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Overcoming barriers to technology transfer: empirical evidence from the German Democratic Republic

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Abstract

This paper provides empirical evidence on a special case of restricted technology transfer: the German Democratic Republic (GDR) characterized by a socialist innovation system with a supply-side-oriented technology-push model encompassing intellectual property rights protection partially distinct from the one employed in most market economies. We exploit the natural experiment setting of the formerly separated regions in Germany and compare the productivity effects of knowledge generation, accumulation, and diffusion in the GDR with those of the Federal Republic of Germany (FRG) between 1970 and 1989. By applying a Cobb–Douglas production function to original primary and harmonized productivity data and manually cleaned patent data, we show that knowledge generation, accumulation and diffusion contributed to sectoral productivity in the GDR similarly compared to the FRG, despite the institutional misalignments in the socialist innovation system. We explain these findings and provide implications for present organizations with regard to incentive schemes for patenting, the support of personal creativity and education, and alternative technology transfer mechanisms in case of institutional barriers to innovation.

Keywords Incentives to patent · Technology transfer · Barriers to innovation · Productivity · GDR

JEL Classification O31 · O34 · O14 · P23

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1 Introduction

Effective knowledge and technology transfer between organizations is essential to achieve innovation and economic growth (O'Dwyer et al., 2023). In recent years, enablers and barriers to technology transfer have received particular attention (Barros et al., 2020; Bengoa et al., 2021). However, while research mostly focused on single policies or organizational measures to overcome these barriers (e.g., ibid.; Grimaldi et al., 2011; Siegel et al., 2007), less is known about institutional factors in the systems of innovation that affect knowledge and technology transfer. Especially in less open economies like former and present socialist states, the increased barriers to technology transfer impact the extent of knowledge generation and diffusion, calling for alternative channels of knowledge sourcing (Wang et al., 2017).

Pre-1990 socialist states such as the People's Republic of China, the Union of Soviet Socialist Republics, and member states of the Council for Mutual Economic Assistance (Comecon) including the German Democratic Republic (GDR) were characterized as inferior to Western market economies in terms of innovation and productivity (Bergson, 1987; Chiang, 1990; Vonyó & Klein, 2019). Although socialist planned economies generated new knowledge and inventions, technologies emerged from innovation systems that suffered from institutional misalignments, barriers to technology transfer and dependency on espionage (Glitz & Meyersson, 2020; Hipp et al., 2022b, 2024; Radosevic, 1999, 2022; von Tunzelmann et al., 2010). So far, we have no evidence on the effects of knowledge generation, accumulation and diffusion on productivity in former socialist economies. In contrast, for market economies, there is ample evidence that the application of new or improved technologies, based upon knowledge generation processes, increases productivity (e.g., O'Mahony & Vecchi, 2009; Venturini, 2015).

Socialist systems used specific institutions related to coordination via economic planning to stimulate inventorship and productivity. The GDR, for example, developed a supply-side-oriented linear technology-push model, whereby planned production defined science objectives, even in basic research (Meske, 1993). In addition, enterprises or research institutes within large conglomerates (*Kombinate*) engaged in applied industrial research and development (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 rather than the inventor held exploitation rights granted by an economic patent (*Wirtschaftspatent*), with the inventor receiving one-off financial compensation and social rewards (Lindig, 1995; Wiessner, 2015). The GDR nevertheless complied with international IP practices by offering another type of patent—called an exclusive patent (*Ausschließungspatent*)—mostly 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 (Glitz & Meyersson, 2020; Wiessner, 2015).

The present study investigates the effects 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 & Meyersson, 2020), we use original primary production, labor, capital and investment data (see Stäglin & Ludwig, 2000) and 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 at the sectoral level for ten industries. In addition, we provide a comparison with the Federal Republic of Germany (FRG) to make use of the conditions of a natural experiment setting (Kogut & Zander, 2000), given that Germany was a pioneer in several technological fields before the Second World War, after which two innovation systems with distinct coordination mechanisms and framework conditions emerged (Ritschl & Vonyò, 2014). From our findings we derive implications for decision-makers in present socialist and market economies to overcome institutional and regulatory barriers to innovation via incentive schemes, the support of personal creativity and education, and alternative technology transfer mechanisms to increase economic productivity.

This paper is structured as follows. Section 2 presents a theoretical background on productivity and inventorship in market and socialist economies and develops hypotheses regarding the productivity effects of inventorship in a system with institutional impediments. Section 3 describes the data and methodology. Section 4 presents our descriptive and regression results. Section 5 discusses the findings, and Sect. 6 concludes.

2 Theory and hypothesis development

2.1 Productivity and inventorship in a market economy

Productivity is commonly used to measure the economic performance of a region (Hulten & Schwab, 1984), firm (Griliches & Mairesse, 1983), or plant (Lichtenberg, 1992) and concerns the relation between input factors and produced output. Typical input factors are labor, capital and knowledge (Griliches, 1979). Because knowledge is an intangible good, it is often proxied by patented inventions (Acs et al., 2002; Baum et al., 2018). 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, the filing of a patent application and the use of an invention in production processes (Acs et al., 2002). For example, the deployment of patented inventions can accelerate manufacturing processes and make production more efficient (Baum et al., 2018; Bloom & Van Reenen, 2002). Before the first industrial revolution, production technologies such as bloomery furnaces enabled the melting and alloying of metals to process components within the industry. Firms' productivity has since been enhanced by the introduction of steam engines based on coal-fueled machine tools for producing goods, and today, flexible automatization based on microelectronics such as chips or robotics (Domini et al., 2021). For a market economy, there is substantial empirical evidence regarding the productivity-enhancing effects of knowledge generation via patented inventions (e.g., Baum et al., 2018; Bloom & Van Reenen, 2002).

Inventorship can be categorized along a continuum from knowledge generation to accumulation to diffusion. Once generated, other inventions build on this previous knowledge, which then accumulates, even though parts of it can become obsolete (Caballero & Jaffe, 1993). Knowledge accumulation can, therefore, be understood as the collection of a body of knowledge gathered in an industry over time (Chandra & Dong, 2018). Empirical studies show that knowledge accumulation increases firm performance and productivity (e.g., Cassidy et al., 2005; Yu et al., 2015). Before knowledge accumulates, it must be absorbed and used by different agents before it diffuses geographically (Chandra & Dong, 2018). For instance, a team of inventors or co-inventors diffuses knowledge in specific areas (Hussler & Rondé, 2007). In this context, foreign inventors might be decisive sources for the diffusion of novel knowledge from abroad to their home country (Kerr & Kerr, 2018; Miguelez

& Noumedem Temgoua, 2020). With regard to knowledge diffusion, Tubiana et al. (2022) observe that interaction among co-inventors in European metropolitan areas shapes the productivity of inventors. Furthermore, Akcigit et al. (2017) have found that the productivity of immigrant inventors is higher than that 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 contributes to productivity in a socialist system remains an open question. Socialist economies are known for their system blockades and steadily decreasing economic growth (Lavigne, 1995). The USSR, Poland, GDR, Czech Republic, Slovakia, Hungary, Romania 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 labor was divided between the countries of the Comecon, which nevertheless came with certain dependency, cost and coordination problems (Lavigne, 1983). Central planning also showed its limitations early on: plans were not fulfilled, there was no competition in the market, and there was high demand for the importation of resources (Gleitze, 1975).

