#2301 Bremen Papers on Economics & Innovation

Nothing new in the East? New evidence on productivity effects of inventions in the GDR

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January 2023

Abstract

Former socialist systems were considered inferior to Western market economies in terms of innovation and productivity. We provide new evidence on the productivity effects of inventorship in the Soviet-type economy of the German Democratic Republic (GDR). We investigate three types of inventorship: knowledge generation, accumulation and diffusion. By applying a Cobb-Douglas production function using original primary and harmonized productivity data and manually cleaned patent data of the GDR between 1970 and 1989, we show that inventorship contributed to productivity in the industry sectors. This holds for knowledge generation, accumulation and diffusion in general, while in the presence of sufficient local interactive capabilities, international knowledge diffusion did not result in productivity gains. We contribute to empirical evidence on the productivity effects from an alternative system of patenting and innovation.

Keywords
Soviet-type economy, productivity, inventorship, knowledge

JEL Classifications
P23; L60; O14

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1. Introduction

In market economies, the productivity of plants, firms and sectors is largely driven by the use of new and improved technologies and inventions (Griliches, 1979). For example, the deployment of patented inventions can accelerate manufacturing processes and make production more efficient (Baum et al., 2018; Bloom and Van Reenen, 2002; Santarelli and Lotti, 2008). Before the 1st industrial revolution, production technologies such as bloomery furnaces allowed to melt and alloy metals to process component parts. Thereafter, steam engines based on coal-fueled machine tools to produce goods, and today, flexible automatization based on microelectronics such as chips or robotics enhance a firm's production efficiency (Domini et al., 2021). In fact, for market economies, there is ample evidence that productivity increases due to the application of improved or new technologies based on the development and use of knowledge (Venturini, 2015; O'Mahony and Vecchi, 2009; Rothaermel and Thursby, 2007).

Former socialist systems such as the Polish People's Republic, the Ukrainian Soviet Socialist Republic or German Democratic Republic (GDR) were characterized as inferior to Western market economies in terms of innovation and productivity (Bergson, 1987; Chiang, 1990; Vonyó and Klein, 2019). Although socialist planned economies generated new knowledge and inventions, technologies had to emerge in innovations systems that suffered from several misalignments, distorted incentive structures, as well as limited application of new technologies in the industry and a certain dependency on espionage (Radosevic, 1999; von Tunzelmann et al., 2010; Glitz and Meyersson, 2020; Hipp et al., 2021, 2022a; Radosevic, 2022).

However, it remains unclear whether or not knowledge generation, accumulation and diffusion contributed to productivity in a socialist system. In contrast to market economies, socialist systems used specific institutions related to coordination via economic planning to stimulate inventorship and productivity. The GDR, for example, applied a supply-side-oriented linear technology-push model, whereby planned production defined science objectives, even in basic research (Meske, 1994). In addition, enterprises or research institutes within large combined firms (*'Kombinate'*) engaged in applied industrial R&D (Von Gusinski, 1993; von Tunzelmann et al., 2010). The GDR also used a patent system to protect intellectual property (IP). However, the state held exploitation rights granted by an economic patent ('*Wirtschaftspatent*') rather than the individual inventor. The latter received a one-off financial compensation (Lindig, 1995; Wiessner, 2015). Arguably, the GDR complied also with international IP practices by offering another type of patent, the so-called exclusive patent (*'Ausschließungspatent'*), to foreign applicants in order to benefit from international knowledge transfer and to protect their inventions from imitation by foreign competitors at home and abroad (Wiessner, 2015; Glitz and Meyersson, 2020).

Even though previous research found that the number of patents (*Wirtschafts-* and *Ausschließungspatent*) per employee was much lower in the GDR than in the FRG in each year, its development over time and the patent portfolio was similar (Günther et al., 2020). In this study, we investigate the effect of knowledge generation, accumulation and diffusion on productivity at the sectoral level of the GDR between 1970 and 1989 - a period in which technical progress and inventorship became increasingly important (e.g., Ludwig, 2017). In contrast to previous studies on the GDR (e.g., Glitz and Meyersson, 2020), we use original primary production, labour, capital and investment data (see Stäglin and Ludwig, 2000) and novel knowledge indicators from the Comprehensive Patent Database (see Hipp et al., 2022a). We apply a Cobb-Douglas production function to compute total factor productivity (TFP) measures on the level of ten industry sectors. In addition, we provide a comparison with the Federal Republic of Germany (FRG) to exploit the conditions of a natural experiment setting (Kogut and Zander, 2000), given that Germany was a pioneer in several technological fields before World War II, after which two innovation systems with distinct coordination mechanisms and framework conditions emerged (Ritschl and Vonyò, 2014).

Our regression results show productivity-enhancing effects from inventorship in the GDR for knowledge generation, accumulation and diffusion. However, we do not find evidence for such effects from international knowledge diffusion when sufficient local interactive capabilities via co-inventions among residents are present in the industry sectors of the GDR. Finally, we provide further insights on sectoral differences and patent infringement in the GDR and a comparison to West Germany.

Our paper is structured as follows. Section 2 includes the theoretical part on productivity and inventorship in a market and socialist economy. It provides the hypotheses development on the productivity effects of inventorship in the GDR. Section 3 describes the data and methodology. Section 4 presents our descriptive and regression results. Section 5 discusses the findings and concludes.

2. Theory and hypotheses development

2.1. Productivity and inventorship in a market economy

Productivity is commonly used to measure the economic performance of a region (Hulten and Schwab, 1984), firm (Griliches and Mairesse, 1983), or plant (Lichtenberg, 1992) and entails the relation between the produced output and input factors. Typical factor inputs are labour, capital, materials and knowledge (Griliches, 1979). Since knowledge is an intangible good, it is often proxied by patented inventions (Baum et al., 2018; Acs et al., 2002). Patents codify knowledge generated from inventive activities, provide a temporary monopoly right to the owner and incentivize inventive activities while their outcomes and processes are usually highly uncertain (Griliches, 1990). There is a time lag between R&D as an input into the invention process, filing a patent application and its use in production (Acs et al., 2002). Inventorship can be thus categorized from the generation over the accumulation to the diffusion of new knowledge. For a market economy, there is substantial empirical evidence on the productivity-enhancing effects of knowledge generation via patented inventions (For example, Baum et al., 2018; Bloom and Van Reenen, 2002).

Consequently, after its generation, knowledge accumulates and diffuses over time, impacting productivity. Once generated, other inventions build on this previous knowledge, which then accumulates, even though parts of it can become obsolete (Caballero and Jaffe, 1993). Knowledge accumulation can be therefore understood as the collection of a body of knowledge gathered in an industry over time (Chandra and Dong, 2018). Recent empirical studies show that knowledge accumulation contributes to an increase in firm performance and productivity (e.g., Cassidy et al., 2005; Yu et al., 2015; Forés and Camisón, 2016).

Before knowledge accumulates, it needs to be absorbed and used by different agents to diffuse in space (Chandra and Dong, 2018). For instance, a team of inventors or co-inventors diffuses knowledge in specific areas (Xiang et al., 2013; Hussler and Rondé, 2007). In this context, foreign inventors might be decisive sources for the diffusion of novel knowledge from abroad to the respective home country (Kerr and Kerr, 2018; Miguelez and Noumedem Temgoua, 2020). With regard to knowledge diffusion, Tubiana et al. (2022) observe that the interaction with co-inventors in European metropolitan areas shapes the productivity of inventors. Furthermore, Akcigit et al. (2017) found that the productivity of immigrant inventors is higher than the productivity of resident inventors. In sum, activities of inventorship in terms of knowledge generation, accumulation and diffusion exert a positive influence on productivity in the context of a market economy.

2.2. Productivity and inventorship in a socialist economy

Whether and how inventorship contributed to productivity in the Soviet-type socialist system remains an open question. Socialist economies were known for their system blockades and steadily decreasing economic growth (Lavigne, 1995). The Union of Soviet Socialist Republics (USSR), Poland, GDR, Czech Republic, Slovakia, Hungary, Rumania and Bulgaria operated under the control of a communist party, state ownership of production factors and a central economic plan (Kornai, 1992). According to Stalin's model of industrialization, production was independent of Western countries. The focus was on heavy industries and a broad range of products, and labour was divided between the countries of the Council for Mutual Economic Assistance (COMECON), which, however, also came with certain dependency, cost and coordination problems (Lavigne, 1983). In addition, central planning showed its limits early on: plans were not fulfilled, there was no competition in the market and a high demand for the importation of resources (Gleitze, 1975). Among the Soviet-type economies, the GDR was highlighted as a role model with the largest rates of economic growth (Lavigne, 1995).

