Unable to innovate or just bad circumstances?
Comparing the innovation system of a state-led and market-based economy

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Abstract
State socialism failed due to its inner contradictions. Despite huge investments into industrial modernization, the soviet-type economy collapsed in 1989 in Germany, and the market-based system prevailed. We compare the two parallel existing innovation systems in Germany to shed light on the success and failure of the state-led innovation system. Based on newly created indicators from archive data we show in a natural experiment setting that modernization investment was much bigger in the socialist as compared to the market economy. These achievements, however, could not fully unfold in favor of economic growth due to obstacles related to research priorities, innovation incentives, and knowledge flow.

Keywords
Comparative economic systems, natural experiment, innovation system, Germany

JEL Classifications
O11, O31, N94

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1. Introduction

Policy makers typically support the generation of new or improved products and technologies with investments in the modernization of the economy to enable technological progress and economic growth (Chaminade et al., 2018). Recent literature argues that there are no major technological breakthroughs and subsequent product innovations in a market economy without underlying large-scale investments of the state (Deleidi and Mazzucato, 2021). In this respect, the state is not reduced to act through regulation and small-scale innovation stimulus. This holds true for the “old economy”, e.g. chemistry, mechanical and electrical engineering, but equally to future digitalization and automation-based economies (European Commission, 2020).

So far, much attention has been put to understand innovation and growth in industrialized market economies, but less or close to nothing on industrialized non-market economies. Soviet-type economies concentrated its investments in the modernization of the economy to leapfrog Western market economies, but the obstacles in its system of innovation impeded its growth or have contributed to its fall (Glitz and Meyersson, 2020). Some economic studies put the conditions for innovation in a centrally planned economy entirely into question (e.g., Allen, 2001; Slifer, 2006; Steiner, 2010; Berliner, 2019). While the failure of state socialism as such is fully accepted (Kornai, 1995), the effects of huge modernization investments and its impact on economic growth have hardly been analyzed to understand mechanisms of success and failure behind. We challenge the wide-spread assumption that there was no growth-relevant innovation in socialist systems and zoom into the empirical details.

The literature on innovation systems describes the variety of resources that enables the actors to achieve innovation and a competitive advantage (Lundvall, 1992; Chaminade et al., 2018; Ghazinoory et al., 2020). Investments play a crucial role to encounter technological backlog and economic growth in the national system (Alaja and Sorsa, 2021; Hekkert et al., 2020; Hipp and Binz, 2020). Nonetheless, the analytical focus is on innovation systems of recent market economies or post-soviet countries (e.g., Radošević, 1998; Kozłowski et al., 1999; Chaminade et al., 2018), and we still know little about the successes and failures of socialist innovation systems. There are considerable parallels in the role of modernization investments between soviet-type and market economies. Due to their long-lasting effects on innovation today (Blind and Grupp, 1999; Wynwich, 2012; Fritsch et al., 2021), we need to understand the configuration of its system and the barriers to innovation therein. Moreover, most of the innovation studies focus on R&D investments, neglecting a broader view on investments into the modernization of an economy and their embeddedness in a system of innovation (Zemtsov and Kotsemir, 2019). We go beyond the focus on firm-level R&D and use the term of modernization investments in the sense of replacement and expansion.
investments into the upgrading of production capacities (Ghosal and Nair-Reichert, 2009). We operationalize this broader definition of the modernization of an economy by using the gross investments into economic sectors that are the key for technological progress and innovation (i.e. R&D-intensive sectors). This approach seems particularly suitable since innovation systems are heterogenous and their complexity and evolution require a better socio-technical understanding to integrate and coordinate investments (Cirillo et al., 2019).

This paper extends the literature on innovation systems to the role of modernization investments and barriers to innovation in an industrialized, state-controlled economy. We define the modernization of an economy in terms of the investments into R&D-intensive sectors that enable technological progress and innovation. We include arguments from the innovation economics literature (Moulaert and Sekia, 2003; Binz et al., 2016; Castellani et al., 2019) and propose a positive relation between modernization investments and the growth of a soviet-type economy. We thus seek to answer the following research question: Do modernization investments characterize a socialist innovation system?

Second, within this framework we scrutinize obstacles to modernization as structural deficits of an innovation system (Galia and Legros, 2004; Chaminade et al., 2012; Torres de Oliveira et al., 2021). We consider obstacles as part of the constrained institutional arrangement in a system of innovation, especially its low research priority, the small incentives to invent and the limited knowledge flow. The second research question is: Which obstacles influence the unfolding of modernization investments in a socialist innovation system?