Technical progress and inventorship were important in socialist economies, including the GDR, for reaching central planning goals and keeping pace with the Western states (Glitz & Meyersson, 2020; Hipp et al., 2024; Lindig, 1995). They were also documented through the patent output of these countries (Hemmerling, 1986). Among the socialist planned economies, the GDR was the role model with one of the largest growth rates (Lavigne, 1995). Recent studies argue that the degree of technical progress in the GDR should not be underestimated. For instance, Hipp et al. (2024) underline the importance of technical progress in the GDR, as evidenced by a larger share of investment in the capital stock of R&D-intensive industries as a percent of GDP compared to West Germany (1970–1989). Glitz and Meyersson (2020)[1] highlight another aspect by showing that industrial espionage led to significantly narrowing the sectoral TFP gap between West Germany and the GDR (1970–1989). 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 and diffusion, as well as their contribution to productivity, we dive deeper into the patent and innovation system

[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). However, Heske (2013) did not account for the interdependence of all stages of the economic cycle and the different types of price settings. In addition, information on capital assets is missing, which led the authors to calculate this data using the perpetual inventory method. Moreover, Glitz and Meyersson (2020) rely on patent application data from conglomerates, although it neglects the granting procedure and disregards patents from research institutions or foreign inventors, and thus underestimates the productivity effects from GDR patents. The present study, in contrast, uses more complementary and original primary economic and patent data based on Stäglin and Ludwig (2000) and Hipp et al. (2022a).

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 called the "economic patent" (*Wirtschaftspatent*), was introduced. Employees of conglomerates (*Kombinate*), state-owned research institutes, and public institutions typically had to file their inventions using this type of patent. The economic patent granted the right to its use and application to the socialist state, i.e., the most important employer and owner of all production inputs (Wiessner, 2015). In most cases, the option to choose between the types of patents was withheld. As a result, resident inventors lost their exclusive rights to the invention in favor of its use among all conglomerates in the GDR, provided that they notified the responsible central authority in advance (Jonkisch, 1964). Application fees were quite low, the inventor received one-off compensation, which, depending on the economic value of the invention, was sometimes twice (or for inventions of particular economic importance up to twenty times) as high as the actual salary, and there was the right to be recognized and named as an inventor (Lindig, 1995). After patent filing, the inventor could further enjoy a high social status and reputation, followed by distinct award ceremonies and gifts from the respective institution (e.g. the reservation of free vacation spots or gifted everyday goods), and the opportunity to participate in specific training initiatives, such as patenting camps. Thus, the incentives to engage in patenting activities were exceptional, and this patenting system was held throughout the GDR, which resulted in a similar development of the number of patents per employee compared to the FRG until the 1980s (Günther et al., 2020). The ruling Socialist Unity Party 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, with licensing and knowledge transfer with Western countries being especially relevant for foreign inventors (Wiessner, 2015). High-quality patents for resident inventors could be applied for in this category, albeit rarely, because foreign exchange needed to be spent at Western patent offices to prepare for an export of the technology (Hinze & Grupp, 1995).

Based on the requirements for international trade and to hold up in international courts, GDR patents conformed to Western standards in terms of quality (Fritsch et al., 2022; Kogut & Zander, 2000). Even though the socialist system included different incentive structures to file patents, lower-quality patents could also have been created in market economies, e.g., when they were of strategic importance to a company. The GDR became a member of the World Intellectual Property Organization (WIPO) 1 year after its foundation (1967), which ensured uniform international standards for patent applications with respect to the degree of novelty, the inventive step, and technical applicability (WIPO, 1970). In 1990, the German Patent and Trademark Office (DPMA) has included the patents of the GDR in its register (DPMA, 2021).

East German patents emerged within a particular socialist innovation system, which included three main actors: large conglomerates, which were vertically and horizontally integrated units of production with industrial research centers; the academic research institutes of the Academy of Sciences; and the institutes of higher education, such as universities and technical schools (Günther et al., 2010; Meske, 1993; von Tunzelmann et al., 2010). The institutes of higher education were mainly concerned with teaching, with the expectation that knowledge would be transferred from the academic research centers to industry, such that the majority of patents originated from the large conglomerates and research institutes (Gläser & 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 inventorship in a system with institutional impediments

2.4.1 Knowledge generation

In the GDR, innovation was spurred by economic planning rather than market forces. Inventive activities were aligned with the central plan, and superordinates in the hierarchy assigned specific R&D projects to operation managers, who 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). Given high-performance targets, severe material restrictions and outdated technologies, managers were rewarded for meeting production output targets and had no incentive to deploy inventions for fear that they might slow down production (Allen, 2001). The R&D personnel had to maintain 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).

The socialist system nevertheless had features that favored innovation, 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 & Zander, 2000). Inventors sought to transfer their application-oriented patents for use in industry (Gläser & Meske, 1996). The economic department in the AfEP supported the use of patents (Wiessner, 2015), and the party aimed to spark 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 & Welskopp, 2017). Despite the outlined shortcomings, the GDR actively used economic planning to stimulate knowledge generation and its application, striving to increase production efficiency, fulfil planning goals, and ultimately leapfrog Western economies. Thus, we hypothesize that:

H1 Knowledge generation has a positive effect on the productivity of industry sectors in a system with institutional impediments.

2.4.2 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. The system also adopted an imitation strategy, including industrial espionage (Glitz & Meyersson, 2020), which did not contribute to domestic follow-up inventions but encouraged copying various 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 & 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, prioritized sectors enjoyed greater support, and thus, more opportunities to accumulate knowledge (Augustine, 2020). For example, microelectronics received continued support from the party during the 1980s, contributing to essential 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 increased 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 a system with institutional impediments.