Arguably, technical progress and inventorship were important in Soviet-type economies, including the GDR, to reach central planning goals and keep pace with the Western states (Lindig, 1995; Glitz and Meyersson, 2020; Hipp et al., 2021). They were also documented by patent output in these countries (Hemmerling, 1986). Recent studies argue that the degree of technical progress in the GDR should not be underestimated. For instance, Hipp et al. (2021) underline the importance of technical progress in the GDR by a larger share of investment in the capital stock of R&D-intensive industries as a percent of Gross Domestic Product (GDP) in comparison to West Germany (1970 – 1989). Glitz and Meyersson (2020)[1] highlight another aspect

[1] Glitz and Meyersson (2020) only used secondary economic data by Heske (2013), who deflated and converted the original primary data of Stäglin and Ludwig (2000). The data of Heske (2013) does not include capital assets, which led the authors to compute this measure using the perpetual inventory method. Moreover, Glitz and Meyersson (2020) rely on patent application data from combines (in

by showing that industrial espionage led to a significant narrowing of sectoral TFP gap between West Germany and the GDR (1970–1989). Furthermore, they detect a reduced TFP gap when controlling for patent applications in the espionage-productivity relationship, implying that patents contributed to TFP in the GDR.

2.3. Inventorship and patenting in the GDR

To understand the patterns of knowledge generation, accumulation, diffusion, and their contribution to productivity, we dive deeper into the patent and innovation system of the GDR. Since 1950, inventions have been protected by the Office for Inventions and Patents (AfEP).

For the first time in German history, a new type of patent, the so-called "economic patent" (*'Wirtschaftspatent'*), was introduced. Employees of conglomerates (*'Kombinate'*), state-owned research institutes, or public institutions had to file their inventions using mostly this type of patent. The *'Wirtschaftspatent'* gave the right to use and apply it to the socialist state, i.e. the employer and owner of all production inputs (Wiessner, 2015). In most cases, the option to choose between the types of patents was cancelled. As a result, resident inventors lost their exclusive rights of the invention to its use of all combinates in the GDR, provided that they notified the responsible central authority in advance (Jonkisch, 1964). However, the inventor received a one-off compensation and had the right to be recognized and named as an inventor (Lindig, 1995). The ruling socialist unity party (SED) also kept the option for a conventional type of patent, the "exclusive patent" (*'Ausschließungspatent'*), which ensured protection rights to the use of the invention for 18 years in order to maintain foreign trade relations, licensing and knowledge transfer with the Western countries, being especially relevant for foreign inventors (Wiessner, 2015). However, high-quality patents from resident inventors could also be applied in this category, albeit rarely, because limited foreign exchange needed to be spent at Western patent offices to prepare for an export of the technology (Hinze and Grupp, 1995).

Based on the requirements for international trade and to hold up in international courts, GDR patents had to be comparable to Western standards in terms of quality

German: Kombinate), which, however, neglects the granting procedure and disregards patents from research institutions or foreign inventors, and thus underestimate the productivity effects from GDR patents. Our study, in contrast, uses more complementary and original primary economic and patent data based on Stäglin and Ludwig (2000) and Hipp et al. (2022a).

and novelty (Kogut and Zander, 2000; Fritsch et al., 2022). Even though the Soviet-type system included different incentive structures to file patents, lower-quality patents could have also been created in market economies, e.g., when they were of strategic importance for a company. The GDR became a member of the World Intellectual Property Organization (WIPO) one year after its foundation (1967), which ensured uniform international standards for patent applications, i.e., the degree of novelty, the inventive step, and the technical applicability (WIPO, 1970). In 1990, the German Patent and Trademark Office (DPMA) integrated the GDR patents into the (West) German system (DPMA, 2021).

East German patents emerged in a particular socialist innovation system, which included three main actors: Large conglomerates (*'Kombinate'*), which were vertically and horizontally integrated units of production with industrial research centers, the academic research institutes of the Academies of Sciences, and the institutes of higher education, such as universities and technical schools (Meske, 1993; Günther et al., 2010; von Tunzelmann et al., 2010). The institutes of higher education were mainly concerned with teaching, and knowledge was supposed to be transferred from the academic research centers into the industry so that the majority of patents originated from the large conglomerates and research institutes (Gläser and Meske, 1996; Günther et al., 2010). However, this supply-driven linear technology-push model suffered from a number of constraints and misalignments affecting knowledge generation and diffusion processes.

2.4. Hypotheses on the productivity effects from inventorship in the GDR

Knowledge generation

In the GDR, economic planning rather than market forces coordinated innovation. The inventive activities were aligned to the central plan and superordinate hierarchy levels assigned specific R&D projects to the operation managers, which had to fulfil the planning goals (von Tunzelmann et al., 2010). Researchers were motivated to invent, and the party was interested in it, but the large conglomerates persisted in their routines (Roesler, 1992). Under high-performance targets, severe material restrictions and outdated technologies, managers were rewarded for meeting production output targets and had no incentive to deploy inventions in case they slowed down production (Allen, 2001). The R&D personnel had to maintain the production with only a little time for patenting, which resulted in few "unplanned" inventions but a number of delayed or aborted development projects (Chiang, 1990). The central planning and the late setting of priorities in R&D led to disruptions in the economic and industry structure and, specifically, the translation of technical inventions into efficient production (Ludwig, 2017).

However, the socialist system also included innovation-favoring factors, such as the relatively high number of R&D personnel (Meske, 1993), broad scientific organizations and an education policy focusing on natural sciences and engineering (Kogut and Zander, 2000). Moreover, the inventors aimed at transferring their application-oriented patents for use in industry (Gläser and Meske, 1996). The economic department in the AfEP supported the use of patents (Wiessner, 2015) and the party aimed at achieving a “scientific-technical revolution” to fulfil the production plans and gain prestige over the West, for example, by fostering innovation in key sectors such as microelectronics (Augustine, 2020). In addition, selected large conglomerates, such as Simson Suhl, could bargain resources for innovation, which supported the processes of knowledge generation and patent creation (Schulz and Welskopp, 2017). Despite the outlined shortcomings, the GDR actively used economic planning to stimulate knowledge generation and its application, aiming at increasing the efficiency of production, fulfilling planning goals, and ultimately leapfrogging Western economies. Thus, we hypothesize that:

***H1**: Knowledge generation has a positive effect on productivity of industry sectors in the GDR.*

Knowledge accumulation

Concerning the accumulation of knowledge over time, centrally set research priorities created challenges. Due to changing research priorities of the economic plan, knowledge accumulation from follow-up inventions could be disrupted. Moreover, the system also adopted an imitation strategy, including industrial espionage (Glitz and Meyersson, 2020), which did not contribute to domestic follow-up inventions but encouraged the copying of selected or different technologies.

Despite these restrictions, we posit that knowledge generation in the GDR was affected by fundamental path dependencies, which led to knowledge accumulation. For instance, scientists in the field of basic research could gain different knowledge from developing projects that enabled the accumulation of their experience over time (Gläser and Meske, 1996). Moreover, while most of the sectors of the GDR suffered from an outdated capital stock, underinvestment in new technologies and materials, and a decline in employees, selected prioritized sectors enjoyed larger support and, thus, more opportunities to accumulate knowledge (Augustine, 2020). For example, microelectronics received continued support from the party during the 1980s, contributing to fundamental R&D capacities, capital investments and knowledge accumulation in this field (Barkleit, 2000). The unfolding of path-dependent knowledge accumulation relevant to specific industry sectors would increase the potential for productivity-enhancing effects over time. Thus, we hypothesize:

***H2**: Knowledge accumulation has a positive effect on the productivity of industry sectors in the GDR.*

Knowledge diffusion

Arguably, one of the key features for the alignment within innovation systems are ‘interactive dynamic capabilities’ emerging in the interaction of firms with their R&D networks, with foreign sources of technology, and market access (von Tunzelmann and Wang, 2007; von Tunzelmann et al., 2010; Radosevic, 2022). In the GDR, central planning entrusted the generation of technologies mainly to R&D institutes of the Academy of Sciences and the research institutes embedded in the large industrial conglomerates. Such new technologies were designed to be the main source of technological diffusion in enterprises (von Tunzelmann et al., 2010). However, the GDR had an innovation system with fairly hierarchical and inflexible structures, which limited opportunities for knowledge diffusion (ibid). The directed transfer of knowledge from the research institutes to industries hampered the application of new technologies in production (Günther et al., 2010), as well as feedback loops from production to research. Furthermore, this GDR patent law provided a few incentives to diffuse new scientific-technical solutions among the large conglomerates when their implementation caused substantial delays in the production process (Wiessner, 2015). As a result, inventions diffused insufficiently amongst the large and dominant conglomerates, which resulted in a gap between the generation and application of knowledge in production (Förtsch, 1997). Thus, existing networks between science and industry were strongly unidirectional, limiting the emergence of interactive dynamic capabilities (von Tunzelmann et al., 2010).

