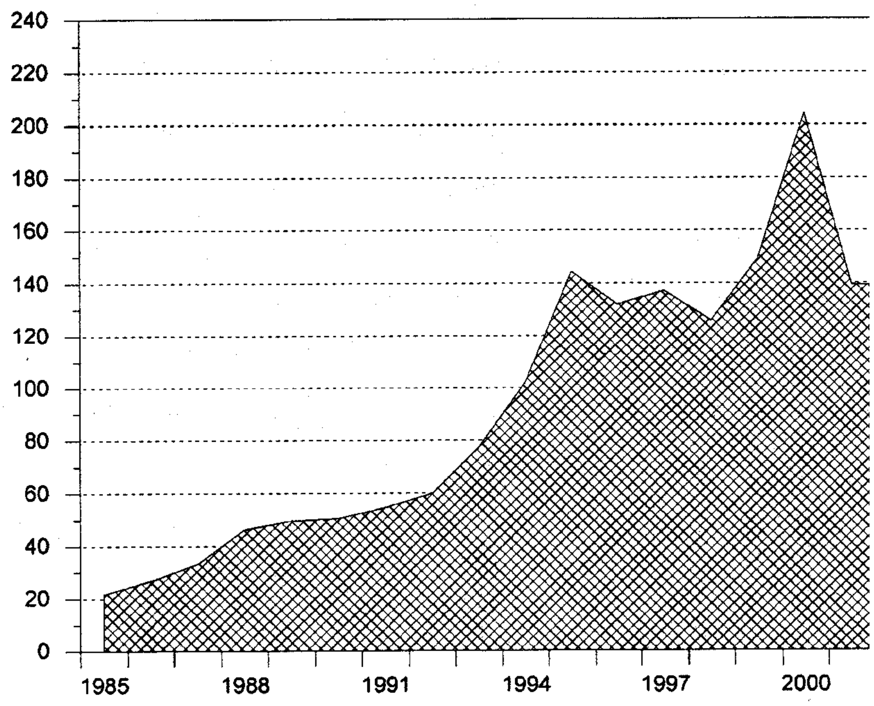

Figure #18: World semiconductor market, billion US-$ (source: Edler et al. 2002, p. 52).

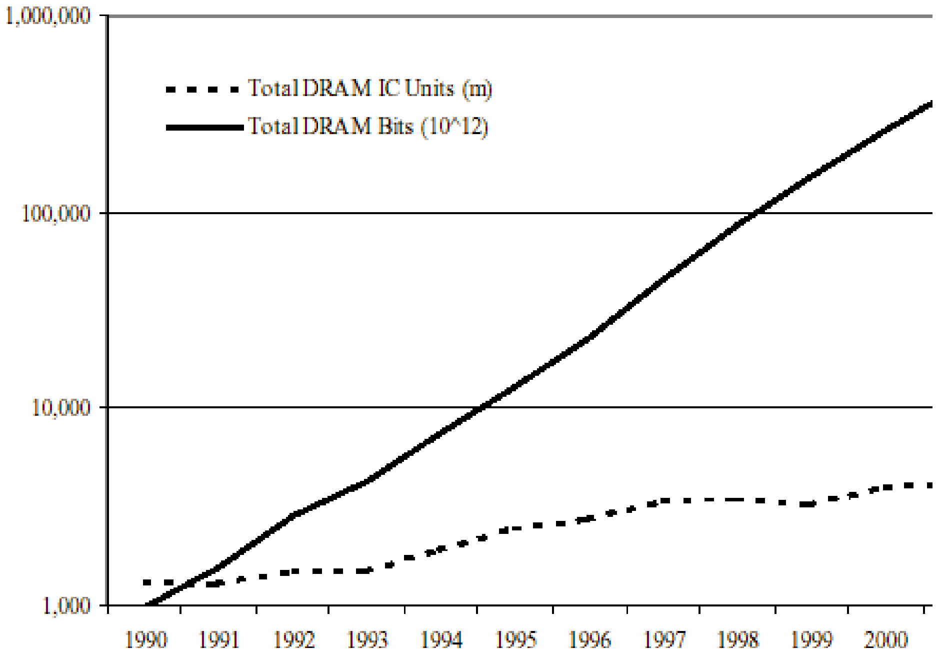

Figure #19: DRAM Unit & Bit Demand, 1990-2000 (source: Future Horizons 2002, p. 14).