We empirically investigate these research questions on the example of the socialist innovation system of the German Democratic Republic (GDR). The GDR was a socialist state with a central planning system after Germany’s separation of the Soviet occupation zone from 1949 to 1989. It was characterized by large investments in the modernization of industrial production since the late 1960s, but also by high innovation obstacles and a steadily decreasing economic growth till its fall (Ludwig, 2017). We use original primary time series data on GDR’s economic growth and its modernization investments from different archival sources such as Stifterverband (1990), Heske (2005a) and Stäglin and Ludwig (2000) that was recalculated according to international standards. We further apply patent-related indicators based on DEPATIS. Comparing these indicators of the GDR to the market economy of the Federal Republic of Germany (FRG) allows us to analyze a case in point in which the formerly unified and after World War II separated regions suit the conditions of a natural experiment (Kogut and Zander, 2000). We provide new empirical evidence on modernization investments and types of barriers to innovation in a soviet-type economy compared to a market system.
This paper is structured as follows. Section 2 provides an overview on the literatures on innovation systems, investments and obstacles. Section 3 describes the case selection, the data and the methods used. Section 4 presents our empirical results on the GDR’s economic and innovation system and section 5 illustrates its obstacles to modernization. Section 6 discusses the findings and provides theoretical implications as well as avenues for further research. Chapter 7 concludes and offers recommendations for policy makers.

2. Theoretical Framework

2.1. National innovation system, policy and economic growth

The literature on national systems of innovation draws upon a country’s actors and institutions to leverage its resources for the generation of innovation and the growth of the economy (Lundvall, 1992). The actors of the system include firms, universities and research labs while institutions exist in form of industrial relations and government policies (Freeman, 1995). They are embedded in a system of structural couplings through which they interact, exchange resources and produce positive externalities for the generation of innovation (Nelson, 1993). The variety of resources relates to tangible resources of production and natural capital as well as intangible resources of intellectual and social capital, of which the latter are less reproducible in other systems (Lundvall et al., 2002). Innovation systems are thus structured by knowledge production and diffusion, financial investments, technological legitimacy and market formation (Binz and Truffer, 2017). They can be considered at the geographical, sectoral or technological level of a market economy (for a recent overview, see Rakas and Hain, 2019). Although originally developed with respect to market economies, the theoretical concept of an innovation system has been used to analyze emerging and transition economies, too (Radosevic, 1998; von Tunzelmann et al., 2010; Günther, 2015; Günther et al., 2020). Soviet-type economies followed the same rationale as market economies: technological progress leads to economic growth. They relied on the same actors (firms, universities, research labs), but institutions differed in design and configuration. Thus, they will be paid special attention when applying the innovation system approach to the socialist innovation system.

Innovation systems can involve failures that hinder the development, diffusion and use of knowledge, which legitimates policy to intervene to ensure learning, innovation and economic growth (OECD, 1997). As opposed to market failures, systemic failures require interventions in form of investments, which can be linked to their occurrence in different R&D-intensive sectors to achieve an economy’s modernization: the industry to make use of knowledge, the infrastructure to diffuse knowledge, and the institutions to create new knowledge through training and education (Edquist, 1997). Policy invests
more in the former than in the latter; but without investments, systemic failures would lead to negative externalities for society (Edquist, 1997; Wieczorek and Hekkert, 2012; Chaminade et al., 2018). Investments are thus used to increase knowledge production (Lundvall, 1992), stimulate the physical, financial and knowledge infrastructure (Wieczorek and Hekkert, 2012), form capital (Binz et al., 2016) and drive private investments (Deleidi and Mazzucato, 2021). They are critical inputs for the creation of innovation and future processes of legitimation or market formation (Binz and Truffer, 2017) and key to solve problems of national competitiveness (Alaja and Sorsa, 2021). Recent innovation system approaches made considerable progress in understanding the role of policy and investments in an innovation system context of market economies (e.g., Binz and Truffer, 2017; Chaminade et al., 2018; Hipp and Binz, 2020). Investments in a socialist system of innovation are considered to principally have the same priority, aim and function in the economy (e.g., Kogut and Zander, 2000; Slifer, 2006; Ludwig, 2017).

Firms can face problems of absorbing new knowledge, transferring technologies or engaging in interactive learning (Polanyi, 1967). Moreover, they may become locked into particular technologies that build on limited or outdated knowledge that is difficult to replace with new knowledge (Smith, 2000). R&D-intensive industries such as biotechnology, pharmaceuticals or electronics, offer new knowledge to rapidly gear industrial problems and seize emerging technological opportunities (Lundvall, 1992). They attract highly-skilled scientists and engineers that engage in learning, capability development and the generation of new solutions (Arundel et al., 1992). R&D capabilities are core to innovation dynamics (Moulaert and Sekia, 2003). However, a pure increase in R&D spending may be insufficient if firms cannot make use of the R&D-related inputs (Castellani et al., 2019).

Empirical evidence on the relation between investments in R&D-intensive industries and the growth of a soviet-type economy are missing to date. Only indirect evidence for investments into R&D-intensive industries in a market economy is provided by O’Mahony and Vecchi (2009) who observe a higher productivity of R&D-intensive industries on basis of investments in knowledge-generating activities for a sample of five countries from 1988 to 1997. Using the EU Industrial R&D Scoreboard from 2002 to 2010, Montresor and Vezzani (2015) show that the output return of investments into knowledge capital is the largest in high-tech sectors. Using the same panel during the 2004–2012 period, Castellani et al. (2019) found that firms in R&D-intensive industries have a higher capacity to translate R&D into production gains while medium and low-tech industries rely on capital-embodied technologies that are not resistant to external changes.

