Ready, Set, Unify: The Uneven Race between Trabants and BMWs*†

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Abstract

Even 30 years after the reunification, regions in East Germany (the former GDR) live in considerably different economic conditions, with the average GDP per capita still about 20 percent below the average level in the West German regions. In this paper, we explore the factors that impeded faster convergence despite massive support to the East with a particular focus on technological differences and firm behavior. In the immediate aftermath of the reunification, production in the former GDR exhibited a rapid catch-up with the West with a pick-up in labor productivity. But the convergence tapered off quickly thereafter, with a stark difference between East and West German firms' product qualities persisting ever since. We build a quantitative model of innovation, competition, and regional integration that can mimic these dynamics and provides a suitable setting to evaluate alternative policies that could have altered these dynamics. We show that large initial technological differences depressed Eastern firms' incentives to compete and invest in technology improvements, perpetuating initial gaps. Delaying reunification, that is, opening up to competition from the West, would not help Eastern firms build up capacity. Sustained support for R&D in the East from the West could have helped shrink persistent gaps in product quality and income, although more effective alternatives appear to be subsidies to Western firms via either R&D support, with knowledge spillovers lifting also Eastern technology, or direct income support to facilitate technology transfer to the East via licensing.

Keywords: German reunification, regional growth, industrial policy, innovation policy, step-by-step innovation models

JEL Classifications: O11, O25, O3, R1

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1 Introduction

Even 30 years after the reunification, regions in the former East Germany (GDR) live in considerably different economic conditions compared to their West German counterparts. While there have been notable improvements in the living standards of Eastern households, as of 2021, GDP per worker in the East still remains about 20 percent lower than that of West Germany (Figure 1), accompanied by a comparable average wage gap, even as the East has received substantial financial support for its economic development over the years (Figure 2). The enduring economic gap between East and West Germany continues to receive perennial attention from both the general public and academia.[1] It also remains a salient topic in political campaigns and contributes to political polarization in Germany and the rise of populist parties (see, e.g., Weisskircher, 2020; Politico, 2021; The Economist, 2023).

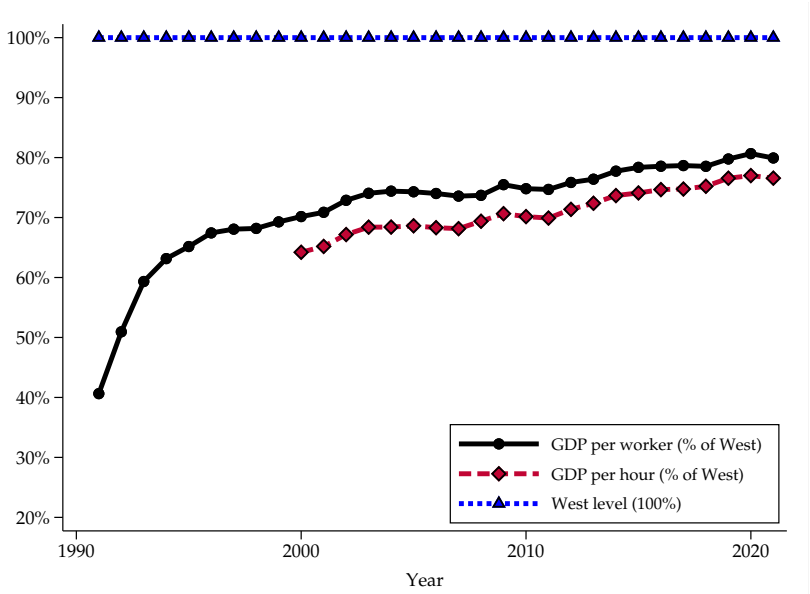


Figure 1: GDP per worker and hours worked, East in percent of West

Notes: The y-axis displays the level in terms of percent relative to the West. Source: national accounts of Germany.

In this study, we investigate the causes of persistent regional disparities in productivity, their link to firms' innovation incentives, and the productivity and welfare implications of policies (financed by the West to support Eastern development) that could have potentially sped up the economic convergence of the two regions. We develop a dynamic general equilibrium model of firm-level competition, innovation, and endogenous growth with two regions that allows us to examine the transitional dynamics set off by the unification of the regional economies. We

[1] See, for instance, The Economist (1999), The Economist (2014a), The Economist (2014b), Euractiv (2023), Becker et al. (2020), and Burda (2020).

combine it with comprehensive micro-level data; in particular, information on firms' prices in very narrow product classes plays an instrumental role in determining the evolution of product qualities and, thus, the relative technological performance of firms in the East and West. Our results highlight that (i) the inferior technological level of Eastern firms initially discouraged them from competing with Western rivals, reducing their incentives to improve their technology, (ii) existing policies did not focus on support to technological upgrading of Eastern firms, and (iii) policies that focus on technology transfers to the East—via direct licensing or spillovers—prove more efficient than providing direct support to Eastern firms' R&D.