Nonetheless, informal networks between inventors, employees and organizations existed and led to the exchange of knowledge and its use in the industry on a daily basis in order to “get things done” (Radosevic, 1999; von Tunzelmann et al., 2010). For example, materials needed to be exchanged outside the production and research plans to compensate for shortages (Günther et al., 2010). This resource exchange occurred systemically as a specificity of the planned economy by giving a stabilizing function to the system (Heidenreich, 1991). It appeared, e.g., in the form of paper lists that moved between conglomerates in which employees could record their search and offer resources for exchange (Grabher, 1992). Apart from that, knowledge could be diffused via the exchange of personnel between the industry and academy to enable an understanding of the problems in production (Gläser and Meske, 1996). Due to the large informal networks and common official personnel exchanges, we propose that:

***H3**: Knowledge diffusion between co-inventors within the country has a positive effect on productivity of industry sectors in the GDR.*

In general, the autarkic economic system of the GDR disrupted links to the broader international scientific communities (Gläser and Meske, 1996) and international markets (Ludwig, 2017), impeding relevant international knowledge exchange. For example, co-inventors from abroad provide access to new knowledge that might diffuse locally (Miguelez and Noumedem Temgoua, 2020). Moreover, they contribute to knowledge transfer by recombining their know-how and knowledge specific to their home country, enabling local structural change and diversification (Miguelez and Morrison, 2022).

In the GDR, this knowledge exchange existed in selected cases via collaborations with foreign actors, e.g., in Japan (Toshiba) or South Korea (Samsung) (Högselius, 2009) or among actors from the COMECON. The latter coordinated trade agreements and promoted technological cooperation between the countries involved (Lavigne, 1983).

Thus, we cannot exclude that international knowledge diffusion via co-inventors from abroad led to new or recombined knowledge, which could be used to develop technologies to upgrade production processes. Therefore, we posit that:

***H4**: Knowledge diffusion with co-inventors from foreign countries has a positive effect on productivity of industry sectors in the GDR.*

Moreover, foreign inventors from Western countries also received the opportunity to file their patents by means of the *‘Ausschließungspatent’*, which retained the exclusive right for the inventor. They mainly filed patents to gain profits from local sales and to create entry barriers for the socialist conglomerates to imitate and export similar products to Western markets (Brada, 1981). Another potential reason for filing patents in the socialist system could have been that Western firms aimed to ensure international priority of developing the invented technology. Moreover, Western firms did not expect some technologies, such as computers, integrated circuits and plastics, to be easily imitated (ibid.). Nonetheless, they could claim their exploitation and prohibition rights only to a limited extent due to the East German state's monopoly on foreign trade and central planning (Wiessner, 2015).[2] Inventors were, therefore, skeptical about the right to protect their inventions in the GDR. In parallel, the espionage and imitation strategy of the GDR (Glitz and Meyersson, 2020) might have incentivized large conglomerates to bypass IP rights and develop lightly-modified and imitated inventions for application in production. There is evidence on the scientific dependency of the GDR as well as the use of "bypass patents" (*'Umgehungspatente'*) to bring the technology into application (Hinze and Grupp, 1995). However, foreign inventors from Soviet-type countries could also apply for the '*Wirtschaftspatent*' to encounter the "capitalist inventor" and to drive technical progress in the socialist sphere (Wiessner, 2015). A central aim of the COMECON was to establish a uniform document of IP protection with a socialist character to use the inventions within the alliance and across borders (Schönfeld, 1978). Despite the outlined constraints and possibilities of knowledge inflows from abroad, these could be essential to improve production processes in the GDR. Thus, we hypothesize:

***H5**: Knowledge diffusion from foreign inventors has a positive effect on productivity of industry sectors in the GDR.*

3. Data and methodology

3.1. Data sources

To test the hypotheses, we use a set of economic variables at the industry level from different original primary and internationally harmonized data sources such as

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[2] Claims for patent infringement, a correction of the description or compensation could be made at the patent court in Leipzig. Most of the patent claims, however, related to the extent of inventor compensation (see Wiessner, 2015).

Stäglin and Ludwig (2000) and Statistisches Bundesamt (2002). Table 1 includes a detailed description of all variables, measures, and sources. We focus on the observation period from 1970 to 1989, when technical progress and inventorship became most important (Lindig, 1995; Glitz and Meyersson, 2020; Hipp et al., 2021), and the party started to compile corresponding statistics. We differentiate between ten sectors according to the GDR's industry classification: Chemicals, Machinery, Electrical Engineering, Energy, Metallurgy, Construction Materials, Water, Light, Textile and Food. We created a balanced panel of a set of variables based on these industry sectors and years of the observation period. We use original primary data on the economic performance, labour, capital and investments for the sectors from the Statistical Office of the GDR by Stäglin and Ludwig (2000). We refrain from using official GDR statistics because the central planners and high-ranking politicians might have had an incentive to publish manipulated data for ideological reasons (Krämer and Leciejewski, 2021).

The economic performance of the GDR was measured according to the material product system (thereafter MPS) that included the national income at the economic level and the net product at the industry level. The net product accounts for all value-added goods by all resident producers in an economy (capital depreciation considered). Capital was measured by 'Grundmittel' as they define work equipment of a gross value of at least 500 Mark, which retains its form of use during its minimum useful life of at least one year and gradually transfers its value to products and technologies (Gesetzblatt der DDR, 1966). At the industry or firm level, materials are historically linked to raw materials and intermediate goods. There are also investments and costs associated with buying finished goods and materials to resell and other production costs. We therefore relate investments to purchased goods at the focal industry, which aligns with the categorization of Hall and Sena (2017). According to MPS, investments relate to the sum of investments in plants, equipment and buildings.

For the FRG, we retrieved data on the economic performance, labour and capital from Statistisches Bundesamt (2002). The economic performance of the FRG was measured according to the system of national accounts (SNA) that included the gross domestic product (GDP) at the economic and industry level. The GDP measures all value-added goods and services by all inhabitant producers in an economy, including product taxes, minus any subsidies (capital depreciation not considered).

Table 1: Variable description

Variables	Description	Sources	
		GDR	FRG
Total Factor Productivity (TFP)	The proportion of output that is not explained by the inputs of labour, capital and materials used in production activities in the industry sectors of the GDR and FRG in a given year.	*Own calculation*	
Resident patents (RP)	Total number of patent grants from inventors residing in the same country (i.e. Economic Patents, in German: '*Wirtschaftspatente*') according to the date of application in the industry sectors of the GDR and FRG in a given year.	Hipp et al. (2022a)	PATSTAT
Cumulative patents (CP)	Sum of the accumulated annual number of patent grants from inventors residing in the same country over a 5-year window in the industry sectors of the GDR and FRG in a given year.		
Coinventors in the country (CIC)	Total number of patent applications with at least two inventors residing in the same country (i.e. GDR or FRG) in the industry sectors of the GDR and FRG in a given year.	PATSTAT	
Coinventors abroad (CIA)	Total number of transnational patent applications with at least one inventor residing in a different country than the GDR and FRG in the industry sectors in a given year.		
Foreign Inventors (FI)	Total number of transnational patent applications exclusively by foreign inventors in the industry sectors of the GDR and FRG in a given year.		
GDP	Economic performance of the industry sectors in a given year measured by the net product of the GDR and gross domestic product (GDP) of the FRG.	Stäglin and Ludwig (2000)	Statistisches Bundesamt (2002)
Labour	Total number of employees in the industry sectors of the GDR and FRG in a given year.		
Capital	Gross fixed capital assets in the industry sectors of the GDR (in German: '*Grundmittel*') and FRG (in German: '*Anlagevermögen*') in a given year.		
Materials	Gross fixed capital investments in plants, equipment and buildings in the industry sectors of the GDR and FRG in a given year.		Statistical Office of the FRG (Investment statistics provided on demand)

Internal data on investments was provided on demand by the Statistical Office of the FRG. Since the former federal territory differed between investments in plants, equipment and buildings according to the SNA, we calculated the sum of investments to enable a comparison to the definition of investments in the MPS of the GDR.

Concerning patent data, we used manually cleaned patent statistics of the GDR from Hipp et al. (2022a), inventor indicators and patent statistics for the FRG from PATSTAT. The database of Hipp et al. (2022a) includes 24 variables with manually cleaned information on a total of 261,822 GDR patents published by the AfEP. However, since inventor data might be incomplete, we retrieved these indicators and comparable patent data for the FRG from PATSTAT. PATSTAT contains bibliographical and legal event data from more than 100 million patent documents of the European Patent Office's databases from leading industrialized and developing countries.