Because modernization investments in R&D-intensive industries contribute to the use of fundamentally new or improved products and technologies, we predict that they will enhance the growth of a soviet-type economy in the long run.
P1. Modernization investments also increase the growth of a soviet-type economy over time.

2.2. System blockades and innovation obstacles

Despite of modernization investments, several obstacles to innovation can arise that impede the generation of innovation and the growth of the economy. The literature on obstacles to innovation identifies different types of obstacles that occur on the level of either the system or a firm in a market economy. In his early work, Lundvall (1992) notes social and institutional changes in the power of users and producers’ use and transfer of knowledge in an innovation system. Later, Edquist (1997) refers to obstacles to innovation that arise from institutions that underperform when they lag behind technological changes. Institutional barriers can impede knowledge diffusion via restrictions in intellectual property rights or the commercial use of knowledge or a lack of interactions among organizations. In the context of technology adoption by firms, Baldwin and Lin (2002) identify five obstacles to innovation that are related to costs, institutions, labor, organizations and information. They show that innovative firms in particular engage in a learning process in which different problems of technology adoption occur. In a further study, Galia and Legros (2004) show that economic risk, innovation costs, a lack of financing, organization and skilled personal as well as missing technological information lead to abandoned projects. According to Chaminade et al. (2012), one can group the obstacles to innovation that occur on a systemic level into three main categories: the low research priority, the small incentives to invent and the limited knowledge flow. The low research priority of the system is manifested in regulations, the law and support for firms and represents the importance of R&D and innovation in the economy. It symbolizes the constrained institutional arrangement with regard to limited knowledge resources, less technical and financial support as well as low openness to innovation. The small incentives to invent relate to the restrictions in the R&D infrastructure and the general conditions to innovate such as the R&D infrastructure in which scientists, engineers, universities and research institutes develop new technologies. The limited knowledge flow refers to the obstacle to the extent of information that could be sourced and knowledge that needs to be exchanged to generate innovation and achieve economic growth (Chaminade et al., 2012).

Empirical evidence on these innovation obstacles in market economies was provided e.g. for specific industries (Costa-Campi et al., 2014; Amara et al., 2016; Belousova et al., 2020) and types of firms (Blanchard et al., 2013; Pellegrino, 2018; Torres de Oliveira et al., 2021), specifically SMEs (Brancati, 2015; Strobel and Kratzer, 2017; Thomä, 2017). By analyzing Spanish CIS data between 2004 and 2010, García-Quevedo et al. (2018) observe that external constraints affect the failure of innovation projects from their start onward while internal constraints play an additional role during the concept stage. Based on the Ecuadorian Survey of Innovation Activities between
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2009 and 2014, De-Oliveira and Rodil-Marzábal (2019) relate the obstacles to innovation to systemic and organizational features particularly perceived by innovative firms. Using survey data in Mexico and Turkey in 2010, De Fuentes et al. (2020) underline that firm characteristics and the institutional context matter as innovation barriers for firms. For soviet-type economies, there is some empirical evidence on particular types of innovation obstacles (e.g., Meske, 1994; Radosveic, 1998; Glitz and Meyersson, 2020), but a comprehensive insight and understanding is missing to date.

We argue that a socialist innovation system’s constrained institutional arrangement, that means the low research priority, the small incentives to invent and the limited knowledge flow negatively influence the relation between modernization investments and economic growth as these obstacles hinder the investments to fully unfold their positive effects. We propose the following:

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P2a. \text{The low research priority has a negative impact on the growth of a soviet-type economy over time.}
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P2b. \text{The small incentives to invent have a negative impact on the growth of a soviet-type economy over time.}
\]

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P2c. \text{The limited knowledge flow has a negative impact on the growth of a soviet-type economy over time.}
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Fig. 1 summarizes the propositions on the influence of modernization investments and obstacles in an innovation system on the growth of a soviet-type economy in a conceptual framework.

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\begin{array}{ccc}
\text{Inputs} & \text{Moderator} & \text{Outcome} \\
P1. \text{Modernization investments} & + & \text{Economic growth} \\
P2. \text{Barriers} & - & \\
a. \text{Research priority} & \\
b. \text{Incentive to invent} & \\
c. \text{Knowledge flow} & \\
\end{array}
\]

\text{Fig. 1. Conceptual framework on modernization investments, obstacles and economic growth.}
3. Case selection, data and methods

3.1. Case selection

We use the case of the GDR because it represents an exemplary soviet-type country to analyze modernization investments and obstacles in an innovation system context. It is internationally known as the showcase model of a soviet-type economy (Lavigne, 1995). The GDR was a socialist state after Germany’s separation of the Soviet zone from 1945 until its resolution in 1989. After the initial reconstruction, this soviet-type economy put large investments into R&D-intensive industries since the 1960s, but it was also characterized by obstacles to the generation of innovation and decreasing economic growth (Slifer, 2006; Steiner, 2010; Ludwig, 2017). A particular advantage to study GDR’s modernization investments and barriers relates to the nature of data on a former, domestic system that mainly excluded any external influences from e.g. globalized competition or spillovers. The legacies of the GDR recently gained attention by policy makers and scientists 30 years after Germany’s unification, which made primary sources available (e.g., Günther et al., 2020; Glitz and Meyersson, 2020). So far, most of the studies on Germany’s innovation system focus on the developments after GDR’s transformation into a market economy (e.g., Fritsch and Graf, 2011; Eickelpasch, 2015; Cantner et al., 2018).