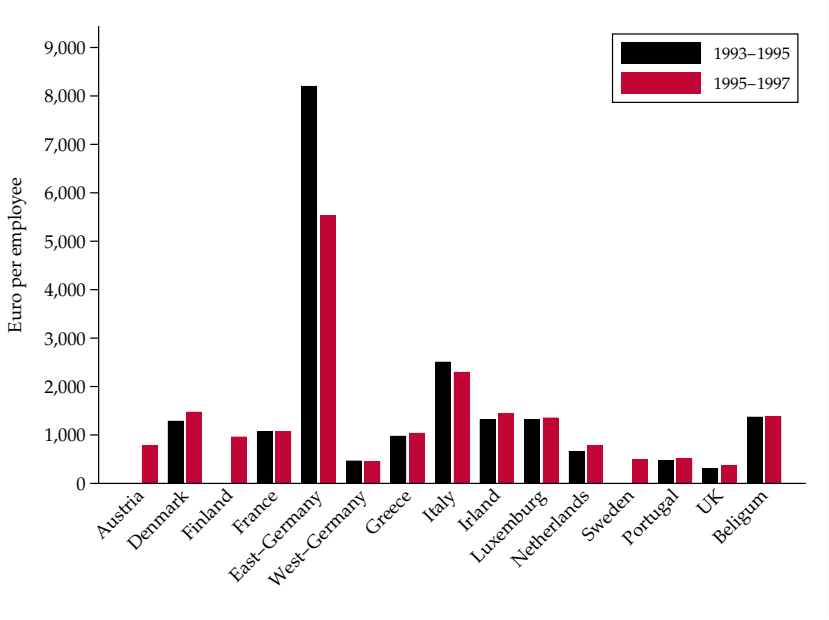


Figure 2: Manufacturing subsidies per employee, by countries

Notes: Manufacturing subsidies in Euro per employee, by countries. Values of 1996. Source: BMF (1999).

Our study is motivated by the established observation that the East struggled to produce competitive products and viable firms vis-à-vis the West at the time of reunification (Akerlof et al., 1991; Collier and Siebert, 1991). Figure 3 uses the example of the Trabant (East) and BMW (West) to illustrate the profound difference in product quality and production technology between the former GDR and West Germany.[2] Figure 3a displays the Trabant 601, produced by Sachsenring Automobilwerke Zwickau from 1964 to 1990. Following the German reunification, the Trabant faced new major Western car manufacturers such as Mercedes, Audi, Volkswagen, and BMW, as new competitors. Figure 3b shows a BMW M3 cabriolet, which was produced from

[2]While certainly being a drastic example, the automobile industry is just one of many industries where Eastern firms faced a significant quality disadvantage compared to their Western counterparts. Upon entering world markets, Eastern firms had to contend with well-established Western brands, such as Adidas, Puma, Hugo Boss (clothing), Nivea (cosmetics), Haribo, Rittersport (food), Bosch, Braun (electronics), and Quelle (retail). Some of these brands even dominated their respective sectors globally.

1986 to 1991 by BMW. Even after substantial price cuts, the Trabant could not retain a reasonable share of the market, and its production was discontinued swiftly.[3]



A) Trabant 1.1, 1990-1991



B) BMW M3 Cabriolet, 1986-1991

Figure 3: Trabant vs. BMW

Source: Trabant: Picture by Phil Simpson at https://www.flickr.com/photos/philippos/4605484707. BMW: https://www.autoevolution.com/news/the-bmw-m3-e30-convertible-was-the-embodiment-of-1980s-open-top-madness-192380.html, accessed 07/11/2023.

The significant technological disparity between Eastern and Western producers contributed to the massive shake-up of the industry in the East in the wake of the reunification, triggering an unprecedented contraction on impact. Still, helped by massive financial support from the West, the Eastern economy was able to recover swiftly, with its GDP per worker reaching two-thirds of the west German level by the mid-1990s. However, convergence has slowed considerably since then (Figure 1). Importantly, most East German producers that remained in business continued to produce goods of inferior quality while competing through lower prices, only taking advantage of lower production costs in the East (Mertens and Müller, 2022). Indeed, similar to many indicators at the macro level, there still exists a strikingly persistent difference between the prices charged by Eastern and Western producers of similar products, as shown in Figure 4 at the 4-digit NACE industry level (we examine this regularity at a more granular level in Section 3). These persistent gaps at the micro level provide key information that guides the theory that underlies our model and allows us to determine the magnitude of the persistent technological gaps between Eastern and Western producers through the lens of the theory.