3.2. Empirical strategy

We use the Cobb-Douglas production function (Griliches, 1979), which can be adapted to a socialist economy (Weill, 2008; Kukić, 2018; Glitz and Meyersson, 2020). We follow the approach of Hall and Sena (2017) and Fink et al. (2021), however, with slightly different components of indicators, where the log of labour (*l*), capital (*k*), and materials (*m*) are inputs. Hence, we use an ordinary least squares (OLS) regression that accounts for year and industry fixed effects. This estimation strategy captures unobserved heterogeneity across industries that is fixed over time.

We estimate a two-stage model in which the first stage indicates the total economic output *(Y: GDP)* as a function of Total Factor Productivity (TFP) *(A),* Capital *(k),* Labour *(l),* and Materials *(m).* TFP is considered a primary driver of economic growth, including a firm or industry-specific growth trajectory (Comin, 2012; Morris, 2018). It measures the efficiency of factor use and production (Faiña et al., 2020), being a residual regression of the log of GDP on the input factors (Fink et al., 2021). Specifically, we estimate the first stage through the ordinary least squares (OLS) method, where we regress the input factors in logs (labour, capital and materials) on the log of GDP. The TFP is obtained by predicting and obtaining the residual of the estimated equation (2) and not the fitted values, representing the normalized outcome variable in equation (3).

$\alpha, \beta\ and\ \gamma$ are the shares of contributions for $k, l\ and\ m.$ A growth in $\alpha, \beta\ and\ \gamma$ will lead to a growth in output. At the industry level, in the absence of profit, revenue or sales, GDP is a better indicator to measure output in the production function:

$$Y_{it} = A_{it} * K_{it}^{\alpha} * L_{it}^{\beta} * M_{it}^{\gamma} \quad (1)$$

The estimated equation follows this specification:

$$\begin{aligned} &ln\, GDP_{it} \\ &= \delta_0 + \alpha_1 ln\, Capital_{it} + + \beta_2 ln\, Labour_{it} + \gamma_3 ln\, Materials_{it} \\ &+ \varepsilon_{it} \end{aligned} \quad (2)$$

Our empirical specification for TFP in the second stage is as follows:

$$\begin{aligned} &ln\, TFP_{it} = \beta_0 + \beta_1\, ln\, RP_{it} + \beta_2\, ln\, CP_{it} + \beta_3\, ln\, CIC_{it} + \beta_4\, ln\, CIA_{it} + \beta_5\, ln\, FA_{it} + \\ &\beta_6\, ln\, Capital_{it} + \beta_7\, ln\, Labour_{it} + \beta_8\, ln\, Materials_{it} + \\ &industy\, \&\, year\, fixed\, effects_{it} + \varepsilon_{it} \end{aligned} \quad (3)$$

with the independent variables for industry $i, i = 1, \ldots, N$ in time $t, t = 1, \ldots, T$ being, $Resident\ patents_{it}$ (*RP*) and $Cumulative\ Patents_{it}$(*CP*), which measure the knowledge generated and accumulated over time in the country (Caballero and Jaffe, 1993). $CIC_{it}, CIA_{it} and\ FI_{it}$ are vectors, representing *Co-inventors in the country* (*CIC*), *Co-inventors abroad* (*CIA*) and *Foreign inventors* (*FI*) to operationalize domestic and international knowledge diffusion according to the definition by Guellec and van Pottelsberghe de la Potterie (2001).

In addition, we use the application date of granted patents and lag our independent and control variables by three years because of the time lag between an invention and its translation into productivity and to mitigate endogeneity and simultaneity concerns. For the inventor variables, we focus on patent applications due to constraints in the retrieval of respective data for granted inventions. We assigned the number of patents and inventors to the respective sectors using a categorization built in accordance with an expert from the Statistical Office of the GDR (Appendix A1). We additionally provide the robustness of this assignment with regard to the current categorization of market economies by Van Looy et al. (2015) and our results remain stable.

While *Model 1* includes only the control variables, we subsequently add the independent variables of inventorship in *Models 2 – 6* and introduce all indicators of knowledge diffusion (*CIC, CIA, FI*) in *Model 7*. To reduce the multicollinearity effects, we refrain from introducing all types of inventorship in one model. Since knowledge diffusion via collaborations with different types of resident and foreign partners and foreign inventors can emerge at the same time (Hipp, 2021), we jointly introduce these variables in the last model. Control variables are *Labour*, *Capital* and *Materials*. All economic variables are in constant prices to account for potential price developments. Since both systems entail high distortions in their standard price settings, growth and structural comparisons between the GDR and FRG are possible (Dietzenbacher and Wagener, 1999). We express all variables as a natural logarithm in the production and regression equations. Lastly, ε_{it} is the idiosyncratic error term.

4. Results

4.1. Summary statistics

The descriptive statistics and correlations of variables are shown in Tables 2 and A2. Figure A1 shows the development of TFP and resident patents per employee in the GDR over time. We observe a TFP growth in most of the industries over time. Notably, TFP growth is higher in Chemical, Electrical, Metallurgy and Textile sectors, followed by Machinery, Construction and Light sectors, than in Energy, Water and Food sectors.[3]

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ln TFP GDR	200	.144	.234	-.552	.622
ln GDR RP	200	4.997	2.912	0	8.775
ln GDR CP	200	7.137	2.6	0	10.295
ln GDR CIC	200	5.18	3.28	0	10.39
ln GDR CIA	200	5.726	3.305	0	9.499
ln GDR FI	200	4.666	4.935	0	12.221
ln GDR GDP	200	2.208	.947	.128	3.688
ln GDR Capital	200	3.753	.671	2.492	5.284
ln GDR Labour	200	5.453	.974	3.059	6.943
ln GDR Materials	200	1.29	.529	.477	2.439
ln TFP FRG	200	-.074	.6	-6.617	.524
ln FRG RP	200	6.49	3.813	0	11.2
ln FRG CP	200	8.922	3.358	0	12.935
ln FRG CIC	200	7.647	4.403	0	12.472
ln FRG CIA	200	5.725	3.324	0	9.382
ln FRG FI	200	4.512	4.777	0	11.95
ln FRG GDP	200	4.835	.608	3.711	5.991
ln FRG Capital	200	4.966	.798	2.421	6.177
ln FRG Labour	200	6.389	1.185	3.135	7.663
ln FRG Materials	200	5.496	1.012	2.566	6.854

[3] The negative TFP in the sectors of Water and Food can be explained by the substantial increase of capital in the respective years that enhanced the production outcome to such an extent that the production efficiency would have turned negative. This result indicates that production efficiency should be particularly regarded in those sectors that are characterized by high patent activities.

With regard to resident patents per employee, we find slow growth for Chemical, Machinery, Electrical, Energy, Metallurgy, Construction and Food sectors between the mid-1970s to the mid-1980s. On the other hand, all patent and inventor intensities are relatively low in Water, Light and Textile sectors. Furthermore, Figure A2 depicts the development of the number of co-inventors from the same country and abroad as well as the number of foreign inventors per employee in the GDR during our observation period. All three indicators are mainly increasing over time. The number of co-inventors from the same country becomes the highest in the Chemical, Machinery, Electrical and Metallurgy sectors since the late 1970s, followed by Energy, Construction and Food sectors. In addition, the number of co-inventors from abroad is the highest in the Chemical and Metallurgy sectors, followed by Machinery, Electrical, Energy, Construction and Food sectors over time.

Moreover, the number of foreign inventors per employee increases since the late 1970s, particularly in the Chemical, Machinery, Electrical, Metallurgy, Construction and Food sectors, while Energy, Water, Light and Textile sectors only show low changes. It is particularly increasing because some of the patents (e.g. DD000000239348A5) include about 28 foreign inventors from the USSR to take part in international knowledge diffusion in the realm of the COMECON. Foreign inventors had the incentive to name colleagues on the patent who were not involved in the technology development because every inventor received the same remuneration (Lindig, 1995).

4.2. Regression results

We run a set of regressions to test the knowledge-productivity nexus in the GDR, including the baseline model and the model that differentiates the effects by R&D-intensity of industry sectors. In the next sections, we present additional robustness tests and a comparison to the FRG.

Main model

Table 2 reports the OLS regression results, including year and industry fixed effects. *Model 1* only includes the control variables, of which capital has a positive and significant impact on TFP, while labour and materials exert a negative and significant influence in all subsequent models. Considering the observed correlation between knowledge generation, accumulation and diffusion, we introduce each indicator independently from *Models 2 to 6*. While controlling for inputs, we find that resident patents, cumulative patents, co-inventors within a country and foreign countries, and foreign inventors, positively and significantly related to TFP in the industry sectors of the GDR. However, the effects are comparatively low, with a productivity increase of only up to 4 % for each type of inventorship. In *Model 7*, we introduce each type of knowledge diffusion to observe the partial effects. Knowledge diffusion by co-inventors in the same country remains positive and significant. However, knowledge diffusion by co-inventors from abroad and foreign inventors renders insignificant.