2.4.3 Knowledge diffusion

Among the key features supporting alignment within innovation systems are “interactive dynamic capabilities” emerging in the interaction of firms with their R&D networks and with foreign sources of technology, and from market access (Radosevic, 2022; von Tunzelmann & Wang, 2007; von Tunzelmann et al., 2010). In the GDR, central planning entrusted the generation of technologies mainly to research institutes of the Academy of Sciences and the R&D 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, the GDR’s patent law provided few incentives to diffuse new scientific-technical solutions among the large conglomerates especially 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). Existing networks between science and industry were thus strongly unidirectional, limiting the emergence of interactive dynamic capabilities (von Tunzelmann et al., 2010).

Informal networks between inventors, employees and organizations did exist and led to the exchange of knowledge and its use in industry on a daily basis to “get things done” (Radosevic, 1999; von Tunzelmann et al., 2010). For example, it was important for materials 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). This appeared, for example, in the form of paper lists that moved between conglomerates, on which employees could record their search and offer resources for exchange (Grabher, 1992). Knowledge could also be diffused via the exchange of personnel between industry and the academy to enable an understanding of the problems in production (Gläser & Meske, 1996). Given the large informal networks and widespread official personnel exchanges, we propose that:

H3 Knowledge diffusion between co-inventors within the country has a positive effect on the productivity of industry sectors in a system with institutional impediments.

The autarkic economic system of the GDR tended to disrupt links to the broader international scientific communities (Gläser & Meske, 1996) and international markets (Ludwig, 2017), impeding relevant international knowledge exchange. Co-inventors from abroad provide access to new knowledge that might diffuse locally (Miguelez & Noumedem Temgoua, 2020). They contribute to knowledge transfer by recombining their know-how and knowledge specific to their home country, enabling local structural change and diversification (Miguelez & Morrison, 2023). In the GDR, this knowledge exchange existed, albeit only in select cases through collaborations with foreign actors, e.g., in Japan (Toshiba) or South Korea (Samsung) (Högselius, 2009) or among actors from 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 the productivity of industry sectors in a system with institutional impediments.

Foreign inventors from Western countries had the opportunity to file their patents by means of exclusive patents, which retained exclusive rights 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 strived for international priority in developing the technologies. Western firms did not expect some technologies, such as computers or integrated circuits, to be easily imitated (*ibid.*). Nonetheless, they could only claim their exploitation and prohibition rights 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. Meanwhile, the espionage and imitation strategy of the GDR (Glitz & 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 of the scientific dependency of the GDR as well as the use of "bypass patents" (*Umgehungspatente*) to adopt and incorporate technologies in production processes (Hinze & Grupp, 1995). Foreign inventors from other socialist countries could apply for economic patents to drive technical progress in the socialist sphere (Wiessner, 2015). A central aim of Comecon was to establish a unified socialist system of IP protection in order to make use of inventions within the alliance and across borders (Schönfeld, 1978). Despite the constraints of knowledge inflows from abroad, these could be essential for improving production processes in a system with institutional impediments. Thus, we hypothesize:

H5 Knowledge diffusion from foreign inventors has a positive effect on the productivity of industry sectors in a system with institutional impediments.

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

Table 1 Descriptions of variables

Variable	Description	Sources	
		GDR	FRG
Total Factor Productivity (TFP)	The proportion of output that is not explained by the inputs of labor, 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)	The 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		
Co-inventors 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 in a given year	PATSTAT	
Co-inventors abroad (CIA)	Total number of transnational patent applications with at least one inventor residing in a country other 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)
Labor	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 the 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)

3 Data and methodology

3.1 Data sources

To test the hypotheses, we use a set of economic variables from the GDR and FRG at the industry level from different original primary and internationally harmonized data sources such as Stäglin and Ludwig (2000) and Statistisches Bundesamt (2002). Table 1 provides detailed descriptions of all variables, measures, and sources. We focus on the observation period from 1970 to 1989, when technical progress and inventorship became most important in the GDR (Glitz & Meyersson, 2020; Hipp et al., 2024; Lindig, 1995), 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 and deflated data on the economic performance, labor, capital and investments for the industry sectors from the Statistical Office of the GDR by Stäglin and Ludwig (2000). However, this reliable, unique data is restricted to a few indicators, which is why we can construct only a limited number of control variables. We refrain from collecting further information from official GDR statistics, such as export data, because the central planners and high-ranking politicians might have been incentivized to publish manipulated data for ideological reasons (Krämer & Leciejewski, 2021).

The economic performance of the GDR is measured according to the material product system (MPS), which includes national income at the economic level and net product at the industry level. Net product accounts for all value-added goods by all resident producers in an economy (capital depreciation considered). Capital is measured by gross fixed capital assets ("*Grundmittel*"), which identifies work equipment of a gross value of at least 500 Mark that retains its form of use throughout a minimum useful life of at least 1 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 in the focal industry, which aligns with the categorization of Hall and Sena (2017). According to MPS, investments encompass the sum of investments in plants, equipment and buildings.

For the FRG, we retrieved economic performance, labor and capital data from Statistisches Bundesamt (2002). The economic performance of the FRG is measured according to the system of national accounts (SNA), which includes GDP at the economic and industry levels. 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). Internal data on investments was provided on demand by the Statistical Office of the FRG. Since the former federal territory distinguished 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 use manually cleaned patent statistics of the GDR from Hipp et al. (2022a) and 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 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 over 100 million patent documents in 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 (Glitz & Meyersson, 2020; Kukić, 2018; Weill, 2008). We follow the approach of Hall and Sena (2017) and Fink et al. (2021), albeit with slightly different components of variables, where the log of labor (*l*), capital (*k*), and materials (*m*) are inputs. Hence, we use an ordinary least squares (OLS) regression accounting 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 TFP (*A*)*,* capital (*k*)*,* labor (*l*)*,* and materials (*m*). TFP is considered a primary driver of economic growth, including a firm or industry-specific growth trajectory (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 OLS method, where we regress the input factors in logs (labor, capital and materials) on the log of GDP. The TFP is obtained by predicting and obtaining the residual of the estimated Eq. (2) and not the fitted values, representing the normalized outcome variable in Eq. (3).

α, β and γ are the shares of contributions for *k*, *l* and *m*. A growth in α, β and γ 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:

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

The estimated equation follows this specification:

$$ln\,GDP_{it} = \delta_0 + \alpha ln\,Capital_{it} + \beta ln\,Labour_{it} + \gamma ln\,Materials_{it} + \varepsilon_{it} \tag{2}$$

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

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

with the independent variables for industry $i, i = 1, \ldots, N$ in time $t, t = 1, \ldots, T$ being $ResidentPatents_{it}$ (*RP*) and $CumulativePatents_{it}$(*CP*), which measure the knowledge generated and accumulated over time in the country (Caballero & 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). ε_{it} is the idiosyncratic error term.