The first goal of our analysis is to investigate the factors that led to persistent technological disparities between producers in the East and West and the ways in which they may have impaired economic convergence between the two regions. To this end, we build a general-equilibrium framework of endogenous firm dynamics based on step-by-step innovation models

[3]Despite significant price declines for the Trabant after the reunification (down to less than 6,000DM), consumers favored West German brands (AUTOStraßenverkehr, 1990). The average new car price back at that time was approximately 30,000DM (Zentralverband Deutsches Kraftfahrzeuggewerbe, 2022). The BMW M3 cabriolet was priced at 93,250DM, while a more affordable BMW 316i was priced at 27,500DM (Bayerische Motoren Werke Aktionsgesellschaft, 1990).

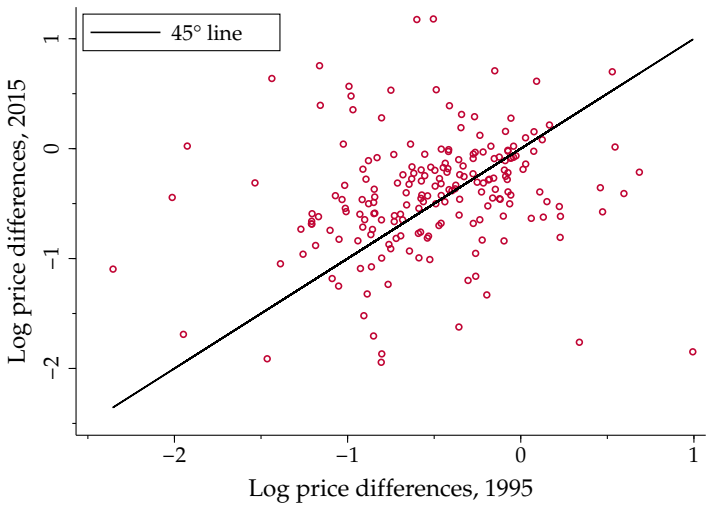


Figure 4: Price differences in 4-digit industries, 1995 vs. 2015

Notes: The figure plots log average price difference between East and West German firms across 4-digit industries in 1995 and 2015 based on the German firm-product-level price data. Price differences are computed as the log differences between weighted average prices for East and West German producers. We first compute the sales-weighted average prices in each product-region pair and then construct log-differences between the regional averages. We drop the top and bottom two percent of 9-digit product-level price gaps. The sample is restricted to products that are manufactured by at least three firms and 199 4-digit industries that are observed in both 1995 and 2015. Negative values indicate lower prices in the East.

(Aghion et al., 2001; Aghion et al., 2005; Acemoglu and Akcigit, 2012; Akcigit and Ates, 2021). We extend the basic framework to include two regions that trade goods without frictions in a unified economy. The unified economy consists of a unit measure of tradable products—in addition to a non-tradable good. In each product line, one firm from each region produces a different variety, and these firms engage in Bertrand competition for higher market share. Their varieties differ in product quality, which affect their prices and the market share of the firm. Firms can enhance their product quality through successive innovations investing in R&D, while the firm with inferior quality also benefits from technology spillovers from the superior firm improving their quality at an exogenous rate. Firms differ also in their production costs due to region-specific labor productivity, which influences their competitiveness in the marketplace and evolves endogenously to reflect the changes in relative wages across the two regions observed in the data. In addition, region-specific R&D efficiency drives comparative advantage in innovation.

Linking competing firms' relative technology level to their position in market competition and their share of the market, which in turn influences the innovation incentives of firms, the step-by-step innovation structure underlying our framework provides a natural setting to investigate how technological differences among firms interact with their innovation investments and determine endogenous dynamics of aggregate productivity growth and economic convergence. A salient implication of this setting, which is the focus of most studies of this framework, is the so-called escape-competition effect; that is, close market competition between firms intensifies

their innovation effort with the goal of getting ahead of their rival and escape competition. In our work, instead, a related but different force is key: the *discouragement effect*. This effect implies that firms that are technologically too laggard lose their hope of catching up with and outpacing their rival, which, in turn, depresses their incentives to innovate. As such, the discouragement of laggard firms perpetuates the technological disparities, weighing on regional convergence.

We quantitatively assess the technological dynamics behind the regional convergence and the role of the discouragement effect in a calibrated version of the model carefully disciplined by micro-level data. We calibrate the transitional path of the model to mimic the dynamics of the Eastern and Western German regions over the period between 1995 and 2015, including the patterns of relative income and wages. While time-varying specifications of regional labor force matched to the data capture the variation in regional population as a result of migration flows, an exogenous path of regional productive efficiency allows the model to capture various technological differences between regions in addition to product qualities.

Most notably, our calibration strategy takes advantage of the detailed price data on the products of Eastern and Western German firms, which cover almost 6,000 product codes within the manufacturing sector. We use the distribution of relative average prices across the products produced in the two regions within each of these finely defined products—as displayed in Figure **??**—to discipline the model counterpart of relative price distribution across product lines and its evolution. The ultimate goal of this exercise is to inform the technology dynamics across the regions in the model, which admits a clear mapping between firms' relative technologies and their relative prices. As a result, the calibration of the price distribution disciplines the distribution of relative product qualities in the model, once the production costs are controlled. Hence, the detailed product-level price data proves instrumental in deriving the dynamics of product qualities through the lens of the economic theory. The calibrated model indeed points to persistent technology gaps between regions owing to the discouragement effect.