Conclusions

1. Economic sustainability will largely depend on whether the major investors will be able to make substantial profits in the future as they did in past booms. Due to the large "sunk" costs, during downturns, investors have to continue production even at revenues below average costs. Therefore, the timing, size and duration of the next boom will be essential. Figure #19 shows that the demand for memory, in terms of bits, so far kept growing all the time. It is expected that, in the near future, it will be in particular the Asian markets which will grow, possibly at about 20% per year in terms of value (World Semiconductor Trade Statistics 2002). Infineon claims cost leadership due to the 300 mm technology, so this should become visible as soon as demand increases. AMD is preparing new products, as reported above (Section 3.3.4). Government funds will only play a minor role in achieving profitability in Dresden, as the subsidies cover only a small share of the investment costs.[19] The author expects that if profitability can be regained, investors will not move in the foreseeable future.

2. A possible perspective for the area, as well as for Germany, becomes visible in remarks made by Schumacher, CEO of Infineon. He reportedly suggested that Germany should consider a branding such as "researched and developed in Germany", to take comparative advantages of Germany into account. That thought can be interpreted to mean that Germany essentially provides scientific engineering, while production could take place in low-wage countries. However, jobs are also needed in Germany for people without a scientific degree in engineering...

[19] Also the case of BMW shows that subsidies do not generally lead to supporting unprofitable businesses. BMW will be given subsidies for their Leipzig investment. Yet, they are making profits.

4.2 Some Relations to the Whole Region of Saxony

In this section, an attempt will be made to view the semiconductor "beacon" from the perspective of Saxony as a whole.

- Regarding employment, income is created by the fabs and their partners and this is spent again and creates more income. This may sound trivial, but is of course not unimportant, see the computation of Edler et al. who estimate that about 2,300 jobs are created indirectly.
- The semiconductor beacon is one of several beacons, in particular there is also the car "beacon". I.e. Saxony has several developing areas in terms of products and regions. As mentioned earlier, Saxony is developing particularly well in the area of manufacturing. This contributes to offsetting the shrinking role of the construction industries.
- Ragnitz et al. conclude that "it is questionable if a concentration of the instruments for regional support policy on poles of growth does indeed lead to the desired broad scale impulses for development." (2002, p. 69) This study has not been the place to investigate whether there has been any significant concentration. However, Ragnitz et al. put the issue on the table whether the "non-beacons", so to say the "darker" areas, have received sufficient attention.
- It has not been possible to analyse, in this study, to what degree the semiconductor manufacturers have relations to customers in the area, such as in machine tool or car production. This would be of special interest, as the Dresden region reportedly has some disadvantage concerning marketing: "In the interviews, there was again and again the message that the region is the ideal location to generate knowledge, but not to implement this knowledge in new products" (Specht 1999, p. 218). The big investors with their global product developments and marketing probably do not experienced any such obstacles. However, increased local relations in general and by smaller companies in particular would certainly be economically helpful.
- Regarding research, non-semiconductor companies are also active, of course. Only 1/3 of the annual subsidies of the state of Saxony go into microelectronics. The remainder is for the car industry, biotechnology, etc. (government expert).
- Regarding education, it can be said that the semiconductor companies contribute to the need for good education on natural science topics, from the primary to the tertiary educational levels.
- Regarding ICT use, in line with general industrial development, and with the general strength in research and education, Saxony has higher rates of ICT use compared to other East German states (Telematikbericht 2001). Of course, the semiconductor cluster re-enforces this somewhat by students studying related subjects, more parents buying PCs, etc.

4.3 Summary of Critical Factors

In this section, an attempt is made to provide an overview of the main effects and the main factors by which they have been created. The objective of this exercise is to ease comparability of the Dresden case study with the other case studies made in the *Tigers* project. Accordingly, there is a differentiation between "output" factors, i.e. results, and "input" factors.