In addition, we use the application date of granted patents and lag our independent and control variables by 3 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 retrieving respective data

Table 2 Descriptive statistics

Variable	Mean	Std. Dev	Min	Max
ln_TFP_GDR	0.144	0.234	−0.552	0.622
ln_GDR_RP	4.997	2.912	0	8.775
ln_GDR_CP	7.137	2.6	0	10.295
ln_GDR_CIC	5.18	3.28	0	10.39
ln_GDR_CIA	5.726	3.305	0	9.499
ln_GDR_FI	4.666	4.935	0	12.221
ln_GDR_GDP	2.208	0.947	0.128	3.688
ln_GDR_Capital	3.753	0.671	2.492	5.284
ln_GDR_Labor	5.453	0.974	3.059	6.943
ln_GDR_Materials	1.29	0.529	0.477	2.439

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 (Table 4). 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. We refrain from introducing all types of inventorship in the same model because the number of patents inherently correlates with the number of co-inventors. However, because knowledge diffusion via collaborations with different types of inventors can emerge simultaneously (Hipp, 2021), we jointly introduce resident and foreign partners and foreign inventors in the last model. Control variables are *Labor*, *Capital* and *Materials*. All economic variables are in constant prices to account for potential price developments. Since both socialist and market systems entail high distortions in their standard price settings (Dietzenbacher & Wagener, 1999), growth and structural comparisons between the GDR and FRG are possible. We express all variables as natural logarithms in the production and regression equations.

4 Results

4.1 Summary statistics

Descriptive statistics and correlations of variables are shown in Table 2 and 5. Figure 1 shows the development of TFP and resident patents per 1000 employees in the GDR over time. We observe a TFP growth in most of the industries over time. Notably, TFP growth is higher in the Chemical, Electrical Engineering, Metallurgy and Textile sectors, followed by Machinery, Construction and Light sectors, than in the Energy, Water and Food sectors.[3]

[3] The negative TFP in the sectors of Water and Food can be explained by the substantial increase of capital in the respective years enhancing 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 1000 employees, we find slow growth for the Chemical, Machinery, Electrical Engineering, Energy, Metallurgy, Construction and Food sectors between the mid-1970s and mid-1980s. On the other hand, all patent and inventor intensities are relatively low in the Water, Light and Textile sectors. Furthermore, Fig. 2 depicts changes in the number of co-inventors from the same country and abroad, as well as the number of foreign inventors per 1000 employees 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 Engineering and Metallurgy sectors starting in the late 1970s, followed by the 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 the Machinery, Electrical Engineering, Energy, Construction and Food sectors over time.

The number of foreign inventors also increases, starting in the late 1970s, particularly in the Chemical, Machinery, Electrical Engineering, Metallurgy, Construction and Food sectors. In contrast, the Energy, Water, Light and Textile sectors only show low changes. The increase is particularly strong because some of the patents (e.g., DD000000239348A5) include more than 20 foreign inventors from the USSR taking part in international knowledge diffusion within the realm of Comecon. Inventors might have had the incentive to name colleagues on the patent who were only marginally 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.

4.2.1 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. Meanwhile, labor and materials exert a negative and significant influence in all subsequent models. These effects can be explained by substantial reductions in labor supply in the GDR, which required more investments over time to increase capital efficiency as a major driver of economic growth. Considering knowledge generation, accumulation and diffusion in Models 2 to 6, we find that resident patents, cumulative patents, co-inventors within a country and foreign countries, and foreign inventors are positively and significantly related to TFP in the industry sectors of the GDR. Cumulative patents show the largest coefficient, resulting in a productivity increase of 11.2%, followed by resident patents and co-inventors in the same country, with a productivity increase of up to 4.2%. Co-inventors from abroad and foreign inventors exert the lowest productivity increase of 3.2% and 1.8%, respectively. In Model 7, we introduce all types of knowledge diffusion to observe their partial effects. Knowledge diffusion by co-inventors in the same country remains positive and significant, and its coefficient slightly increases to 4.4%. However, knowledge diffusion by co-inventors from abroad and foreign inventors renders it insignificant.

4.2.2 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 & 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 6). The coefficient for knowledge generation by resident patents and knowledge diffusion by co-inventors in the same country and abroad even increases by up to 6.4%. Only the coefficient for cumulative patents is lower in non-R&D sectors than in the full sample, resulting in a productivity increase of only 7.6%. In the full model, only knowledge diffusion by co-inventors abroad remains positive and significant. While materials remain negative and significant, capital and labor become insignificant in most models, which can be explained by the particular necessity of investments in these sectors, as well as below-average capital resources and above-average labor migration.

4.3 Robustness tests

4.3.1 Overview

We perform several robustness tests, including GDP as a dependent variable, different lag structures, alternative productivity measures, a narrow focus on exclusive patents, 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 7), 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 1 year because one could argue that knowledge from economic patents could be used faster in production processes due to a lack of IP rights and rapid knowledge diffusion (Table 8). The coefficients remain positive and significant, and their effect increases in all models, except for co-inventors from the same country, which become insignificant in the full model. This confirms that knowledge from economic patents rather than exclusive patents was faster transferred and applied in production processes.

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 size-effect for all types of inventorship (Table 9, Models 1–7), hinting at the general lower labor productivity of the GDR. 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

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

patents, which becomes insignificant. Moreover, the results remain stable when excluding the input factors of capital, labor and materials from the second-stage estimation.[5]

Fourth, when testing only for exclusive patents (i.e., the patents for which mostly foreign inventors from Western countries applied), we observe productivity-enhancing effects, which nevertheless 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 10).

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 9, Model 8).

Last, we retrieved economic and patent data (total number of patent grants from inventors residing in the country to proxy the possible number of economic patents) to conduct a quasi-experiment on the productivity-related effects of knowledge generation, accumulation and diffusion for the FRG (Table 11). We find the expected positive and significant effects for all types of inventorship on TFP in the industry sectors of the FRG, which supports the reliability of our findings.

4.3.2 Accounting for endogeneity

The relationship between TFP, patents and inventors works both ways in that a higher TFP may also impact the degree of patenting, for which OLS cannot provide reliable estimates. The degree of patenting and inventing can be associated with the quest for industry performance regarding the necessity to increase productivity as a preferred option to measure industry functionality despite being primarily unobserved. Since productivity is additionally driven by input, a continuous increase in patenting for knowledge production and diffusion should be expected. In this situation, the quest for increased productivity can promote the degree and quality of patenting, including inventor mobility and cohabitation in a specific industry. This form of endogeneity cannot be ruled out.