The calibrated model serves as a laboratory to examine several counterfactual policy settings. To start, we evaluate the implications of delaying reunification—an alternative debated fiercely at the time—which we model as minimal goods trade between the regions via high tariff barriers approximating autarky. The temporary increase in trade barriers depresses the technological progress—measured by the average quality of products in a region—and reduces welfare (in consumption-equivalent terms), because firms lose access to the market in the other region, and the reduced rents weigh on innovation incentives. Subsidizing concurrently R&D in the East could boost innovation effort, but the resulting benefits could offset the associated costs only over the longer policy horizons.

Next, we evaluate various transfer schemes to the East funded by the West. Two prominent schemes in the aftermath of the reunification were lumps-sum transfers to households and firms,

which we model as consumption subsidies to Eastern consumers, and production subsidies to Eastern firms. Neither of these policies prop up the technological development of Eastern firms. They do improve welfare in the East but at the expense of the welfare of Western consumers. By contrast, channeling the same amount of resources to subsidize R&D expenditures by Eastern firms indeed accelerates average product quality upgrading in the East. However, it leads to notable welfare losses in both regions over the short to medium policy horizons stemming from lump-sum taxation of Western consumers to fund subsidies and the shift of production resources to R&D activity in the East, with benefits from higher product qualities accumulating and dominating welfare over time.

Given that doing R&D is less costly for Western firms in the calibrated economy, an alternative policy could be subsidizing R&D by Western firms, with the expectation that knowledge spillovers help lift average quality of Eastern products. This policy indeed proves more effective: average product quality growth picks up in the East, although, in relative terms, it falls behind the West faster than in the simulated baseline (calibrated) economy. Welfare increases in both regions (except for the immediate term in the West) and more so over longer horizons. Alternatively, we consider licensing of Western technologies to Eastern firms, with resources for transfers in other policy schemes analyzed being used to make up for the losses of Western firms that stem from reduced market share as Eastern firms improve their quality through licensing. A salient finding is that this policy front loads welfare gains in both regions as opposed to R&D subsidies. Therefore, a policy mix that smooths out welfare gains over time would be the combination of technology licensing by Western firms while subsidizing their R&D expenditures.

To sum, our analysis delineates technological underpinnings of persistent economic gaps between the East and West Germany. It points to initial technological differences coupled with the dynamics of market competition as the root cause of persistent product quality disparities between the East and the West and the slow pace of economic convergence. The main mechanism sketches how initial, inferior technological conditions of Eastern firms could perpetuate technology and income gaps by feeding into endogenous forward-looking decisions of competing firms. Policies that aim at boosting technology upgrading of Eastern firms could alleviate this problem. That said, our results emphasize that standard support schemes such as R&D subsidies to Eastern firms would not be welfare-improving over the relevant policy horizons in light of the estimated high cost of doing R&D in the East. A more effective use of resources would rely on technology transfers from Western firms via licensing while also supporting their innovative activity. Instead of requiring Eastern firms to build up their technology base themselves, this arrangement would have brought them to a more equal technological and competitive position more quickly, allowing them to benefit from advancements in the region with comparative advantage in R&D through knowledge diffusion.

Literature Review. Applying a theory based on the step-by-step innovation framework, our study contributes to the burgeoning work on the quantitative analysis of this framework (Akcigit and Ates, 2023; Cavenaile et al., 2023; Chikis et al., 2021; Liu et al., 2022). While not an open-economy model per se, our setting analyzes the integration of two regional economies, whose firms are trading and competing with each other, taking it closer to the recent open-economy examples of the step-by-step innovation framework (Akcigit et al., 2018; Akcigit et al., 2024; Choi and Shim, 2024). As in rare examples, the analysis concerns the transitional dynamics; yet, our model offers a richer and more nuanced environment of firm-level competition guided by the empirical analysis. It features regional firms that differ along multiple margins (product quality, productive efficiency, and labor cost) all of which evolve over time and affect firms' competitiveness, pricing decisions, and market share.