3.2. Generation of data and indicators

To derive empirical evidence on the modernization investments and obstacles for the case of the GDR, we collected a set of archive, patent and publication data on a yearly basis. We take the entire period from the GDR’s foundation in 1945 to its fall in 1989 into account and put a particular focus on the role of modernization from the 1970s onward for reasons of political significance and data availability. After World War II, the GDR initially had to reconstruct its production facilities and the primary focus was on the development of heavy industries within Stalin’s model of industrialization. Only the late 1960s became a turning point towards a modern industry policy in which technological progress gained significance. In 1990, the unification treaty between the GDR and FRG allowed for a monetary, economic and social union that firstly guaranteed private property, market-based competition, free pricing mechanism and freedom of work and entrepreneurial decisions (Staatsvertrag, 1990). We take an evolutionary view on modernization investments and the obstacles to innovation during the development of the socialist innovation system.

Our dataset refers to the GDR’s innovation system including its economic performance and obstacles. We collect and prepare archival data from statistical sources of the GDR. In addition, we use existing recalculated indicators (e.g. GDP) from the
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literature in order to make a comparative study possible. Our approach requires clarification with respect to data usability and comparability. Krämer and Leciejewski (2021) recently questioned the reliability of GDR statistics due to the tendency of the planners to publish manipulated material for ideological reasons. However, the planners put strict requirements on the compilation and communication of internal, confidential statistics and exercised respective control mechanisms throughout different hierarchical levels to retrieve unfalsified data for the purpose of economic planning (Steiner, 2016). Moreover, operation managers rather tended to deviate from the fulfillment of production plans in order to retract from future planning goals; but the severe sanctions also hindered them from manipulating the data (Heske, 2005b). We therefore use original primary, harmonized and internationally comparable data to exclude any biases from potential manipulation approaches at the publication stage.

The first group of data relates to GDR’s economic performance and the types of modernization investments. We use data by Heske (2005a) that was recalculated according to international statistical conventions to calculate the compound annual growth rate (CAGR) of the GDP in the GDR. The GDP as a standard economic indicator is calculated in constant prices of the year 1995 to exclude any biases in the price setting of primary and core products over time. We provide a comparison to the CAGR of the GDP in the FRG based on data from Statistisches Bundesamt (2002).

GDR’s national statistical office collected data on the yearly amounts of gross fixed capital investments on basis of ten industries, of which only three roughly covered the categorization of R&D-intensive industries. Stäglin and Ludwig (2000) categorized the data according to the more precise international standard classification scheme that allows us to identify the sectors with R&D intensive activities. We therefore used the more sophisticated and original primary data of Stäglin and Ludwig (2000). Moreover, the authors calculated the investments in current prices that enable a better comparison to the extent of investments in each year in the FRG. We used the differentiation of R&D-intensive industries by Gehrke et al. (2013) and identified nine R&D-intensive industries out of 31 industries. We calculated the sum of investments into all R&D-intensive industries for each year and related it to the GDP. For comparing the figures with the FRG, we retrieved internal data on the yearly amounts of gross fixed capital investments.

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1 We refrain from using data from Merkel and Wahl (1991), Maddison (1995) or Slifer (2006) because they do not base their analyses on primary statistics and apply a system of indicators that is not harmonized across the different aspects of the national account.

2 Due to the missing exchange rate from GDR Mark to Deutsche Mark a direct comparison to the FRG is not possible. Based on real prices of foreign trade, only Valuta-Mark could be used as an equivalent.

3 The classification of R&D-intensive industries includes (1) the chemical industry, (2) the production of plastic products, (3) rubber processing, (4) steel and light metal construction as well as railroad equipment, (5) engineering, (6) the production of office machines, (7) automotive manufacturing and repair of motor vehicles, (8) electrical engineering and the repair of appliances as well as (9) medical, precision and optical instruments.
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of the former federal territory from the federal statistical office and applied the same calculations as above.

The second group of data encompasses GDR’s obstacles to modernization. Mostly, evidence on modernization obstacles is based on survey data over a short period of time (e.g., García-Quevedo et al., 2018; De Fuentes et al., 2020; Torres de Oliveira et al., 2021). However, long-term survey data on modernization barriers of a former socialist system does not exist, which leads us to focus on archival data sources.