Considering that patents and inventors are potential endogenous variables, it is possible that the estimate may be affected by reverse causation or, more probably, that the underlying unobserved factors are covarying with patents and inventors, resulting in an omitted variable bias. To address the potential endogeneity concerns surrounding patenting, inventorship, and TFP, we use FRG patents as well as the log of domestic co-inventors, co-inventors abroad, and foreign inventors (3-year lag) as instrumental variables. We follow the study of Glitz and Meyersson (2020) to select our instruments, referencing the level of industrial espionage by GDR on FRG. We assume knowledge espionage occurred due to the possibility of the GDR learning about the rapid integration of knowledge in West Germany. This is because, in the FRG, human capital and absorption capacity levels were relatively high. This allowed personnel to learn efficiently and to integrate the knowledge gained into production processes. Hence, the GDR illicitly leveraged this human capital quality in the FRG, enabling knowledge access and copying of the technologies and processes within the system. Based on technological capabilities, this resulted in a remarkable similarity in the direction of patenting efforts between the GDR and FRG in particular industries (Kogut & Zander, 2000). Consequently, while FRG patents may influence other observed industry performance outcomes (e.g., employment or profitability) in GDR, they are likely not to affect the rate of TFP (our GDR-dependent variable).

[5] Results are available upon request.

Table 3 Baseline model for TFP in the GDR

Variables (GDR)	(Model 1) ln_TFP	(Model 2) ln_TFP	(Model 3) ln_TFP	(Model 4) ln_TFP	(Model 5) ln_TFP	(Model 6) ln_TFP	(Model 7) 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_Labor	−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

***$p<0.01$; **$p<0.05$; *$p<0.1$

Hence, we tested the reliability of our instruments in a first-stage regression (controlling for industry and year-fixed effects) with regard to the instrumented variables (Table 12). In the table, patents and inventors (endogenous regressors in our central equation) are a function of FRG patents and FRG inventors (our instruments) and other GDR inputs (capital, labor and materials). We find that the instruments have a positive and significant impact on the endogenous variables. We observe a high explanatory power in the coefficients and the F-statistics above the standard threshold of 10. Both outcomes indicate that our instruments are sound.[6]

In the second step, we regress TFP on the instrumented variables by applying the generalized method of moments approach (IV GMM) (Table 13). To a large extent, the IV

[6] Alternatively, we use a different set of instruments, such as the predicted probability of patent equation, which follows the idea of estimating the predicted probability of the first stage in the Heckman two-stage

results converge significantly with the OLS results (see Table 3). We consistently observe the significant effect of patents on TFP, which underlines the reliability of our results. The role of inventorship in GDR TFP cannot be discounted. These results are robust enough to support our proposition that domestic and foreign knowledge is fundamental to industry performance in the GDR. The results on the inputs (capital, labor and materials) converge significantly with the baseline estimation.

5 Discussion

Our study contributes to the literature on productivity, innovation and technology transfer, and the history of the socialist economy. First, we show that the number of resident patents positively impacts sectoral productivity in the GDR. This finding remains robust across all model specifications, supporting our Hypothesis 1 that knowledge generation positively affects productivity in a system with institutional impediments. This is an important finding that challenges previous research highlighting the inferiority of socialist economies to Western market economies in terms of innovation and productivity (Bergson, 1987; Chiang, 1990; Vonyó & Klein, 2019). In fact, our evidence suggests the existence of a nexus between knowledge generation and productivity in socialist economies despite manifold institutional constraints of their innovation systems, thereby extending previous research, which was restricted to studies of market economies (e.g., Baum et al., 2018). This key finding could point to different explanations, including the 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 education policy (Kogut & Zander, 2000). We find that productivity effects of knowledge generation are particularly strong for low-R&D sectors, such as Metallurgy, being the driver of Stalin's model of industrialization. Yet, further estimations on knowledge inflows from Western countries, measured by exclusive patents, also show productivity-enhancing effects, which points to bypassing of IP rights and application of the slightly modified Western technologies in the GDR, e.g. via "bypass patents", in addition to industrial espionage (Glitz & Meyersson, 2020).

In line with Hypothesis 2, we observe productivity-enhancing effects from knowledge accumulation, measured by the cumulative number of patents, in the industry sectors of the GDR. Knowledge accumulation is a path-dependent and long-term process. Thus, changing centrally coordinated research priorities according to adjusted economic planning objectives might disrupt knowledge accumulation and might limit productivity effects by diverting resources (i.e., those that are independent of existing knowledge and progress) in particular technologies. Yet, we find no evidence that there were no productivity gains from knowledge accumulation in the industry sectors of the GDR, even though research priorities dramatically changed for key sectors over time (Augustine, 2020; Ludwig, 2017).

Moreover, we provide new evidence on the effects of knowledge diffusion in a system with institutional impediments. In particular, we found positive effects of knowledge diffusion through co-inventorship in the same country (Hypothesis 3) but inconsistent effects of co-inventorship from abroad (Hypothesis 4) and foreign inventors (Hypothesis 5) across our models. This suggests that productivity gains were a result of knowledge diffusion inside the GDR but not necessarily from international knowledge transfer and inflow.

Footnote 6 (continued)

model (fitted values not residuals). Interestingly, our results remain stable and consistent across the specifications.

Previous research has argued that the restrictions for interactions by the GDR and other socialist economies with international scientific communities limited access to international markets and knowledge inflows, in turn, constraining international knowledge diffusion (Gläser & Meske, 1996; Ludwig, 2017; von Tunzelmann et al., 2010) in comparison to market economies (Miguelez & Morrison, 2023; Miguelez & Noumedem Temgoua, 2020). Furthermore, within Comecon, institutional inequalities complicated cooperation and often resulted in a formalized necessity rather than an opportunity for technology co-development (Kochetkova, 2021). In addition, Comecon often opposed collaborative programs or was dysfunctional in its division of labor (Lindig, 1995). In principal, our findings indicate that knowledge diffusion by international (co-)inventors did not increase production efficiency when knowledge diffusion by resident inventors was efficient enough in the industry sectors.