With regional economic disparities at its center, our study relates to the literature on regional convergence (Barro and Sala-i Martin, 1992; Blanchard and Katz, 1992; Sala-i-Martin, 1996; Caselli and Coleman II, 2001; Barro, 2012; Gennaioli et al., 2014). The extraordinary experiment of German reunification has attracted notable attention in this context (Canova and Ravn, 2000; Burda and Hunt, 2001; Sinn, 2002; Burda, 2006; Uhlig, 2008). Most studies of the dynamics of economic differences between East and West Germany approach the issue with a focus on factor markets, particularly the labor market (Burda and Hunt, 2001; Hunt, 2006; Uhlig, 2006; Snower and Merkl, 2006; Fuchs-Schündeln and Izem, 2012; Findeisen et al., 2021; Heise and Porzio, 2022).[4] Our study offers a complementary yet distinct perspective. It highlights another factor that has been barely explored methodologically—namely, the technological underpinnings of persistent regional economic disparities at the firm level. We uncover these technological factors and the endogenous mechanisms underlying them with the help of a structural dynamic general equilibrium model that is carefully disciplined by macro and detailed micro-level data. In this regard, our study sheds fresh light on the dynamics of regional economic development and convergence, which can face significant challenges even when it concerns two regions that are much alike and integrate under felicitous circumstances (Burda and Hunt, 2001).[5]

Finally, our policy analysis contributes to the literature on industrial policy, which has received renewed interest recently (Aghion et al., 2015; Acemoglu et al., 2018; Akcigit et al., 2022; Criscuolo et al., 2019; Liu, 2019; Lane, 2022).[6] Evaluating policy implications over the transition of the economy and differentiating between the short and long term, our investigation shares the spirit of Akcigit et al. (2018) and Choi and Shim (2024). Moreover, the distinction between R&D subsidies and licensing policies provides a more nuanced study of technology policy in a

[4] On a different note, Burchardi and Hassan (2013) examine the effect of social ties on regional growth dynamics.

[5] For instance, East and West Germany do not differ much in salient characteristics such as climate, legal system, or language, as noted by Uhlig (2008).

[6] See Juhász et al. (2023) for an expansive review.

departure from recent applications (Atkeson and Burstein, 2019; Akcigit et al., 2018; Akcigit et al., 2024). In their seminal contribution, Acemoglu et al. (2006) distinguish between policies that foster technology adoption or innovation and provide a theoretical analysis of their implications depending on the development stage of a country. More recently, Choi and Shim (2024) provide a quantitative analysis of the role adoption and imitation policies played in South Korea's rapid economic development. Our work complements these papers by studying place-based policies, carefully evaluating their implications in the two regions and also contrasting them with various other policy alternatives.

In the remainder, Section 2 provides a historical and institutional account of German reunification. Section 3 presents stylized facts from the empirical analysis of both aggregate and detailed firm-product-level data. Section 4 introduces the model, and Section 5 describes the quantification of the model. Section 6 discusses policy evaluation and welfare implications. Finally, Section 7 ends with concluding remarks.

2 Institutional and Historical Background

At the end of World War II, Germany was divided into a democratic capitalist West and a socialist East, a partition that lasted until the fall of the Berlin Wall on November 9, 1989, and the reunification in 1990. The integration of 16 million East Germans was a formidable challenge for the West. A key political issue in the 1990 federal election, which included participation from the East, was the timing and speed of economic integration. West German Social Democrats (SPD) expressed reservations about a swift monetary and economic union and advocated for a more gradual adjustment process while maintaining some degree of separation between the two German regions for a certain period. By contrast, conservative leaders from the Christian Democrats (CDU), like Chancellor Helmut Kohl, advocated for a more rapid integration process, and ultimately, the CDU prevailed in the 1990 federal elections.

After the reunification, it quickly became clear that the former centrally planned East German economy was ill-equipped to compete in a globally-intergrated market economy. Evidence suggests that before 1990, only 10 percent of the former GDR's workforce were employed by firms viable at world market prices (Akerlof et al., 1991; Collier and Siebert, 1991). Moreover, East German firms struggled with low product quality when entering the global market (Collier and Siebert, 1991; Mertens and Müller, 2022). Exposure to high-quality West German products from world-leading manufacturers (e.g., BMW, Volkswagen, Adidas, Bosch, Braun, Siemens, Bayer, Haribo among many others) has eroded the confidence of even East German consumers in their own regional products. The swift transition to a monetary union with the West further eroded the competitiveness of East German producers, causing wages and labor costs to surge.

The gyrations caused by the rapid economic integration resulted in an unprecedented economic breakdown in East Germany. Between 1990 and 1991, East Germany lost about one third of its GDP, and non-employment rose from zero to 30 percent.[7] The severe economic breakdown and social discontent prompted the government to respond with substantial transfers.[8] Between 1991 and 2008, the East received about 1,400bn Euros in transfers from the West, primarily (about 900bn) in the form of social benefits such as pensions, unemployment insurance, and active labor market policies (Paqué, 2009). The remaining 500bn Euros mainly funded public expenditures such as infrastructure development, repayment of GDR debt, and horizontal federal transfer schemes among the German states ("Länderfinanzausgleich"). That said, only about 100 billion Euros (approximately 2% of East Germany's cumulative nominal GDP between 1991 and 2008) were disbursed as direct investment subsidies to private firms.