The first obstacle relates to the low research priority that we operationalize by using data on the amount of spending for R&D for each year based on data from Stifterverband (1990). Due to the distinct definition and categorization of R&D in the GDR, Stifterverband (1990) recalculated the R&D statistics according to international standards of the OECD (Frasci Manual) and provides harmonized data on GDR’s R&D spending for the years 1981 to 1989. We relate R&D spending to the GDP and compared these figures to the respective indicator of the FRG based on data from the federal statistical office. Data on the amount of spending for R&D in the FRG is available from 1975 to 1989.

The second obstacle to modernization refers to the small incentives to invent that is measured by using data on the number of patent applications per employee from 1950 to 1989. Since 1950, inventions were protected by the Office for Inventions and Patents of the GDR (Amt für Erfindungs- und Patentwesen/AfEP) (DPMA, 2021a). In 1968, one year after its foundation, the GDR became a member of the World Intellectual Property Organization (WIPO), which required the compliance to international standards for the application of patents, i.e. its degree of novelty, the inventive activity and the technical applicability. As a result, GDR’s number and quality of patents is comparable to the patents of other countries such as the FRG. In 1990, the AfEP was integrated into the German Patent and Trademark Office, which is the central authority for intellectual property protection in Germany since 1877 (DPMA, 2021b). Its database DEPATIS offers bibliographical and legal event patent data such as the application ID, date, family size, citations and IPC classes. After removing the duplicates, the total number of applications in the GDR counts more than 280,000 patents. We calculated the mean value of the number of applications for each decade to account for the high volatility of patents when used on a yearly basis (Günther et al., 2020). We retrieved employment data from the GDR’s national statistical office and equivalent data of the FRG from DEPATIS and the federal statistical office to point out GDR’s obstacle to modernization in the restricted R&D infrastructure.

The third modernization obstacle regarding the limited knowledge flow is measured by the number of co-inventors per employee in each year. The number of co-inventors is frequently used as a proxy to measure the extent of knowledge exchange and circulation (e.g., Zaggl, 2017). It is retrieved from the patent data and calculated as
mean value of each decade. We relate it to the number of employees in each year and compare this indicator with the respective data of the FRG.

4. The soviet-type economy, its innovation system and modernization investments

The soviet-type economy was based on a central regulation plan without a dependency on capitalist countries and any private property on production inputs. A communist party governed the system; in the GDR the Socialist Unity Party (SED) targeted at a primacy of production with a focus on the autarkic, large-scale industries of heavy engineering and raw materials (Gesetzblatt der DDR, 1958). As other soviet-type economies, the GDR was dominated by commodities (i.e. material goods, fuels, natural resources) to regulated and constant held prices and political strategies based on bargaining and export (Radosevic, 1998). Compared to market economies, manufacturing was more capital-intensive and the focus was on means on production instead of consumer goods (Ludwig, 2017). To serve the high demand for raw materials in line with regional specialization, the closed economy aligned their production and cooperation agreements with other countries of the Council for Mutual Economic Assistance (Rat für gegenseitige Wirtschaftshilfe/RGW) (Steiner, 2013).

Fig. 2 depicts the development of the compound annual growth rate (CAGR) of the GDP as an indicator of the performance and production output of the economy of the GDR from 1971 to 1988. The CAGR of the GDP in the GDR takes 5.3 % in 1971, an average value of 3.2 % over time and decreases to 2.3 % in 1988. It shows an overall downward trend but also some positive outliers that can be explained by e.g. the last wave of privatization and the social-political program during the 1970s as well as the export surplus after the balance of payments crisis during the early 1980s. The CAGR of the GDP in the parallel economy of the FRG takes a value of 10.8 % in 1971, an average value of 6.6 % over time and decreases to 5.3 % in 1988. Despite of its decreasing trend, it is at all times above the CAGR of the GDP in the GDR, which highlights the backlog of the GDR in terms of economic growth.
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The socialist innovation system was characterized by three types of actors: the combintes with their industrial research centers, the institutes of the academy of sciences (AoS), and the higher education facilities. Combinates were large, scale-intensive, vertically and horizontally integrated units of production (Radosevic, 1999; Günther et al., 2010; Ludwig, 2017) and their 38 industrial research centers engaged in applied research to support the implementation of new products and production processes in the GDR (von Tunzelmann et al., 2010). The 60 institutes of the AoS were juridically independent academic research institutes that conducted basic research to prepare new technologies for the industry (Mayntz, 1994). The various institutes of higher education comprised universities and technical schools with an exclusive focus on teaching (Chiang, 1990; Meske, 1993, 1994; von Tunzelmann et al., 2010). There is evidence that GDR’s number of R&D employees in total and across industry sectors was comparable to the FRG even though more employees worked in the public sector (without universities) than in the industry (Meske, 1993).