Input Factors
Regarding the development of the semiconductor companies, the analysis made in particular in section 3.3 can be summarised as follows:

1. Highest skill levels maintained for generations at the levels of craftsmanship and science are the most important "input". Achievements such as the mastering of the copper process, the fast ramp-up of production and high yields produced have been attributed to skills achieved before 1989, i.e. due to education which took place even earlier. It should be noted that these skills have been described as being vocational or ethical, and were maintained and developed in very different political regimes (i.e. are not caused by "democracy"). It is, of course, important that people with such skills were available, i.e. not fully employed. Many scientists know each other, i.e. form a network or cluster. After 1989, the new companies were founded or run by people who had already worked for Forschungszentrum Mikroelektronik, Elektromat or Robotron (Bruch-Krumbein 2000, p. 169ff).
2. "Foreign" direct investment in particular from West German and US investors has been a major force to light the "beacon".
3. Public funding through state, federal and EU governments is another important factor, as emphasised by the investors.
4. Local speed of government decision making has been said to be important, as opposed to e.g. processes for obtaining permits which take years.[20]
5. The provision of a high-quality infrastructure (motorways, airport, cables, water) was also mentioned as important.

Output Factors
Regarding the semiconductor "beacon", the main results are:

1. Development in terms of employment in the semiconductor industry is above expectations.
2. Profitability needs yet to be achieved.

[20] Fast and transparent decision making by public authorities is by no means trivial or ubiquitous in Germany. Recent reports in the media indicate room for improvement in a ongoing semiconductor investment by Intel and the Emirate of Dubai in Frankfurt an der Oder, in the East German state of Brandenburg. The investors founded "Communicant Semiconductor Technologies". One objective is to produce semiconductors for mobile Internet applications with a particularly low power consumption, based on a Silicon/Germanium/Carbon technology (SiGe:C) developed at Frankfurt an der Oder. Here, decisions have been delayed, the state government reportedly found it difficult to provide € 38 mio. as a subsidy (Heise 2002c), and finally the Minister of Economics, Wolfgang Fürniß, had to resign after reports that he obtained privately $ mio 1.5 from a Dubai Sheikh (Spiegel 2002).

5 Open Questions and Policy Conclusions

In this section, some open questions which emerged during the course of the work, are listed. Furthermore, an attempt is made to draw conclusions, in particular for the Candidate Countries.

5.1 Open Questions for Further Research

During the course of the short *Tigers* project, a few issues could not be addressed or emerged as issues for future research. These are listed below in no particular order.

1. **Development of high skill levels:** Consider the following simple calculation: an engineering scientist with good qualifications as appreciated by AMD must have started his professional work in the 1970s or 1980s, and his engineering education must therefore have started in the 1960s or 70s. The teachers of these engineers must have had their education at least about 30 years earlier. In other words: It takes at least one or two generations to build up such skills, unless one were taught by foreigners (which was definitely not the case in the GDR). In sections 3.1.1-3.1.3 it was shown that the engineering tradition is more than 100 years old, and the vocational tradition is even about 500 years old. If we take one or two generations as a hypothetical minimum time span to fully develop qualifications in a region, does the case of Ireland show that such a development can take place much faster? Or are skill levels as in the case of Dresden rather a local factor which can only be developed elsewhere within generations?[21] A more in-depth investigation of vocational ethics and levels of skills would certainly be helpful for underpinning any such analysis.
2. **Comparison of skill levels:** Two experts expressed that the general level of skills of potential operators in the Candidate Countries is somewhat lower and that some investors already withdrew from such countries. This is another issue to be investigated.
3. **Design and evaluation of government policies:** One issue which emerged is that policies could ideally be based on achieving objectives such as the Lisbon objectives for competitiveness, high quality jobs, social cohesion and environmental sustainability. In 1998, the Saxonian Audit Court raised the question if the government could have done better. For instance, they wrote that the government should have objectives such as "We want to reduce the rate of unemployment by 4 % over the next 3 years", or "We want to create 5,000 more jobs for …" They requested a study which was made by Dresden university. These researchers brought up questions such as: "Were the right clusters of technological development selected?" and "Were the resources distributed in the right way?" (Sabisch, Esswein 1998). The question thus arises whether government policies as a whole are designed in a way to achieve such objectives. Likewise, in a recent communication by the European Commission the issue was brought up that an "impact assessment of legislative and political initiatives [should be made] to measure likely effects of policy options on various categories of stakeholders." (Commission 2002, p. 24; cf. Beutel 2002). Similar demands for assessments of expected costs and benefits have been demanded by Fier and Harhoff (2002) to evaluate government spending on research. They argue that both benefits of discrete measures as well as windfall effects of general measures should be estimated before a decision is made, and after. Thus, three questions arise: (1) Are policy options assessed with respect to the Lisbon objectives? (2) Are they evaluated accordingly?