Another major undertaking at the time was the overhaul of the productive capacity in the East. In a quest to revamp the Eastern production units and establish economically viable private enterprises that can operate in the integrated market economy, a publicly owned privatization agency, the *Treuhandanstalt*, founded in 1990, overtook the assets and liabilities of the state-owned enterprises of the former East Germany. The Treuhand inherited firms that employed about 4 million employees with the mandate to dismantle these enterprises, determine and privatize viable units, and shut down the unviable ones.[9] Policy makers opted for a rapid and comprehensive privatization process, with a tight deadline for the Treuhand to privatize the entire Eastern economy by the end of 1994, which the Treuhand managed to accomplish to a large extent.

Helped by these extensive efforts, the Eastern production quickly recovered in the first half of the 1990s following the massive sudden blow on impact. GDP per worker in the East increased rapidly to two thirds of the West German level by 1995 from about one third at the turn of the decade (see Figure 1), likely reflecting quick gains from substantial capital investment and improved reallocation of labor across new establishments. However, the convergence quickly lost steam in the second half of the decade—a striking twist that we strive to comprehend through our analysis.

To summarize, the German reunification entailed a swift yet challenging process of economic integration, enormous economic dislocations in the East, and a major transformation of the Eastern economy, supported by the substantial financial transfers from the West to the East. While the early years were characterized by a rapid recovery following a large contraction on impact, the pace of economic convergence has weakened abruptly in the aftermath of this initial period of

[7] Non-employment includes unemployment and employment in publicly subsidized labor market programs. See Burda and Hunt (2001) for an insightful analysis of the early years of transformation.

[8] Based on national account data, we calculated that in the initial years of unification, total consumption in East Germany exceeded East German GDP by over 70%.

[9] Akcigit et al. (2023) provide an in-depth analysis of how the terms imposed by the Treuhand affected subsequent firm performance.

fast economic growth. It is this period of tepid convergence, which has contributed to sustained economic disparities between the East and the West, and it is the focus of our investigation.

3 An Empirical Account of Convergence and Firm Performance

We use various data sets to collect key stylized facts on the German economy. We rely on aggregate data and rich firm- and product-level micro data supplied by the German statistical offices. In the following, we first describe our micro data. Subsequently, we present our stylized facts that motivate our theory. Throughout our empirical analysis, we define East and West Germany without Berlin because the German data does not allow to differentiate between its former Eastern and Western parts.

3.1 German Firm- and Product-level Data

We use annual panel data on German manufacturing firms and their products from 1995 to 2017. The data are collected and supplied by the German statistical offices and comprise two separate statistics covering firm-level and product-level information, respectively.[10]

Firm-level cost structure survey. We obtain information on firms' R&D and production workers from the cost structure survey (KSE), which is an annual firm-level panel data provided by the German statistical offices. The KSE is a representative and stratified survey that rotates every 4-5 years and covers a 40 percent sample of all German manufacturing firms with at least 20 employees. Firms are defined as legal units. The data cover firm location, sales, and several cost positions such as wage bills and intermediate input costs by various categories. Most relevant to our analysis is the information on firms' R&D and production workers. We clean the data following Mertens (2022).

Firm-product-level data. We use annual information on sales and quantities of firms' individual products from the manufacturing sector product survey (product module). The product module covers the population of products manufactured in plants with at least 20 employees. The data links products to plants and firms, and we focus our analysis on the firm-level. 90 percent of firms in our data are single-plant firms. Products are categorized by an extremely fine nine-digit product classification, defining around 6,000 distinct products in our data.[11] From the sales and quantity information, we constructed product prices. For 30 percent of products,

[10] Data sources: RDC of the Federal Statistical Office and Statistical Offices of the Federal States, DOI: 10.21242/42131.2017.00.03.1.1.0 and 10.21242/42221.2018.00.01.1.1.0.

[11] The product codes include an additional tenth number indicating if the product was manufactured as part of a contracted work agreement. Examples of products are "Long trousers for men, cotton", "Coats for women, chemical fibre", or "Passenger cars, petrol engine $\leq 1,000 cm^3$".

the statistical offices do not collect quantity information. This mostly regards product categories for which quantity information is less meaningful, like the purification of products, service-like activities (e.g., printing of newspapers), or that are difficult to express and compare in terms of quantities (e.g., production of vitamins).

We clean the data from the top and bottom one percent of outliers with respect to product-level price deviations from the average product price. Together with the changes in firms' industry classification, product codes have been redefined twice over our period of observation. To construct a time-consistent product and industry classification, we follow Mertens (2022) and use official concordances and information on firms' product mix before and after reclassification periods to translate all product codes into the GP2002 classification scheme. The first four digits of this classification corresponds to the NACE rev. 1.1 industry definition. We therefore assign industries to firms based on firms' main production activities. Over all years, we reclassify 97 percent of products. Furthermore, for the years 2002-2007, we can compare our industry assignment with the statistical offices classification and find that we match the two-digit level in 95 percent of all cases. We drop the three percent of products products that we cannot reclassify. Moreover, as we study relative price differences between East- and West-Germany, we focus on products that are manufactured in both regions and by at least three firms (across both regions). This sub-sample covers 62 percent of production in the data.