Modernization investments played a crucial role in the GDR’s innovation system only since the late 1960s when they were treated as a means to accelerate the dynamics of the economy (Lindig, 1995). Due to disproportions in the economic base caused by the division of Germany, investments in heavy industries dominated the portfolio by about 25% and adding investments in energy and automobile accounted even for four-fifths of all industry investments in the 1950s (Ludwig, 2017). The economic reforms during the 1960s led to a massive increase of investments in R&D-intensive sectors and loosened the control of central planning (Kogut and Zander, 2000), which enables innovation activities based on close-to-the-market decisions (Augustine, 2020). These
decisions and investments mostly related to the electrical, apparatus and mechanical engineering industry (Ludwig, 2017). In the 1970s, additional modernization investments were allocated to the chemical, microelectronics and consumer goods industry (RGW, 1971).

Fig. 3 shows the share of modernization investments to GDP in the GDR from 1970 to 1989 compared to the FRG. It increases from 4 % in 1970 to 7 % in 1989 and only the first years of both decades are marked by a short decrease. The share of modernization investments to GDP in the FRG takes an initial value of 4 % in 1970 that slightly decreases to 3 % in 1989. Except for the first year, it is at all times below the modernization investments in the GDR, underlining the comparably higher relevance for modernization in the soviet-type economy.

![Fig. 3. Share of modernization investments to GDP (in %) in the GDR and the FRG.](image)


5. Obstacles to modernization in the socialist innovation system

Despite of the relatively large and increasing investments, GDR’s innovation system included severe obstacles to modernization that have contributed to the backlog of the soviet-type economy compared to the parallel market economy of the FRG with regard to its performance (Allen, 2001; Slifer, 2006; Steiner, 2010). In 1989, the final net debt of the GDR was 19.9 billion Valuta-Mark (Deutsche Bundesbank, 1999) and the productivity accounted for only one-third of the FRG (Ludwig, 2017). We use the categorization of Chaminade et al. (2012) to transfer the obstacles to innovation in a
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A market-based system to the case of a soviet-type economy. There is empirical evidence that the obstacles to innovation in a socialist innovation system include the low research priority, the small incentives to invent and the limited knowledge flow (Meske, 1990; Günther et al., 2010; von Tunzelmann et al., 2010).

Manifold studies argue that the relatively low research priority in the central plan produced inadequate incentives and capabilities to innovate and achieve economic growth (Allen, 2001; Slifer, 2006; Steiner, 2010; Berliner, 2019). At least the failure to comply to the central plan and the loss of economic activities were identified early as the deficits of the system (Gleitze, 1975). The system was based on a linear model of technology push in which knowledge was only transferred from the AoS to the industry (Balázs, 1993; Meske, 1994; Allen, 2001; von Tunzelmann et al., 2010; Günther et al., 2020). As a result, research of the AoS was oriented towards central planning goals and only insufficiently separated from production (Radosavic, 1998), suffered a lack of demand (Balázs, 1993) and often could not get into the application phase (Chiang, 1990). The system was not able to integrate innovations in different business functions and learning by doing or using was less common in relation to externalized R&D (Radosavic, 1999). Because of the rewards for meeting the central planning goals, managers in the industry often employed their R&D personnel in the production unit to avoid a slowdown in the rate of output (Allen, 2001). It is the poverty of institutional support rather than firm’s knowledge that lacked coordinated innovation on markets with competition, specialization, prices, contracts and experimentation (Kogut and Zander, 2000). Political conformity and the reliance on authority and hierarchy were more important than original ideas in the socialist innovation system (Augustine, 2020).

Fig. 4 illustrates the comparatively low research priority in the GDR that is operationalized by the share of spending for R&D to GDP compared to the FRG from the 1975 to the 1989. The share of spending for R&D in the GDR accounts for 3.2 % of GDP in 1981, takes an average value of 3.1 % over time and slightly diminishes to 2.9 % in 1989. In the parallel market economy of the FRG, the share of R&D spending to GDP is 4.3 % in 1975, takes an average value of 4.9 % over time and increases to 5.3 % in 1989. It is above the share of the GDR’s spending for R&D at all points in time. Thus, we identify a relatively low research priority in the GDR.
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The R&D infrastructure was characterized by a continuous decrease of researchers and graduates that faced smaller incentives to invent as a result of GDR’s distinct patent system and its inadequate supply of inputs (Lindig, 1995). The organizations received a financial budget based on their size rather than their projects or the market demands, which reduced the performance competition and demotivated the R&D staff (Chiang, 1990). R&D employees often had only little time and resources to develop new technologies (Lindig, 1995), why they favored mainly small improvements with low financial costs or even pursued non-R&D-related tasks such as trouble-shooting to maintain the production of a broad range of goods (Radosevic, 1998). They were restricted in the implementation of their ideas as a result of the technology-push model (Balázs, 1993) and mainly served production activities with only limited access to equipment, resulting in a lower quality of research (Mayntz, 1994) and frequency and impact of patents (Meske, 1994). The primary function of GDR’s patents was to formulate and solve R&D tasks (Hemmerling, 1986) and they were treated as ‘free goods’ (Hanson and Pavitt, 1987). The ministries provided ‘soft incentives’ to trigger the development of technologies, but the results from the inventive processes could not be appropriated from commercialization (Radosevic, 1998). Research projects were only assigned by higher level authorities and not by production or sales units that would allow for the technology’s practical use (Allen, 2001). The lack of innovation incentives and modern production equipment impeded a diffusion of new technologies in the GDR (Günther et al., 2010; von Tunzelmann et al., 2010). In addition, the focus on certain disciplines (Kozlowski et al., 1999) and the imitation of Western products reduced the emergence of new technologies (von Tunzelmann et al., 2010). Especially industrial espionage served as a means to retrieve knowledge on Western technologies (Glitz and Meyersson, 2020). R&D capacities were mainly concentrated in mechanical engineering but less in electronics and software (Katkalo and Mowery, 1996) and many industries had to maintain obsolete and worn-out facilities (Ludwig, 2017). Despite of its