[21] The still famous Sonnar lense design was created by Bertele of the Ernemann factory (mentioned in section 4.1.3), in 1929 (Kyocera 2002). How did it happen that Japanese engineers of Nikon apparently outperformed it already in 1950, by producing the sharper Nikkor lenses, using barium flint glass (Nikon 2002a)?

A sub-question would be: (3) What is justifiable support for labour-intensive industries, as e.g. the software industry, which does not heavily invest in buildings or equipment? The scope of such assessments should be at the European scale, at least.

4. **Solutions for marketing new ideas and improving local sales relations:** The area of Dresden is at some distance to leading markets. This is not a problem for the major investors operating globally. However, in the interviews the issue arose that emerging local companies would need to do better in developing their markets. In the field of microelectronics, networks would be needed with both American and Asian players. As quoted above, Specht summarised his interviews by stating that "the region is the ideal location to generate knowledge, but not to implement this knowledge in new products". It would be interesting to know more about the existing local relations between chip producers and their regional customers e.g. in the production of computers, machine tools and cars. Answers could be sought to questions such as: Why do mobile phones not contain digital cameras produced in Dresden? For public policy, the generic question is: How could an emerging industrial core such as the Saxonian one be better supported to become more successful on the world market? Note that even Ulrich Schumacher, Infineon's CEO, pointed out that his company increasingly needs to know more about end-users: "we are currently learning to talk to the end-user, our customers' customer, to get to know his desires and needs, to anticipate which products and solutions he might need tomorrow, or might wish." (Schumacher 2002).
5. **Reasons for different profitability:** What is the reason why another European-based semiconductor manufacturer, STMicroelectronics (a merger of Thomson Semiconducteurs and SGS-Microelettronica), is more profitable? The company made a turnover of $ 6.3 billion, in 2002, with net earnings of $ 439 million (cf. Table #7). Another question is: How do Infineon and Samsung compare in terms of costs and profits of producing DRAM chips?
6. **Transparency of government decision making:** Two experts remarked that sometimes governments in the Candidate Countries are less transparent and efficient than the Saxonian. This issue could be investigated as well. Identifying "best practice" was recommended by one of the experts.

5.2 Policy Conclusions

In this section, some conclusions for government policies are presented. The whole report showed the significance of government action. This became visible when discussing early roots, such as Dresden as the residence of the Saxonian Elector. It also became visible when during communist times education and research in the field of electricity and later electronics were maintained. Finally, it became visible in the post-1989 government policies in East Germany in general, and in particular in the supportive policy of the city and state governments in favour of the semiconductor investments starting in the 1990s. This does not imply that the author thinks the government is the most important factor, see the list in section 4.3. In a theoretical world economy without government subsidies, the author would bet the investors would still have gone to Dresden because of the skills.

Given the above evaluation, it appears policies should exactly address the Lisbon economic, social and environmental objectives. More concretely:

- Economic objectives, in particular GNP growth, employment, and profitability, which do not necessarily move in parallel.
- Social objectives, such as achieving a high job quality, low needs for migration, low inequality or sufficient birth rates.
- Environmental objectives, such as preventing flood risks.

With the Candidate Countries in mind, the analysis of the case of Dresden points out that to pursue such a policy can actually mean:

1. **Foresight activities:** An analysis would be beneficial which explores the future economic, social and environmental effects of government policies. Certainly the economic aspect is very important, i.e. policies should aim at producing "most bang for the buck". But the social and environmental quality of regions should be taken into account as well. The foresight activity should address effects across borders as well, such as brain-drain, re-location of industries, soil sealing, etc.
2. **Controlling activities:** Such activities should take place in order to later check whether the objectives are met and whether investments bear their costs in terms of education, infrastructure, etc.
3. **Support of industries in competitive areas***:* The Dresden experience points out that special efforts are needed to sustain areas of a region's comparative expertise. It appears that it will be extremely difficult to copy the Dresden semiconductor developments, given the significant role of the pre-existing cluster. The areas of comparative advantage in Candidate Countries need not necessarily be the usually assumed high-tech areas, but can be in other fields, e.g. other knowledge-based industries, forest-based industries, tourism, etc.
4. **Support of companies with local ties rather than of "enlarged workbenches":** Several experts pointed out that "enlarged workbenches" do not only tend to require only a relatively low level of skills, it was also pointed out that in case of a crisis, disinvestments may happen quickly.[22] Therefore, companies with strong local roots, embedded both in local co-operation and in global markets would be needed, to provide lasting employment. It would therefore be good if Candidate Countries could produce something which is new or close to unique on the world market. If a region has no tradition in an area such as microelectronics, other industries in which the region could become competitive should possibly be supported. Furthermore, one expert suggested that governments should improve local ties, e.g., by creating the motivation for increasing contacts, by supporting regional industrial meetings, by supporting international procurement and sales contacts and public relations such as booths at fairs, and by supporting high quality external consultants.
   The same expert stated that concepts which are not yet completely mature could possibly be subsidised earlier. Such case-specific investment support may have an arbitrary element. It was said, however, that decision makers could possibly be encouraged to subsidise concepts which are less mature based on the proposer's merits and reputation. This is in some contrast to textbook recommendations according to which the government should keep out of such decisions as the markets can make them better, but it denotes a possible type of actions governments can take if funds are available.
5. **Support of education in competitive areas:** A solid educational system is certainly needed to retain global competitiveness. The Dresden experience points out that special efforts are needed concerning a region's comparative advantages and expertise.[23]

[22] In interviews made for the ESTO-project *MAB*, national experts from Candidate Countries pointed out that certain investors who had moved to European transition economies in 2002 moved towards China. For instance, in Estonia there is the *Elcoteq* company, assembling phones for Ericsson and Nokia. "During the last two years the number of people has decreased. *Elcoteq* moved its construction site to China, it is building its mobile phones and other products there, because it is cheaper there." (interview) Similarly, a Hungarian expert pointed out that *IBM Storage* is moving its production to China (Weber, Wehn 2002).

[23] This may also apply to Germany, in which the relatively poor scoring in the OECD's "PISA" pupils assessments was discussed widely. While Germany as a whole still is a strong exporter in many sectors, since 2001 a sense of crisis emerged, with dismissal of employees in many companies, and tax returns below expectations. Therefore effectively developing vocational ethics and resulting skills can become the clue to success, see Schumacher's remarks at the end of Section 4.1.

6 Summary

Objectives, Method

This study takes the European Council's objectives as agreed at the Lisbon summit as a starting point: "The Union has today set itself a new strategic goal for the next decade: to become the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion." It was decided that it would make sense to investigate a development in Eastern Germany, which is a transition economy, yet already part of the EU. As opposed to analysing a large part of Eastern Germany, it was felt that it would make sense to investigate a relatively small cluster in which IT-related developments play a special role, i.e. the Dresden cluster of semiconductor production, in order to see whether it gets closer to meeting the Lisbon objectives. The methods used were to review the most important studies, and to conduct 8 expert interviews in Dresden.

Statistical Overview

In Section 2, a statistical overview of general developments in Saxony and in Dresden, as well as of related information society and semiconductor developments is provided, stating, e.g., that Saxony has a shrinking population of 4.4 million inhabitants, with unemployment of about 19 %.

The Development of the Dresden Semiconductor Cluster

In Section 3 the development of the Dresden semiconductor cluster is described. In that section, early roots of industrial development in Saxony are mentioned, as they are deemed to be important for understanding how such a regional cluster can develop. Saxony was the most industrialised area in Germany before World War II. The Dresden region manufactured such items as watches, computing machines, high-volt transformers, crystal detectors, optical lenses and cameras before World War II. An important factor is the Dresden Technical University which has its origins in 1828. During GDR times, aircraft, cameras, and even whole computer centres were produced. Dresden was the GDR's largest research centre, e.g., piloting semiconductor production such as for Europe's first Megabit memory chip in 1988.

In the course of the re-unification of Germany, employment shrank considerably. After an initial boom, growth rates later reached the relatively low West-German levels. Therefore it makes sense to analyse the so-called "beacons" of development. Major beacons are the car production factories in Eisenach and Mosel, and semiconductor production in Dresden.