3.2 Stylized facts

Fact 1: The convergence in output per worker and wages was initially fast, but slowed markedly in subsequent years. Figure 5 shows that in 1991 East German relative GDP per worker was around 40 percent of the West German level. Until the mid-1990s, the East grew to two thirds of the West German productivity level, with a commensurate rise in the relative wage level. This initial recovery is a rebound from an abysmal state of economic activity at the outset of integration, likely reflecting the quick returns from substantial capital investment, infrastructure improvements, and enhanced reallocation of labor within the East (Findeisen et al., 2021; Heise and Porzio, 2022). However, subsequently, the convergence tapered off. Even three decades after the fall of the Berlin wall, East German GDP per worker and the average wage level are still about 20 percent below the West German values.[12] Our goal is to study the mechanisms that underlie this sustained disparity.

Fact 2: After reunification, East German firms struggled to produce competitive products. Akerlof et al. (1991) document that, in the former GDR, about only 10 percent of the workforce were employed by firms capable of competing at global market prices. While the transformation

[12]The findings also apply to measures based on hours worked, although the series are available for a shorter period (see also Figure 1).

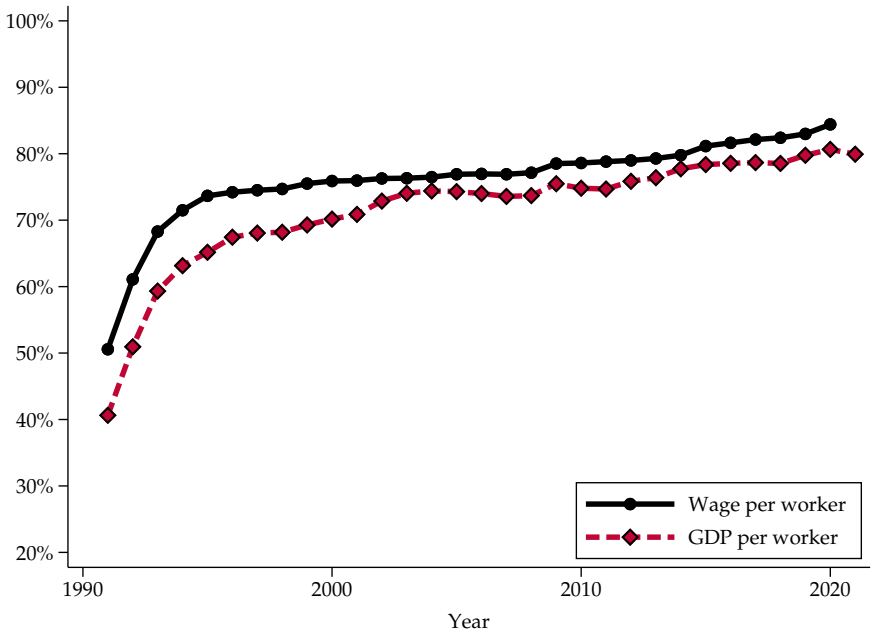


Figure 5: GDP and gross wages per worker and hours worked in East Germany, relative to West

Notes: GDP and gross wages per worker in East Germany, relative to West Germany. Berlin is excluded. Source: German national accounts, data for German Länder

of the production landscape by the Treuhand helped create economically and financially viable businesses in the East, overall, Eastern firms found it challenging to remain competitive. A reflection of this issue at the aggregate level is that the total market share captured by Eastern manufacturing firms—measured in terms of sales or quantities sold in Germany as a whole—remained limited (Figure 6). Over the three decades following the reunification, these shares remained markedly lower than the relative size of the Eastern region by population, which hovered between 16 and 19 percent. The inability of the Eastern firms to expand their market shares within the unified German market points to a notable competitive disadvantage for the Eastern economy following reunification.

Next, we present further evidence from the micro-level data on the competitive and technological disadvantage of East German firms. Importantly, the competitive and technological state of Eastern firms vis-à-vis their Western counterparts forms the basis of our theoretical framework. In the model, we explicitly consider Eastern firms' relative performance and examine its influence on Eastern firms' incentives to invest and enhance their competitiveness.