Table 3: Baseline model for TFP in the GDR

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)
VARIABLES (GDR)	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP
ln_RP_3		0.042***					
		(0.010)					
ln_CP			0.112**				
			(0.047)				
ln_CIC_3				0.040***			0.044**
				(0.008)			(0.019)
ln_CIA_3					0.032***		-0.010
					(0.009)		(0.017)
ln_FI_3						0.018***	0.005
						(0.005)	(0.006)
ln_Capital	0.750***	0.500***	0.383***	0.504***	0.559***	0.433***	0.529***
	(0.137)	(0.142)	(0.138)	(0.142)	(0.156)	(0.144)	(0.145)
ln_Labour	-1.101***	-0.950***	-0.889***	-0.954***	-0.976***	-0.840***	-0.952***
	(0.153)	(0.149)	(0.143)	(0.149)	(0.160)	(0.153)	(0.153)
ln_Materials	-0.165***	-0.156***	-0.141***	-0.156***	-0.161***	-0.162***	-0.162***
	(0.049)	(0.047)	(0.045)	(0.047)	(0.048)	(0.046)	(0.047)
Constant	3.201***	3.137***	3.137***	3.144***	2.460***	2.830***	3.077***
	(0.743)	(0.706)	(0.675)	(0.706)	(0.795)	(0.702)	(0.718)
Observations	200	200	200	200	200	200	200
R-squared	0,845	0,861	0,873	0,861	0,85	0,864	0,857
RMSE	0,816	0,834	0,849	0,834	0,821	0,838	0,829
Adj R^2	0,1	0,095	0,091	0,095	0,099	0,094	0,097
F-stat	29.54***	32.337***	35.892***	32.294***	29.61***	33.193***	31.152***
ll	193,737	204,672	213,717	204,558	197,135	206,927	201,467
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Heterogeneity of industry sectors in terms of R&D intensity

The effect of investments and technology on the likelihood of innovation varies across sectors (Morris, 2018). In particular, low-tech sectors characterized by low average R&D intensity are essential for knowledge generation, diffusion and use and thus economic growth because of their specialized-supplier and scale-intensive character (Hauknes and Knell, 2009). To investigate differences in the effect of inventorship on productivity, we split our sample into non-R&D and R&D sectors.[4] In the GDR, low-tech or non-R&D sectors such as Metallurgy, Construction and Textile were the focus of Stalin's model of industrialization. For these sectors, we find that the coefficients for all types of inventorship remain positive and significant, except for knowledge diffusion by foreign inventors (see Table A3). The size-effect for knowledge generation by resident patents and knowledge diffusion by co-inventors in the same country and abroad even increases. Only knowledge diffusion by co-inventors abroad remains positive and significant in the full model. While materials remain negative and significant, capital and labour become insignificant in most models, which can be explained by the necessity of investments, particularly in GDR's low-R&D sectors, as well as below-average capital resources and labour migration (Hipp et al., 2022b).

4.3. Robustness tests

We perform several robustness tests, including GDP as a dependent variable, different lag structures, alternative productivity measures, an exclusive focus on '*Ausschließungspatente*', non-linear estimations and an alternative assignment approach of patents to the industry sectors in the GDR. First, using GDP as a dependent variable (Table B1), we observe stable results identical to estimations in Table 3. The coefficients of all types of inventorship are positive and highly significant, except for cumulative patents. In the second set of robustness tests, we lag our dependent variable (TFP) by one year (Table B2). The coefficients remain positive and significant, and their effect increases in all models, except for co-inventors from the same country that become insignificant in the full model. Third, we use an alternative explanatory measure, i.e. patents and inventors per employee, which is commonly used in the innovation-productivity literature to measure the impact of knowledge intensity (Crepon et al., 1998). The results remain robust but decrease in their size-effect for all types of inventorship (Table B3, Models 1-7). In addition, we apply the Levinsohn and Petrin (2003) production function to test for consistency and the results are identical, except for the coefficient of cumulative patents that becomes insignificant. Moreover, the results remain stable when excluding the input factors capital, labor and materials from the second-stage estimation[5].

[4] We refrain from estimating the productivity effects for R&D-high sectors only (i.e. Chemicals, Electrical and Machinery) because they produce only 60 observations in sum, on basis of which we cannot perform a reliable regression.

[5] Results are available upon request.

Fourth, when testing only for '*Ausschließungspatente'*, i.e., the patents for which mostly foreign inventors from Western countries applied, we observe productivity-enhancing effects, which, however, decrease in their size-effect over time (single models). They are also observable as other types of knowledge diffusion are present in the same year but not over time (full models) (Table B4). Our fifth set of robustness tests estimates potential non-linearity effects to relax the monotonicity effect and we use an alternative assignment approach of patents to the GDR industry sectors based on the classification by Van Looy et al. (2015) to detect possible changes in the patent-productivity nexus. However, the results hold (Table B3, Model 8).

4.4. Comparison to West Germany

Finally, we compare the results from the GDR to FRG. First, the descriptive statistics show that the TFP per employee in the FRG is higher in Machinery, Construction, Water, Light and Food sectors compared to the GDR, which has a higher TFP in Chemicals, Electrical, Energy, Metallurgy and Textile sectors. The FRG has a higher patent intensity in Chemical, Machinery, Electrical, Energy, Metallurgy, Construction and Food sectors, which increased to a larger extent than in the GDR over time. It is equally low for both countries in Water, Light and Textile sectors.

Moreover, the number of co-inventors inside the country per employee is higher in Chemical, Machinery, Electrical, Energy, Metallurgy and Food sectors and similarly low in Construction, Water, Light and Textile sectors in the FRG compared to the GDR. On the other hand, the number of co-inventors from foreign countries per employee is lower in the FRG for Chemical, Machinery, Electrical, Metallurgy, Construction and Food sectors and equally low for Energy, Water, Light and Textile sectors in the GDR. Similar trends exist for the number of foreign inventors per employee, yet, the gap between the GDR and FRG is substantially increasing over time.

With regard to the statistical analysis, we retrieved data on the total number of patent grants from inventors residing in the country (i.e., resident patents) to proxy the possible number of '*Wirtschaftspatente'* as a quasi-experiment setting for the FRG (Table B5). By using the productivity and inventorship data described above, we find the expected positive and significant effects for all types of inventorship on TFP in the industry sectors of the FRG.

5. Discussion and conclusion

This study provided novel evidence on the productivity effects of knowledge generation, accumulation and diffusion in the GDR as a Soviet-type economy. We developed a set of hypotheses based on an innovation systems approach (Radosevic, 1999, 2022; von Tunzelmann et al., 2010; Hipp et al., 2021), which we tested using industry-level data from the GDR between 1970 and 1989. In the GDR, industrialization focused primarily on heavy industries (e.g., Metallurgy and Construction) and key sectors of technical progress (e.g., Chemicals and Electricity). These are the sectors in which our descriptive analysis showed a comparatively large TFP. However, we found only slow growth in resident patents and co-inventors in the GDR for most sectors, while the number of co-inventors from abroad and foreign inventors was particularly high in Chemical, Machinery, Electrical, Metallurgy, Construction and Food sectors in the GDR.

Our findings showed that the number of resident patents positively impacts sectoral TFP, a finding that remains robust across all model specifications, supporting our Hypothesis 1 that knowledge generation positively affects sectoral productivity in the GDR. This is an important finding that challenges previous research highlighting the inferiority of Soviet-type economies to Western market economies in terms of innovation and productivity (Bergson, 1987; Chiang, 1990; Vonyó and Klein, 2019). Our evidence suggests the existence of a nexus between knowledge generation and productivity in Soviet-type economies despite manifold constraints. This could point to different explanations, including the individual motivation and incentives for employees to deploy inventions in production processes (Roesler, 1992) or systemic elements such as a relatively high share of R&D personnel (Meske, 1993) and the focus of the education policy (Kogut and Zander, 2000). These effects are particularly strong for R&D-low sectors such as Metallurgy, being the driver of Stalin's model of industrialization.

Moreover, we observe productivity-enhancing effects from knowledge accumulation, measured by the cumulative number of patents, in the industry sectors of the GDR (Hypothesis 2). Knowledge accumulation is a path-dependent and long-term process. Changing centrally coordinated research priorities in line with focused economic planning objectives might disrupt knowledge accumulation and limit the effect on productivity by diverting resources in particular technologies independent from existing knowledge and progress towards the technological frontier. These obstacles to innovation seem to have no effect on productivity in the industry sectors of the GDR, even though research priorities dramatically changed for key sectors over time (Ludwig, 2017; Augustine, 2020).