In sum, our research extends the scope of the patent–productivity nexus to the significance of knowledge generation, accumulation, and diffusion for productivity gains in a system with institutional impediments. We provide insights into the innovation system of the GDR as a socialist economy, examining how it addressed barriers to technology transfer to increase efficiency in production. A comparison to the FRG confirms that successful application of knowledge was possible in a socialist economy, indicating that effective technology transfer is subject to different incentive schemes and mechanisms (e.g., training, financial and social rewards). Nonetheless, the distinct incentive scheme of a socialist and a market economy led both to productivity-enhancing effects of inventorship despite institutional misalignments of socialist innovation systems.

6 Conclusion

This study provides novel evidence from the productivity effects of knowledge generation, accumulation and diffusion in the GDR as an example of socialist economies characterized by innovation systems with institutional impediments. We developed a set of hypotheses based on an innovation system and technology transfer approach (Miguelez & Morrison, 2023; Miguelez & Noumedem Temgoua, 2020; Radosevic, 1999, 2022), which we tested using industry-level data from the GDR (1970–1989). In the GDR, industrialization focused primarily on heavy industries (e.g., Metallurgy and Construction) and key sectors of technical progress (e.g., Chemicals and Electrical engineering). Our descriptive analysis shows a comparatively large TFP in these sectors. Our regression results underline that knowledge generation, accumulation and diffusion by resident co-inventors positively affected sectoral productivity in the GDR—a finding that might be explained by the incentive scheme for patenting, the support of personal creativity and education, and alternative technology transfer mechanisms.

Our results are not only relevant from a historical perspective but also provide implications for technology transfer practices today, especially with regard to enhancing innovation and productivity in innovation systems with institutional impediments. While some discussed barriers to technology transfer are specific to the socialist institutional context (e.g., economic patents), other barriers may exist in market economies. For instance, the case of the GDR teaches us that one-off financial compensation, social rewards, or training opportunities were important incentives for knowledge generation in a closed economy; however, these mechanisms can be relevant in other institutional contexts. For example, in market economies including economies with state-capitalism such a China, managers could extend incentive schemes or educational opportunities for employees to overcome institutional barriers to innovation. Many organizations already use financial incentives to foster knowledge generation and transfer, with ambiguous effects (e.g., Wright et al., 2004; Derrick, 2015), while one-off financial compensation and certain types of social rewards are less often used.

With respect to knowledge accumulation, the example of the GDR shows that strict institutional regulation did not fully disrupt knowledge trajectories. Thus, the concentration of investments in prioritized sectors such as microelectronics supported domestic follow-up inventions and led to the development of fundamental R&D capacities, even though it caused imbalances in the production structure of the economy (Ludwig, 2017). This finding on investment-led growth via coordinating research activities in the context of socialist planned economies perhaps supports the current shift towards 'mission-oriented policies' in market economies, which emphasize the need of public intervention to steer innovation and create new markets (e.g. Deleidi & Mazzucato, 2021). However, any overtly strict application to policy induced research targets at the organizational level might lead to risks of limiting individual creativity in knowledge generation, which would constrain knowledge accumulation and potentially disrupt path dependencies.

While knowledge diffusion was economically effective inside a socialist economy, links to the wider international community and Western markets were disrupted, which impeded knowledge diffusion. Thus, in innovation systems with institutional constraints, the participation in international knowledge transfer could be stimulated via cooperative initiatives within the wider international scientific communities or support to employees seizing opportunities of international research exchange to assure knowledge transfer at the technological frontier. This could be also true for difficult-to-access systems with limited institutions, such as rural areas, in which home-based organizations may seek to enter into global partnerships to take part in international knowledge diffusion. On the other hand, if political leaders of states with institutionally constrained innovation systems prefer to control exchange with international scientific communities, as it is currently the case for the Russian Federation, not only negative effects for knowledge diffusion but also for productivity could be the long-term result.

Finally, we would like to direct the readers' attention to our thoughts on possible future research in the field of technology transfer in systems with institutional impediments. First, it has been indicated that inventions from innovation systems of socialist economies were of lower quality (e.g. Hinze & Grupp, 1995), but evidence of this phenomenon is scarce. Patent citations or text analysis could help to identify cutting-edge research (Acosta et al., 2021) and would enable a more fine-grained assessment of the quality of knowledge flows. On basis of this, future research could investigate the mechanisms of 'high-quality' knowledge transfers within centrally planned or highly regulated economies. Second, patents only proxy codified knowledge, but tacit knowledge and competencies can also enable productivity gains. Therefore, future studies could find corresponding proxies, such as employee qualifications, to better understand their impact on productivity. Third, future research could explore the relevance of knowledge in the transformation process of socialist planned economies. For instance, the mobility of skilled workers during the transformation processes could provide more insights into the transfer of high-quality and tacit knowledge.

Appendix 1

See Figs. 1, 2 and Table 4, 5, 6.