**Fig. 4. Share of spending for R&D to GDP (in %) in the GDR compared to the FRG.**

*Data source: GDR: Stifterverband (1990); FRG: Federal statistical office (Statistical yearbooks of 1978-1990).*
comparable number of R&D employees, the portfolio and dynamic of patent applications to the FRG, the GDR could not catch-up in terms of how many patents were filed per R&D employee (Günther et al., 2020).

Fig. 5 depicts the incentives to invent in terms of the average number of patents per 1,000 employees in the GDR compared to the FRG from the 1950s to the 1980s. It takes an initial value of 0.3 in the 1950s, an average value of 0.9 over time and increases to 1.5 during the 1980s. In the FRG, the average number of patents per 1,000 employees begins with 1.0 in the 1950s, takes an average value of 1.6 over time and increases to 2.1 during the 1980s. Even though both average values increased over the entire observation period, GDR’s number of patents per employee was constantly lower than in the FRG, which we relate to the smaller incentives to invent. A similar trend is observed for the number of patents per residents over time (Günther et al., 2020).

Moreover, the GDR encompassed severe constraints in the knowledge flow. The combinates indeed developed trustful and long-term cooperations with the scientific institutes to share knowledge (Meske, 1994), but they had only limited opportunities to cooperate with other actors (Radosevic, 1998), especially with regard to innovative activities (Radosevic, 1999). These cooperations based on central planning decisions and hindered the industry to receive any feedback from customers or to profit from knowledge spillovers (Günther et al., 2010; von Tunzelmann et al., 2010). Because of the separation between production and markets, managers were only poorly informed of the international state-of-the-art which made own technological developments rapidly

4 Some minor cooperations to selected Western suppliers existed to negotiate on technical belongings; however, they were constrained by foreign trade organisations (Sandberg, 1989).
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Technological developments were in conflict between the (international) state-of-the-art, the (mostly unrealistically high) central planning goals and the (often dysfunctional) division of labor between the countries of the RGW (Lindig, 1995). While formal cooperations between the actors were often weak, informal networks to exchange materials and spare parts were needed to compensate the shortages and achieve the production plans (Radosevic, 1999). A research regulation in 1986 aimed to increase the knowledge transfer between science and the industry through demanding the AoS and universities to achieve 50% of their revenues from contract research, which, however, led to huge capacity deficits in implementing innovations, an increased focus on incremental improvements and a neglect of basic research instead (Meske, 1990; Mayntz, 1994). The compliance with the central plan and the independency from international competition and markets led to devastating information deficits (Günther et al., 2010).

Fig. 6 illustrates the limited knowledge flow as the average number of co-inventors per 1,000 employees. There are no co-inventors in the GDR until the 1970s, after which the average value takes 0.2 over time and increases to 0.6 during the 1980s. In the FRG, the average number of co-inventors per 1,000 employees starts with 0.4 in the 1950s, takes an average value of 1.0 over time and increases to 1.2 during the 1980s. The graph indicates a continuous increase of the GDR’s number of co-inventors over time in contrast to the initially increasing but during the 1980s decreasing value of the FRG. However, it is largely below the average values of the FRG, which we refer to GDR’s limited knowledge flow.

Fig. 6. Average number of co-inventors per 1,000 employees in the GDR per decade compared to the FRG.

Data source: Number of patents: DEPATIS; Number of employees in the GDR: National statistical office (Statistical yearbooks of 1969-1989); Number of employees in the FRG: Federal statistical office (Statistical yearbook of 2005).

However, military sectors could use larger formal networks in contrast to civil sectors that relied on informal networks (Radosevic, 1999). Due to the arms race with the US, the military sectors gained a more prominent role in the soviet-type economy (Allen, 2001).
6. Discussion

Our findings have important implications for the literature on innovation systems, innovation barriers and policy. First, our study shows that GDR’s innovation system was characterized by large modernization investments that shaped its evolution and outcome (Proposition P1). In particular, the share of modernization investments to GDP in this socialist innovation system increased over time. At all points in time, it is above the share of modernization investments as compared to the market economy of the FRG. This finding is of crucial importance for recent studies that underline the role of investments in an innovation system context (Binz and Truffer, 2017; Chaminade et al., 2018; Hipp and Binz, 2020). We extend the present focus on investments into R&D to provide new empirical evidence on the evolution of modernization investments in a socialist system of innovation compared to a market economy.