In addition, we observe positive effects of knowledge diffusion by co-inventorship in the same country (Hypothesis 3) but inconsistent effects from co-inventorship from abroad (Hypothesis 4) and foreign inventors across our models (Hypothesis 5). This implies that productivity gains were indeed a result of knowledge diffusion inside the GDR, but not necessarily from international knowledge transfer and inflow, provided that local interactive capabilities were present in the industry sectors of the GDR. Nonetheless, previous research argued that the foreclosure to international scientific communities limited access to international markets and constrained knowledge inflows limited international knowledge diffusion in the GDR and other Soviet-type economies (Gläser and Meske, 1996; von Tunzelmann et al., 2010; Ludwig, 2017), in contrast to market economies (Miguelez and Morrison, 2022; Miguelez and Noumedem Temgoua, 2020). Furthermore, concerning the COMECON, cooperation was complicated in its design and bureaucracy through institutional inequalities and often resulted in a formalized necessity rather than an opportunity for technology co-development (Kochetkova, 2021). Besides, the COMECON often opposed collaborative programs or came with a dysfunctional division of labour (Lindig, 1995). We can partly support these findings with regard to their missing effects on productivity in the industry sectors of the GDR in some of our specifications. This means that knowledge diffusion by international (co-)inventors did not increase the efficiency of production when knowledge diffusion by resident inventors worked in the industry sectors of the GDR. Yet, additional estimations indicate that this does not hold for '*Ausschließungspatente*', meaning that protected knowledge inflows from Western countries indeed affected productivity gains in the industry sectors in any case, which points to patent infringement in the GDR (Hinze and Grupp, 1995).

Moreover, a comparison to West Germany reveals that the GDR had a higher TFP in five of ten industry sectors (i.e., Chemicals, Electrical, Energy, Metallurgy and Textile). This is in contrast to former studies (Glitz and Meyersson, 2020), which, however, used a different estimation approach and did not include original primary data on capital assets and knowledge indicators by inventorship. However, patent and collaborative intensities inside the GDR were much lower than in the FRG. Only knowledge diffusion by collaborations with inventors abroad and foreign inventors was higher in those sectors in which the GDR needed respective know-how (i.e. Chemical, Machinery, Electrical, Metallurgy, Construction and Food sectors). The regression analysis confirms that productivity gains were achieved by knowledge generation, accumulation and diffusion in the FRG, as previously observed by numerous scholars for market economies in general (e.g., Baum et al., 2018). Contemporarily, patents in Western countries have another function, i.e., to protect knowledge from inventive activity (Griliches, 1990). This knowledge protection mechanism produced adequate incentives to generate and deploy patents in the production process, but we also observed similar positive effects concerning productivity gains from the Soviet-type patent system in the industries of the GDR.

Our study contributes to the literature on productivity, innovation and the history of the socialist economy. Unlike related studies (e.g., Santarelli and Lotti, 2008; Baum et al., 2018), our research extends the scope of the patent-productivity nexus by investigating the role of knowledge generation, accumulation and diffusion for productivity gains in a Soviet-type economy. This is the first study to estimate the patent-productivity nexus for the GDR while accounting for important knowledge synergies, thereby extending previous studies on the socialist system (Ritschl and Vonyò, 2014; Vonyó and Klein, 2019). Furthermore, we provide insights into the innovation system of a socialist planned economy, which, concerning the configuration and blockades of inventorship, worked with regard to efficiency increases in the production of the industry sectors.

Our findings underline that knowledge generation, accumulation and diffusion by resident co-inventors positively affected sectoral productivity in the GDR. This supports the claim that the successful application of knowledge in the industry was possible in Soviet-type planned economies, even though the focus was on key industries (Augustine, 2020). Thus, in Soviet-type economies, industries could gain significantly from the generation, accumulation and cross-fertilization of planned knowledge inside the country. However, this does not apply in every case for international knowledge diffusion, particularly when sufficient local interactive capabilities were present in the industry sectors of the GDR.

While we investigated the productivity-related effects of inventorship in a socialist system, some research on the quality of these knowledge flows needs to be done in future. It was claimed that the contents of socialist patents were of lower quality, but evidence on this phenomenon is scarce. Patent citations or text analysis could help to identify leading-edge research (Acosta et al., 2021) and estimate their impact after the economic transformation into a market system. Moreover, patents only proxy codified knowledge, but tacit knowledge and competencies can also contribute to productivity gains. Future studies could find proxies for other kinds of human capital, such as employee qualifications, to understand better their role in a socialist system of production and innovation.

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Appendix A

Figure A1: TFP and number of resident patents per employee in the GDR and FRG (1970-1989)

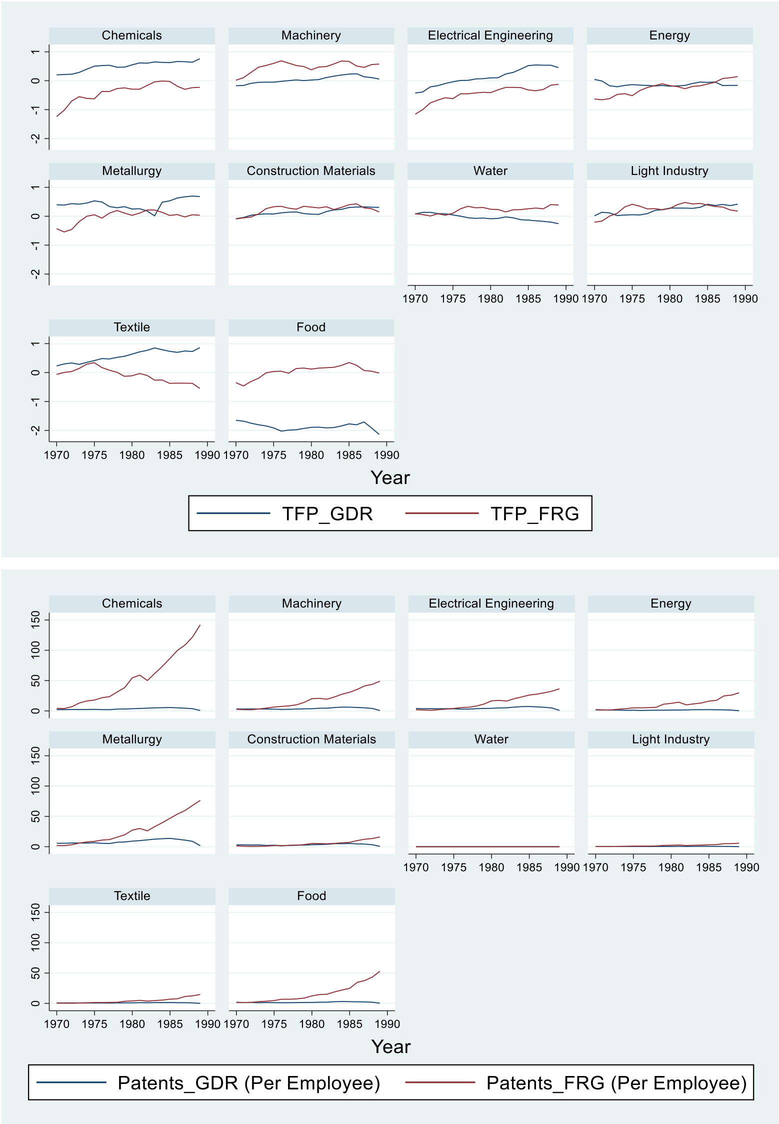

Figure A2: Number of co-inventors in the same and foreign countries and foreign inventors per employee in the GDR and FRG (1970 – 1989)