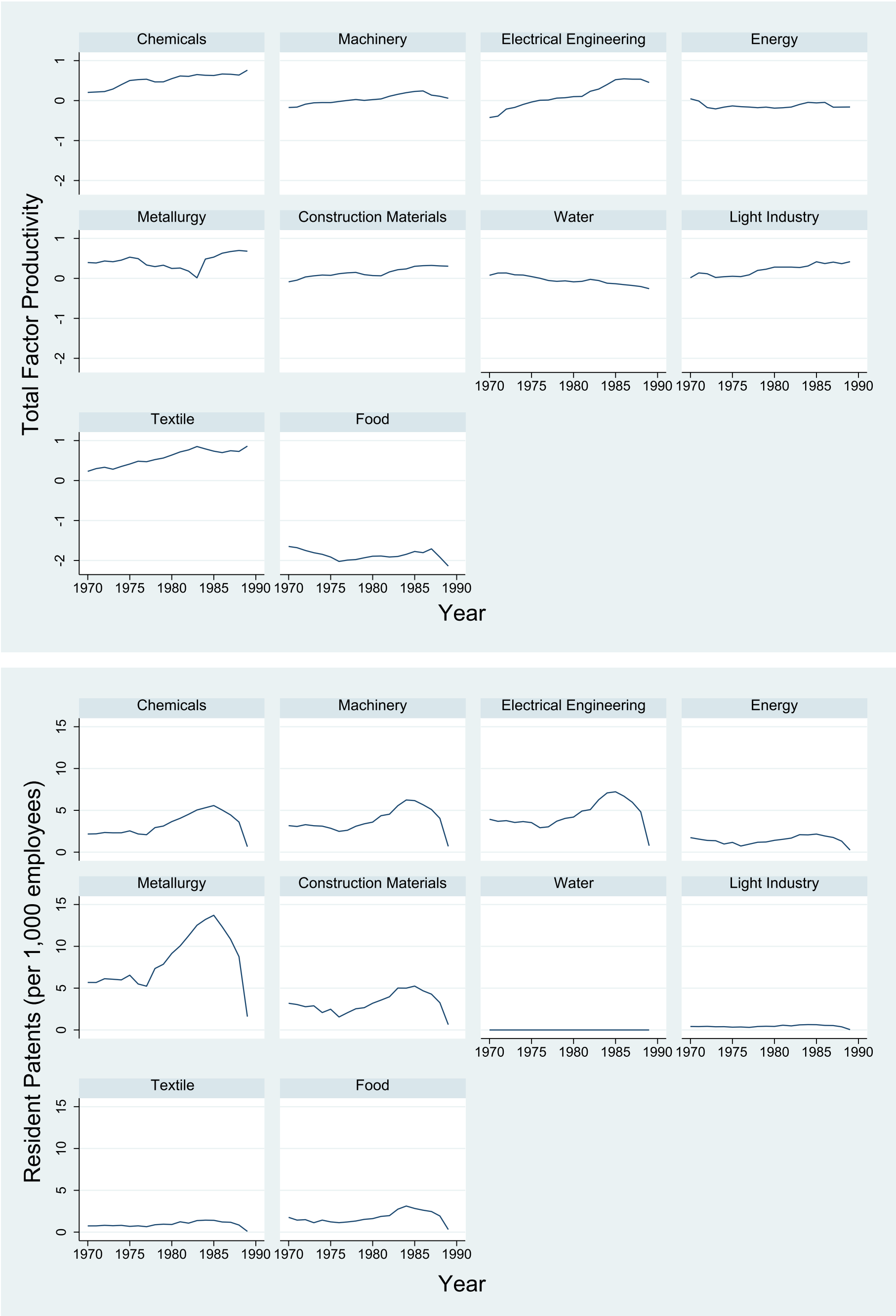
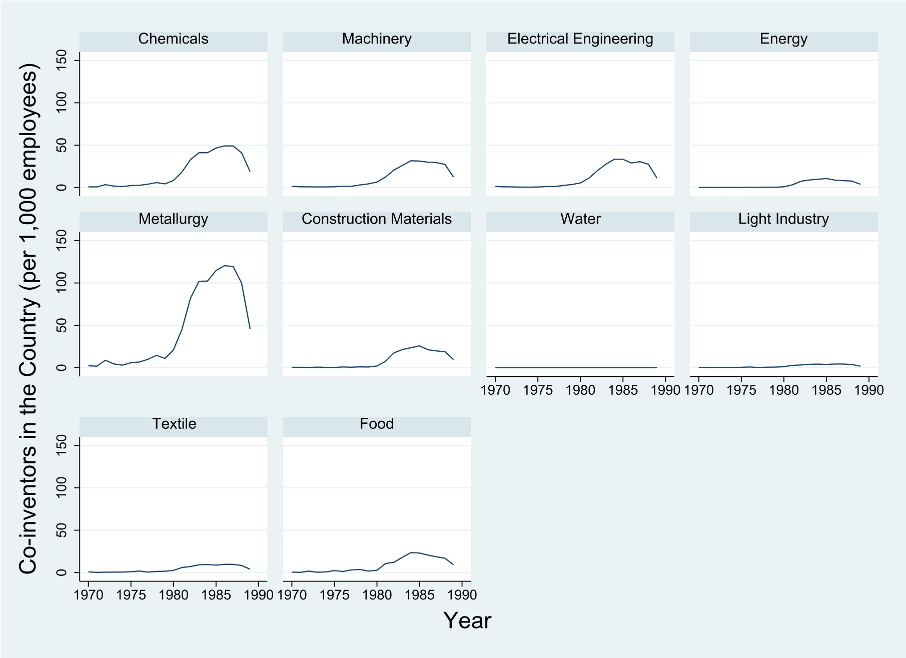


Fig. 1 Total factor productivity and number of resident patents per 1000 employees in the GDR (1970–1989)



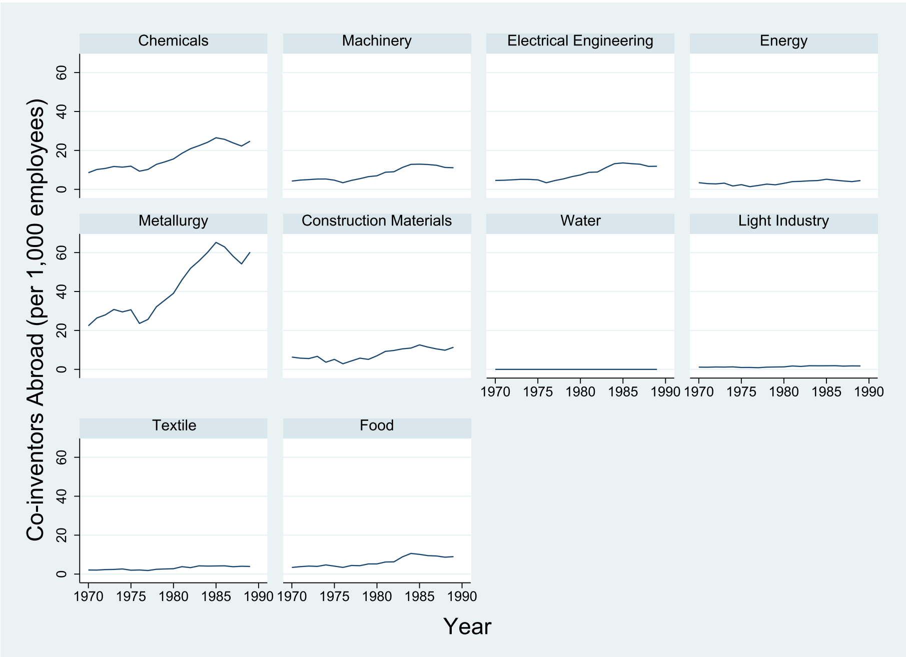


Fig. 2 Number of co-inventors in the same and foreign countries and foreign inventors per 1000 employees in the GDR (1970–1989)