For the latter, the decision by Siemens, made in 1993, to invest the equivalent of € 1.38 bn into a semiconductor plant was essential. In December 1995, AMD announced its decision to build a semiconductor "fab" in Dresden and decided against Ireland. The fabs were subsidised with public funds. These subsidies cover only a fraction of the total investment costs of about € 6.5 bn (by 2002). The decisions by Siemens and AMD to invest and keep investing cannot be explained with public funding alone, as other locations offered financial subsidies on a similar scale. Rather the human factor was essential. For example, AMD was impressed by the skills of the German engineers, and the precision the operators were used to in their work. In 1999, Siemens in Dresden produced the world's first 256-Mbit-DRAM-chip. After floating of Siemens Halbleiter in the year 2000, it was renamed Infineon. With support from the German Ministry of Education and Research (BMBF), a technology for wafers of the size of 300 mm was developed by Infineon, Motorola and Wacker. The world's first 300 mm product was

produced in 2001, a 64-Mbit-DRAM chip. Infineon was awarded the "Fab of the Year" prize of the year 2000 for the 300 mm pilot line.
AMD decided to use a technology for copper interconnects to build a very fast microprocessor. One of the problems of using copper is that it is poison to transistors. With the first GHz-rated Athlon microprocessor produced in 2000 using the new technology, the AMD made a profit of about $ 1 billion. The fab was awarded the "Fab of the Year" prize for the year 2001.

With the decision of AMD to invest in Dresden, other players saw that Dresden is developing into a global centre of development. In May 2002, AMD, Infineon and DuPont Photomasks founded AMTC, the Advanced Mask Technology Center, as a global research centre. For about 30 international equipment producers, the major investments made it economic to open permanent offices themselves. Also new producers started business such as DAS who design processes for the environmentally safe disposal of poisonous wastes. The decision by Wacker Siltronic to produce silicon crystals for 300 mm wafers in near-by Freiberg has been another important step. A few successful new companies emerged, producing new products, such as KSW and Systemonic.

Assessment

About 10,000 semiconductor-related jobs were created in the region, more than initially expected. Government subsidies of about € 1.2 billion will probably be much smaller than the expected social insurance and tax payments, which should be about € 5.9 billion, by 2010.

Both AMD and Infineon are currently making losses, due to the downturn of the global semiconductor market. Economic sustainability will largely depend on whether these investors are able to make substantial profits in the future, just like they made in past boom times. Due to the large "sunk" costs, during downturns, investors have to continue production even at revenues below average costs. Therefore, the timing, size and duration of the next boom will be essential. It is estimated that the largest market growth will be in Asia.

The most important "input" and "output" factors of the Dresden developments are:

Input Factors

1. Highest skill levels maintained for generations concerning craftsmanship as well as scientific skills, with such people being "available", i.e. unemployed.
2. "Foreign" direct investment in particular from West German and US investors.
3. Public funding through state, federal and EU governments.
4. High speed of local government decision making.
5. A high-quality infrastructure (motorways, airport, cables, water).

The main results are:

Output Factors

1. Development in terms of employment in the semiconductor industry is above expectations.
2. Profitability needs yet to be achieved.

Regarding the East German transition process as a whole, it can be said that the "beacons" such as the car production in Eisenach and Zwickau, and the semiconductor production in Dresden, contribute to offsetting negative effects such as of the shrinking turnover in the construction industries.

Conclusions

In Section 5, first some open questions are enumerated, such as that the building up of skills over centuries in Dresden contrasts with recent faster "Tigers" processes as in Ireland. In particular the question is raised how new companies with new business ideas could be better supported, and whether the lack of closeness to end-user markets is an issue.

Finally, the following conclusions for policies regarding the Candidate Countries are drawn:

1. **Foresight activities***:* An analysis would be beneficial which forecasts the economic, social and environmental effects of government policies, to provide a basis for the selection of policies.
2. **Controlling activities:** Such activities should take place in order to later check whether the objectives have been met.
3. **Support of industries in competitive areas***:* The Dresden experience illustrates that special efforts are needed to sustain the field of a region's comparative expertise, e.g. metal or wood industries, or tourism.
4. **Support of companies with local ties rather than of "enlarged workbenches":** Several experts pointed out that "enlarged workbenches", as they have been emerging in the Candidate Countries, do not only tend to require only a relatively low level of skills, it was also emphasised that in the case of a crisis, disinvestments may happen quickly. Therefore, companies with strong local roots, embedded both in local co-operation and in global markets would be needed, to provide lasting employment.
5. **Support of education:** A solid educational system is certainly needed to support a region's comparative expertise.

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