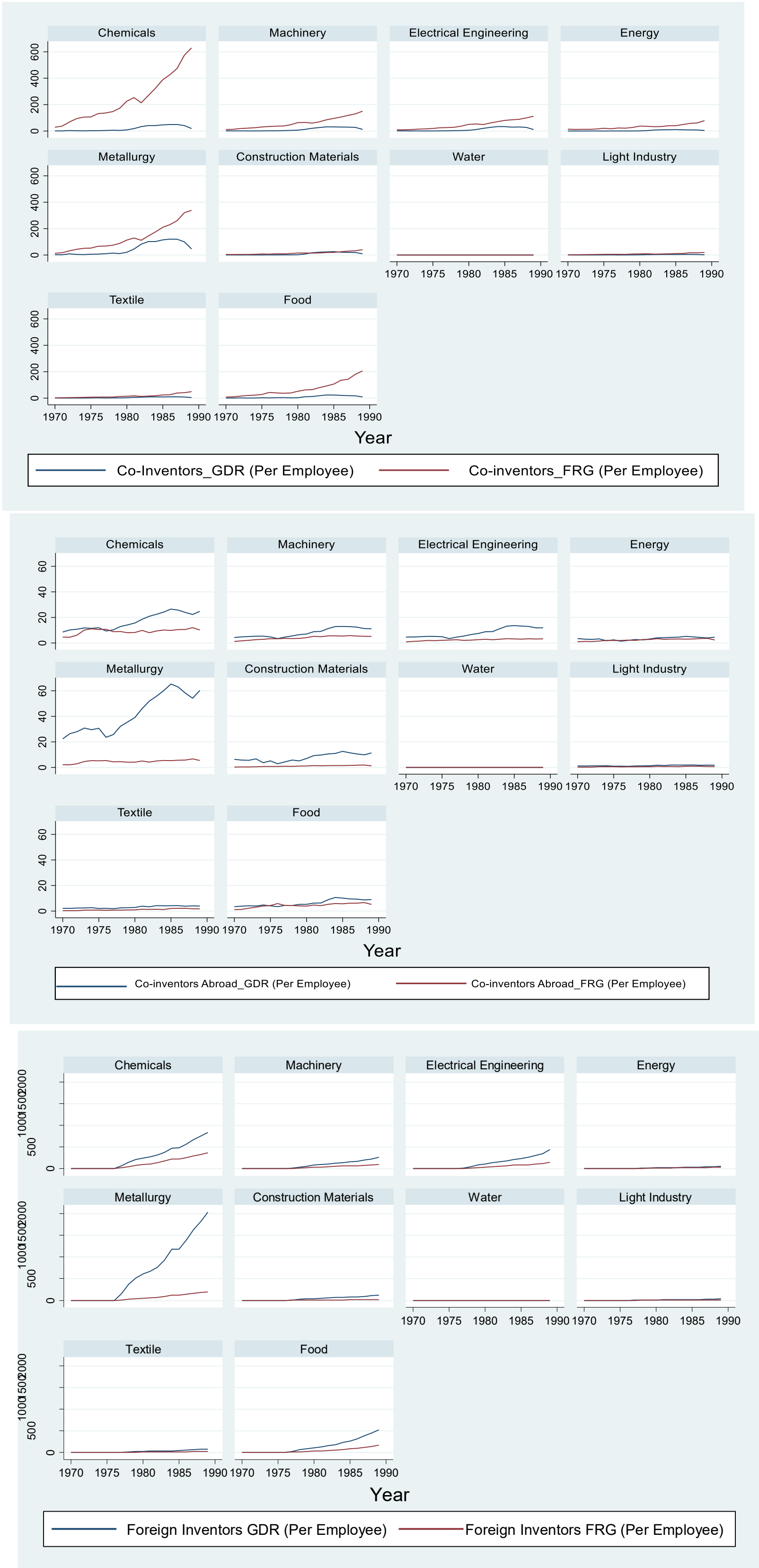

Table A1: Classification of patents and sectors

Patent classification	Assignment to the industry
A Human necessities	Human necessities
B Performing Operations; Transporting	Machinery and vehicle construction
C Chemistry; Metallurgy	Chemistry; Metallurgy
D Textiles; Paper	Textiles; Light industry
E Fixed Constructions	Construction materials/Energy and fuel
F Mechanical Engineering; Lighting; Heating; Weapons; Blasting	Machinery and vehicle construction
G Physics	Electrical, electronic, apparatus engineering/Machinery and vehicle construction
H Electricity	Electrical, electronic, apparatus engineering

Table A2: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
ln_TFP_GDR	1																		
ln_GDR_RP	0.370***	1																	
ln_GDR_CP	0.305***	0.746***	1																
ln_GDR_CIC	0.489***	0.938***	0.708***	1															
ln_GDR_CIA	0.419***	0.994***	0.736***	0.947***	1														
ln_GDR_FI	0.432***	0.594***	0.472***	0.776***	0.610***	1													
ln_GDR_GDP	0.395***	0.453***	0.522***	0.463***	0.443***	0.354***	1												
ln_GDR_Capital	-0.088	0.368***	0.276***	0.417***	0.370***	0.426***	0.543***	1											
ln_GDR_Labour	0.132*	0.545***	0.825***	0.511***	0.520***	0.294***	0.572***	0.327***	1										
ln_GDR_Material	-0.194***	0.343***	0.333***	0.335***	0.332***	0.298***	0.593***	0.929***	0.414***	1									
ln_TFP_FRG	0.093	0.162**	-0.108	0.177**	0.164**	0.157**	-0.054	0.057	-0.081	-0.028	1								
ln_FRG_RP	0.434***	0.980***	0.730***	0.967***	0.989***	0.697***	0.431***	0.401***	0.509***	0.344***	0.175**	1							
ln_FRG_CP	0.410***	0.797***	0.971***	0.804***	0.804***	0.609***	0.498***	0.333***	0.762***	0.343***	-0.043	0.820***	1						
ln_FRG_CIC	0.426***	0.985***	0.727***	0.950***	0.996***	0.638***	0.414***	0.372***	0.509***	0.324***	0.171**	0.995***	0.810***	1					
ln_FRG_CIA	0.405***	0.984***	0.730***	0.939***	0.993***	0.606***	0.398***	0.367***	0.524***	0.327***	0.172**	0.989***	0.807***	0.996***	1				
ln_FRG_FI	0.431***	0.596***	0.474***	0.779***	0.612***	1.000***	0.355***	0.428***	0.296***	0.301***	0.157**	0.699***	0.611***	0.639***	0.607***	1			
ln_FRG_GDP	0.230***	-0.013	-0.078	0.011	-0.007	0.016	-0.061	-0.432***	-0.040	-0.471***	0.448***	-0.008	-0.062	0.000	-0.019	0.012	1		
ln_FRG_Capital	0.093	0.637***	0.871***	0.598***	0.638***	0.414***	0.488***	0.516***	0.723***	0.546***	0.010	0.639***	0.865***	0.637***	0.636***	0.415***	-0.087	1	
ln_FRG_Labour	0.307***	0.552***	0.892***	0.518***	0.544***	0.286***	0.380***	-0.030	0.846***	0.054	-0.038	0.530***	0.843***	0.537***	0.548***	0.288***	0.143**	0.736***	1
ln_FRG_Material	0.333***	0.418***	0.738***	0.398***	0.424***	0.250***	0.381***	-0.049	0.644***	0.004	0.019	0.416***	0.712***	0.424***	0.410***	0.248***	0.478***	0.716***	0.810***

Table A3: The impact of inventorship on productivity (Non-R&D sectors)

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)
VARIABLES (GDR)	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP
ln_RP_3		0.064**					
		(0.031)					
ln_CP			0.076**				
			(0.030)				
ln_CIC_3				0.056***			0.041
				(0.017)			(0.039)
ln_CIA_3					0.065***		0.102*
					(0.021)		(0.056)
ln_FI_3						0.010	-0.068***
						(0.014)	(0.022)
ln_Capital	-0.020	-0.042	-0.017	-0.042	-0.058	-0.028	-0.038
	(0.080)	(0.080)	(0.080)	(0.079)	(0.079)	(0.076)	(0.077)
ln_Labour	0.037	0.063*	0.033	0.062*	0.075**	0.029	0.058*
	(0.030)	(0.032)	(0.031)	(0.032)	(0.033)	(0.029)	(0.029)
ln_Materials	-0.275***	-0.259***	-0.273***	-0.259***	-0.244**	-0.251***	-0.257***
	(0.096)	(0.095)	(0.096)	(0.095)	(0.094)	(0.092)	(0.092)
Constant	0.204	0.119	0.210	0.119	-0.352	0.247	0.127
	(0.224)	(0.225)	(0.225)	(0.225)	(0.313)	(0.214)	(0.216)
Observations	120	120	120	120	120	120	120
R-squared	0,555	0,573	0,557	0,574	0,582	0,6	0,595
RMSE	0,454	0,471	0,451	0,472	0,482	0,504	0,499
Adj R^2	0,165	0,162	0,165	0,162	0,16	0,157	0,158
F-stat	5.505***	5.606***	5.244***	5.619***	5.818***	6.262***	6.144***
ll	58,894	61,369	59,105	61,449	62,653	65,262	64,579
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix B

Table B1: The impact of inventorship on GDP

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)
VARIABLES	ln_GDP	ln_GDP	ln_GDP	ln_GDP	ln_GDP	ln_GDP	ln_GDP
ln_RP_3		0.033***					
		(0.011)					
ln_CP			0.072				
			(0.052)				
ln_CIC_3				0.030***			0.037*
				(0.009)			(0.021)
ln_CIA_3					0.024**		-0.010
					(0.010)		(0.020)
ln_FI_3						0.012**	0.002
						(0.006)	(0.007)
ln_Capital	0.980***	0.784***	0.654***	0.787***	0.858***	0.740***	0.815***
	(0.150)	(0.160)	(0.157)	(0.160)	(0.174)	(0.164)	(0.163)
ln_Labour	-1.153***	-1.036***	-0.965***	-1.039***	-1.074***	-0.957***	-1.042***
	(0.168)	(0.168)	(0.163)	(0.168)	(0.177)	(0.174)	(0.172)
ln_Materials	0.360***	0.367***	0.381***	0.368***	0.363***	0.363***	0.363***
	(0.054)	(0.053)	(0.051)	(0.053)	(0.054)	(0.052)	(0.053)
Constant	3.817***	3.767***	3.760***	3.772***	3.345***	3.536***	3.724***
	(0.816)	(0.796)	(0.768)	(0.797)	(0.883)	(0.798)	(0.805)
Observations	200	200	200	200	200	200	200
R-squared	0,989	0,989	0,99	0,989	0,989	0,989	0,989
RMSE	0,987	0,987	0,988	0,987	0,987	0,987	0,987
Adj R^2	0,11	0,107	0,104	0,107	0,11	0,107	0,108
F-stat	470.488***	478.49***	514.832***	478.214***	458.285***	481.553***	469.398***
ll	175,121	180,519	187,763	180,462	176,252	181,15	178,621
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B2: The impact of inventorship on productivity (Lag by one year)