Future studies could build on our findings by providing statistical evidence on the influence of modernization investments on the growth of an economy such as the production growth or productivity of the actors therein. As other research in this field, we focus on a single-case study (e.g. Alaja and Sorsa, 2021). Since innovation systems depend on their geographical and political context, one can expect different evolutionary patterns for e.g. market economies, but similar patterns for centrally-organized or highly regulated economies such as China or Russia (Dominguez Lacasa et al., 2019). Cross-comparative studies of different countries would contribute to more generic results on the effects of modernization investments.

Our second contribution concerns the literature on innovation barriers by extending our knowledge on their embeddedness within a socialist system of innovation (Propositions P2a-c). Despite of the large modernization investments in a soviet-type economy, a constantly decreasing economic growth is observed that can be partly explained by the structure of the innovation system. Our findings show that several types of modernization barriers exist in the socialist system that influence its structural development. I.e. the amount of spending for R&D, the number of patents and the number of co-inventors increased over time but remained at a much lower level in the GDR compared to the FRG. We relate these findings to the obstacles to modernization that include the low research priority, the small incentives to invent and the limited knowledge flow in a socialist innovation system. We add to recent research on innovation barriers (e.g., De Fuentes et al., 2020; de-Oliveira and Rodil-Marzábal, 2019; García-Quevedo et al., 2018) and show that the combination and persistence of these obstacles influence the evolution of an innovation system. We went beyond the use of survey data (e.g., Torres de Oliveira et al., 2021) and apply a set of comparative economic and innovation-related indicators to a former socialist regime in which long-term survey data on modernization barriers is limited at its best.
Further research could find alternative measures of innovation barriers in a former or current state-led economy and examine their influence in the relation between modernization investments and economic growth. We used several comparative indicators to operationalize the obstacles to modernization but combine internal information such as the number and quality of products or materials stocks was impossible to obtain. Despite of our effort to compile a comprehensive set of archival data sources, future studies may access more fine-grained information. The findings could then be linked to recent studies that include various firm-level determinants (e.g., De Fuentes et al., 2020). Especially for the case of a former soviet-type economy, a more complete picture on the determinants of its fall should be gained.

The last contribution relates to the literature on innovation policy. Recent innovation policy approaches use investments as means to solve macro-level societal problems or follow specific missions in an innovation system (Ghazinoory et al., 2020; Hekkert et al., 2020; Deleidi and Mazzucato, 2021). Especially regarding current missions such as digitalization or energy transition, potential barriers in the underlying innovation system should be considered. Our study focuses on a former soviet-type economy that was characterized by increasing investments, but the persistent obstacles to modernization in the structure of the system have impeded their effects and contributed to its demise.

Future studies should anticipate the role of modernization investments to be included in the direction of mission-oriented innovation systems. In parallel, the obstacles embedded in a system of innovation should receive attention since they can change the direction of structural change that is pursued by policy makers. Their role beyond a national framework and within global value chains should be disentangled as well.

7. Conclusion

This study attempted to develop a new framework on the role of modernization investments and obstacles during the evolution of a socialist system of innovation. By combining knowledge on innovation system and barriers literatures, we derived new propositions on the importance of modernization investments for a system’s evolution and how this link is influenced by several obstacles to innovation. Using original primary time series data, we provide empirical evidence on the economic growth, investments and barriers to modernization of the GDR as an exemplary socialist country and link these features to the configuration and limits of its system of innovation.

The results show that the GDR’s innovation system was characterized by large modernization investments that shaped its structure and evolution. The modernization of an economy is related to the investments in R&D-intensive industries, which were at all time larger in the GDR compared to the parallel market economy of the FRG. However,
the obstacles to modernization affected the evolution of its socialist system of innovation. A comparison to the FRG shows that the GDR was not only marked by lower and decreasing economic growth, but also by severe obstacles to innovation that related to its low research priority, the small incentives to invent and the limited knowledge flow. I.e. the amount of R&D spending and the number of patents and co-inventors in the GDR remained largely below the benchmark of the FRG. Based on these findings and recent studies on policy mixes (e.g., Magro and Wilson, 2019), we recommend policy makers to adopt the investments in R&D-intensive sectors to enable the economy’s modernization and to reduce its obstacles with regard to the features of the specific and evolving innovation system.

These findings are important since policies allocated significant amounts of support to R&D-intensive industries without considering the obstacles embedded in the system of innovation. Recent evidence shows that investments in key sectors such as digitalization or renewable energies could not unfold their effects due to substantial obstacles in the innovation system structure (e.g., Belousova et al., 2020; Hipp and Binz, 2020; Moraes Silva et al., 2020). Especially the modernization obstacles of former soviet-type regions left their mark in today’s system structures in terms of the low research priority, the small incentives to invent and the limited knowledge flow. Our study provides an explanation on the mechanisms behind the missing effects from investments and delivers new insights on the embeddedness and persistency of modernization obstacles in a national system of innovation. Future innovation policies could examine the related system structures of the respective regions and their potential obstacles to modernization by applying our proposed framework.

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