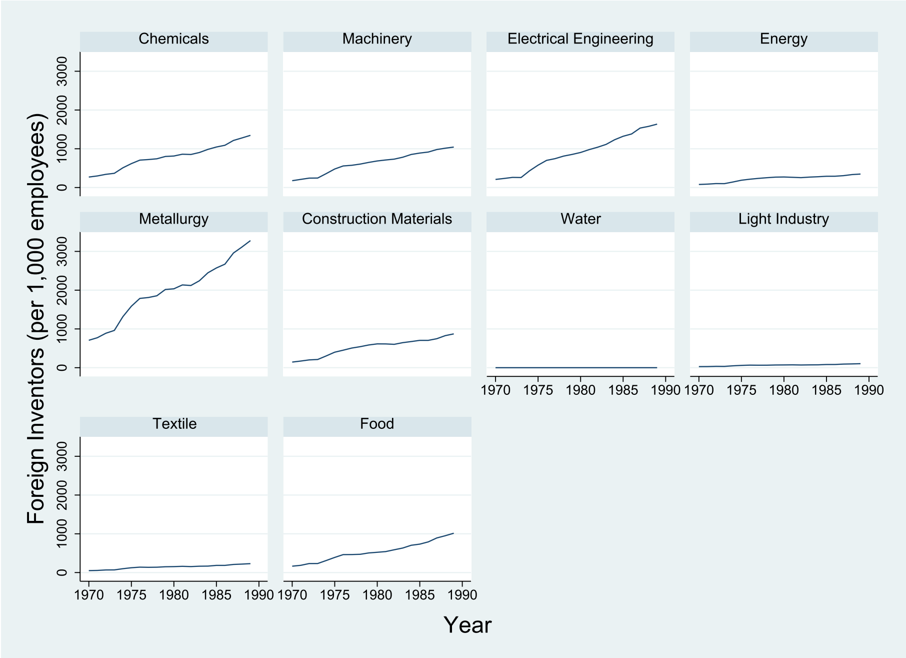


Fig. 2 (continued)

Table 4 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 5 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
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

Table 6 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 2

See Table 7, 8, 9, 10, 11, 12 and 13.

Table 7 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 8 The impact of inventorship on productivity (Lag by one year)

Variables (GDR)	(Model 1) ln_TFP	(Model 2) ln_TFP	(Model 3) ln_TFP	(Model 4) ln_TFP	(Model 5) ln_TFP	(Model 6) ln_TFP	(Model 7) 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 9 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 10 The impact of exclusive patents on productivity

Variables	(1) Current		(2) 1-year lag		(3) 2-year lag		(4) 3-year lag
ln_Exclusive_ patents	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 11 The impact of resident patents on productivity in the FRG

Variables	(Model 1) TFP_FRG	(Model 2) TFP_FRG	(Model 3) TFP_FRG	(Model 4) TFP_FRG	(Model 5) TFP_FRG	(Model 6) TFP_FRG	(Model 7) 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

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 12 First-stage results (IV GMM)

Variables	(Model 1) ln_GDR_RP	(Model 2) ln_GDR_CP	(Model 3) ln_GDR_CIC	(Model 4) ln_GDR_CIA	(Model 5) ln_GDR_FI	(Model 6) ln_GDR_CIC	(Model 7) ln_GDR_CIA	(Model 8) ln_GDR_FI
ln_FRG_RP_3	0.769***	0.134***	0.814***	0.865***	0.710***			
	(0.019)	(0.008)	(0.035)	(0.016)	(0.101)			
ln_FRG_CIC_3						0.681***		
						(0.033)		
ln_FRG_CIA_3							0.918***	
							(0.018)	
ln_FRG_FI_3								1.023***
								(0.004)
ln_GDR_Capital	−0.680*	0.554***	1.018	−0.537*	8.099***	1.627**	1.664***	−0.049
	(0.350)	(0.155)	(0.654)	(0.310)	(1.912)	(0.704)	(0.310)	(0.105)
ln_GDR_Labour	1.715***	−0.197	−1.004	1.258***	−8.422***	−1.745**	−0.606*	−0.353***
	(0.372)	(0.164)	(0.694)	(0.329)	(2.030)	(0.748)	(0.337)	(0.113)
ln_GDR_Materials	−0.130	−0.023	0.005	−0.001	1.284**	0.058	−0.033	−0.017
	(0.112)	(0.049)	(0.209)	(0.099)	(0.611)	(0.228)	(0.105)	(0.033)
Constant	−5.930***	5.316***	1.611	−4.346***	17.326*	3.417	−1.177	1.740***
	(1.707)	(0.755)	(3.186)	(1.511)	(9.324)	(3.469)	(1.591)	(0.505)
Observations	200	200	200	200	200	200	200	200
R-squared	0.995	0.999	0.986	0.997	0.946	0.983	0.996	1
Adj R^2	0.994	0.998	0.983	0.996	0.936	0.98	0.996	1
RMSE	0.229	0.101	0.427	0.203	1.251	0.466	0.214	0.067
F-stat	1000.365***	4094.934***	360.944***	1648.037***	91.599***	302.496***	1477.117***	33,459.861***
ll	29.023	192.241	−95.764	53.428	−310.502	−113.154	42.516	274.041
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

***$p<0.01$; **$p<0.05$; *$p<0.1$

Table 13 The relationship between TFP, patents and inventors (IV GMM)

	(Model 1)	(Model 2)	(Model 3)	(Model 4)	(Model 5)	(Model 6)
Variables (GDR)	lnTFP	lnTFP	lnTFP	lnTFP	lnTFP	lnTFP
ln_RP_3	0.040***					
	(0.010)					
ln_CP		0.229***				
		(0.068)				
ln_CIC_3			0.038***			0.222***
			(0.009)			(0.066)
ln_CIA_3				0.036***		−0.154***
				(0.009)		(0.049)
ln_FI_3					0.043***	−0.023*
					(0.011)	(0.012)
ln_Capital	0.514***	0.360**	0.449***	0.506***	0.136	0.367**
	(0.134)	(0.159)	(0.137)	(0.136)	(0.205)	(0.158)
ln_Labour	−0.960***	−0.846***	−0.854***	−0.936***	−0.526**	−0.672***
	(0.143)	(0.170)	(0.157)	(0.150)	(0.236)	(0.201)
ln_Materials	−0.156**	−0.156**	−0.162**	−0.162**	−0.217***	−0.133*
	(0.065)	(0.068)	(0.065)	(0.066)	(0.071)	(0.071)
Constant	3.147***	1.691*	2.849***	3.064***	2.158***	2.287***
	(0.649)	(0.941)	(0.684)	(0.678)	(0.808)	(0.822)
Observations	200	200	200	200	200	200
R-squared	0.861	0.845	0.864	0.856	0.835	0.79
Adj R^2	0.834	0.815	0.838	0.829	0.803	0.746
RMSE	0.087	0.092	0.086	0.088	0.095	0.107
Chi^2	5604.864***	4698.69***	6727.381***	5750.968***	4169.494***	1922.318***
Industry-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

***$p<0.01$; **$p<0.05$; *$p<0.1$

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