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)
VARIABLES (GDR)	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP
ln_RP_1		0.155***					
		(0.031)					
ln_CP			0.175***				
			(0.050)				
ln_CIC_1				0.058***			0.028
				(0.015)			(0.021)
ln_CIA_1					0.196***		0.088
					(0.049)		(0.075)
ln_FI_1						0.021***	0.008
						(0.006)	(0.008)
ln_Capital	0.566***	0.451***	0.527***	0.450***	0.269	0.378**	0.340**
	(0.150)	(0.145)	(0.154)	(0.142)	(0.169)	(0.151)	(0.155)
ln_Labour	-0.696***	-0.807***	-0.690***	-0.851***	-0.502***	-0.539***	-0.664***
	(0.168)	(0.162)	(0.168)	(0.160)	(0.172)	(0.166)	(0.161)
ln_Materials	-0.095*	-0.085*	-0.092*	-0.097*	-0.089*	-0.101*	-0.103**
	(0.054)	(0.051)	(0.054)	(0.050)	(0.052)	(0.052)	(0.052)
Constant	1.820**	1.604**	1.700**	1.939**	0.668	1.335*	1.029
	(0.815)	(0.777)	(0.822)	(0.764)	(0.857)	(0.791)	(0.806)
Observations	200	200	200	200	200	200	200
R-squared	0,804	0,824	0,805	0,829	0,817	0,821	0,821
RMSE	0,768	0,79	0,768	0,796	0,782	0,786	0,786
Adj R^2	0,11	0,105	0,11	0,103	0,106	0,105	0,105
F-stat	22.207***	24.357***	21.576***	25.288***	23.299***	23.87***	23.895***
ll	175,248	185,838	175,963	188,938	182,196	184,18	184,266
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B3: The impact of inventorship on productivity (alternative measures)

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)	(Model 8)
VARIABLES (GDR)	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP	ln_TFP
ln_RP_3		0.033***						0.056***
		(0.009)						(0.009)
ln_CP			0.005***					
			(0.002)					
ln_CIC_3				0.002***			0.010***	
				(0.001)			(0.002)	
ln_CIA_3					0.005***		-0.007	
					(0.002)		(0.008)	
ln_FI_3						0.000*	-0.001***	
						(0.000)	(0.000)	
ln_Capital	0.057	0.067	0.047	0.065	0.056	0.050	0.057	0.383***
	(0.073)	(0.070)	(0.065)	(0.070)	(0.071)	(0.069)	(0.071)	(0.138)
ln_Labour	0.095***	0.102***	0.097***	0.103***	0.092***	0.103***	0.101***	-0.889***
	(0.034)	(0.033)	(0.030)	(0.032)	(0.033)	(0.032)	(0.033)	(0.143)
ln_Materials	-0.093	-0.151**	-0.141**	-0.149**	-0.118*	-0.133**	-0.128*	-0.141***
	(0.065)	(0.064)	(0.058)	(0.064)	(0.064)	(0.063)	(0.065)	(0.045)
Constant	0.105*	0.003	-0.053	-0.007	0.070	0.089*	0.072	3.137***
	(0.056)	(0.061)	(0.056)	(0.061)	(0.055)	(0.053)	(0.056)	(0.675)
Observations	153	153	153	153	153	153	153	200
R-squared	0,862	0,875	0,893	0,875	0,871	0,876	0,869	0,873
RMSE	0,832	0,846	0,868	0,847	0,841	0,848	0,84	0,849
Adj R^2	0,097	0,093	0,086	0,092	0,094	0,092	0,095	0,091
F-stat	28.9***	30.87***	36.805***	31.112***	29.793***	31.186***	29.449***	35.892***
ll	155,427	162,757	174,646	163,279	160,387	163,439	159,615	213,717
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B4: The impact of Ausschließungspatente on productivity

	(1)		(2)		(3)		(4)
VARIABLES	Current		1-year lag		2-year lag		3-year lag
ln_Ausschließungspatent	0.104***	0.079***	0.037**	0.010	0.031**	0.001	0.027**
	(0.029)	(0.029)	(0.016)	(0.017)	(0.013)	(0.017)	(0.011)
ln_CIC_3		0.038**		0.050***		0.051***	
		(0.016)		(0.016)		(0.016)	
ln_CIA_3		-0.004		-0.016		-0.014	
		(0.017)		(0.017)		(0.019)	
ln_Capital	0.710***	0.439***	0.675***	0.435***	0.635***	0.436***	0.615***
	(0.132)	(0.141)	(0.139)	(0.145)	(0.143)	(0.145)	(0.146)
ln_Labour	-1.301***	-1.020***	-1.154***	-0.858***	-1.111***	-0.831***	-1.074***
	(0.158)	(0.166)	(0.153)	(0.162)	(0.151)	(0.161)	(0.151)
ln_Materials	-0.187***	-0.179***	-0.168***	-0.163***	-0.165***	-0.162***	-0.165***
	(0.048)	(0.046)	(0.048)	(0.046)	(0.048)	(0.046)	(0.048)
Constant	3.780***	3.299***	3.659***	2.915***	3.558***	2.785***	3.432***
	(0.735)	(0.717)	(0.759)	(0.745)	(0.747)	(0.743)	(0.739)
Observations	200	200	200	200	200	200	200
R-squared	0.856	0,871	0.85	0,865	0.85	0,865	0.85
RMSE	0.097	0,844	0.099	0,837	0.099	0,837	0.099
Adj R^2	0.829	0,092	0.821	0,094	0.822	0,094	0.821
F-stat	31.081***	32.663***	29.544***	31.08***	29.648***	31.006***	29.619***
ll	201.273	211,834	196.946	207,523	197.244	207,318	197.161
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B5: The impact of Wirtschaftspatente on productivity in the FRG

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)	(Model 7)
VARIABLES	TFP_FRG	TFP_FRG	TFP_FRG	TFP_FRG	TFP_FRG	TFP_FRG	3-year lag
ln_RP_3		0.095***					
		(0.032)					
ln_CP			0.237***				
			(0.086)				
ln_CIC_3				0.081***			0.266*
				(0.028)			(0.142)
ln_CIA_3					0.086**		-0.276
					(0.036)		(0.175)
ln_FI_3						0.065***	0.034
						(0.021)	(0.026)
ln_Capital	1.002*	1.330**	1.403**	1.280**	1.148*	1.606***	1.768***
	(0.588)	(0.585)	(0.595)	(0.584)	(0.583)	(0.607)	(0.614)
ln_Labour	0.599	0.489	0.554	0.501	0.578	0.342	0.209
	(0.629)	(0.615)	(0.617)	(0.616)	(0.620)	(0.619)	(0.622)
ln_Materials	-0.219	-0.189	-0.283	-0.153	-0.160	-0.347	-0.256
	(0.254)	(0.248)	(0.250)	(0.249)	(0.251)	(0.251)	(0.255)
Constant	-7.006***	-7.983***	-9.650***	-8.075***	-7.900***	-7.252***	-7.802***
	(2.554)	(2.516)	(2.680)	(2.528)	(2.547)	(2.494)	(2.505)
Observations	200	200	200	200	200	200	200
R-squared	0,527	0,552	0,548	0,55	0,543	0,553	0,565
RMSE	0,449	0,438	0,44	0,439	0,443	0,438	0,435
Adj R^2	0,44	0,466	0,462	0,464	0,455	0,467	0,475
F-stat	6.05***	6.425***	6.335***	6.375***	6.201***	6.446***	6.297***
ll	-106,142	-100,856	-101,639	-101,292	-102,805	-100,681	-97,93
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Imprint

Bremen Papers on Economics & Innovation

Published by
University of Bremen, Faculty of Business Studies & Economics,
Institute for Economic Research and Policy (ierp)
Max-von-Laue-Straße 1, 28359 Bremen, Germany

Bremen Papers on Economics & Innovation #2301

Responsible Editor: Prof. Dr. Michael Rochlitz

ISSN 2629-3994