Fact 3: Eastern firms produce with lower prices, which in part reflect lower product quality. Long-standing differences in productivity and wages are accompanied by persistent price differences across varieties produced in both regions within granular products, and these product-level

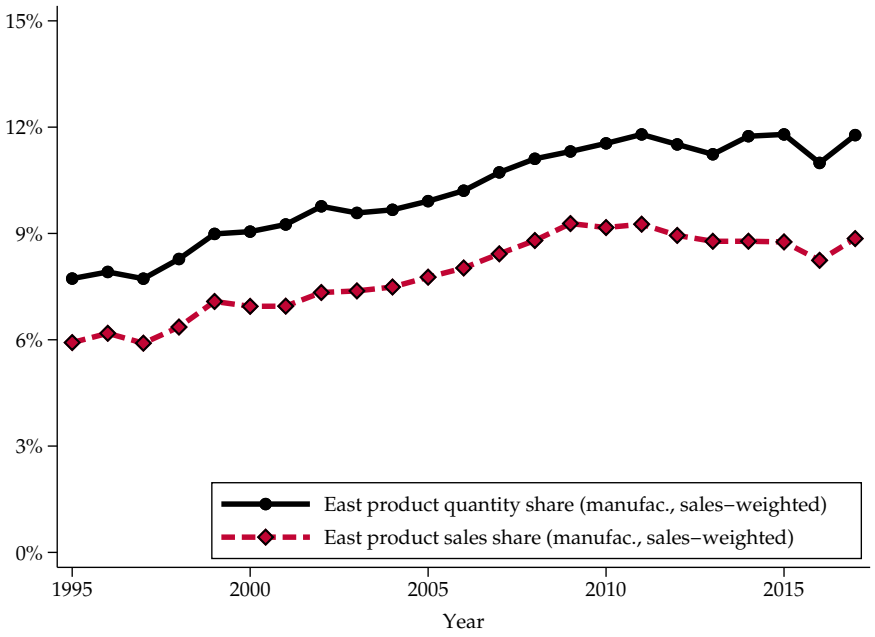


Figure 6: Market shares of Eastern firms

Notes: Market shares of East German firms. Product market shares (1995-2017) are derived from our firm-product level data. Each product-level market share is weighted with product-level sales to derive the aggregate series. Berlin is excluded. Source: German national accounts, data for German Länder.

price gaps naturally map to the theoretical framework we adopt. Figure 7 presents the distribution and dynamics of these price gaps between varieties of manufacturing products (defined at the nine-digit level) produced by Eastern and Western firms.[13] First, the figure highlights that in 1995 the prices of Eastern goods were lower than their Western rivals in most narrowly defined product categories. Second, it documents the remarkable stationarity of the distribution in these regional price differences across products over two decades, with the varieties of a specific product produced in the East still being priced significantly less than their Western counterparts. Our theoretical framework, inherently fit to analyze dynamics at the product-market level, will admit a tight mapping to these features of the data, and the product-level price difference distributions and the evolution of these differences over time will provide key information to discipline firm-level technological differences.

Overall, the results suggest that Eastern firms were less productive on average and remained in business by charging lower prices on their products, helped in part by lower input costs as demonstrated in Figure 5. However, differences in input costs are probably not the only factor explaining the lower output prices in the East. As exemplified by the comparison of car

[13]To arrive at these figures, we first calculate output prices for each firm-product combination using our sales and quantity information. To obtain regional product-level prices, we weight firm-product-level output prices by firm-product-level sales. From these regional product-level prices, we finally construct log price differences between products produced in both regions and which are manufactured by at least three firms in Germany.

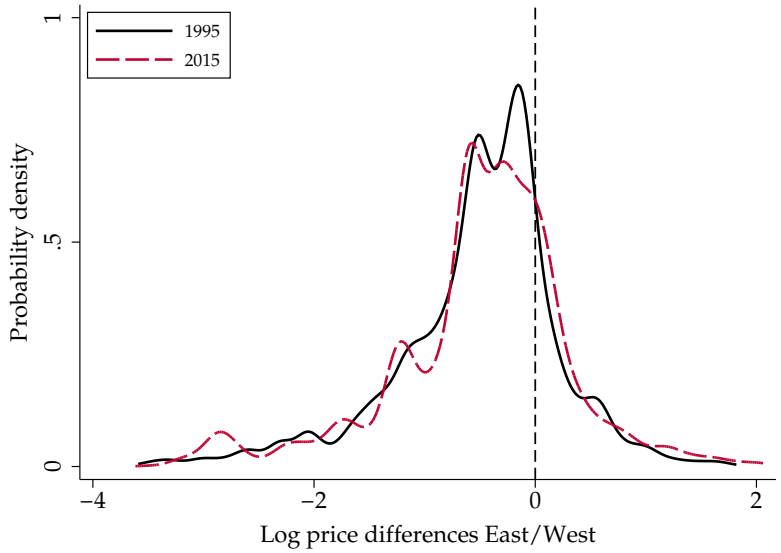


Figure 7: Relative price differences, East/West

Notes: The distribution of log differences of prices between the East and the West across products, with negative values indicating lower prices in the East. Regional output prices are first derived at nine-digit product level as a sales-weighted average of firm-product-level prices. Product-year price differences are only constructed for products produced in both regions and by at least three firms in Germany (for confidentiality reasons). We exclude 2 percent of top and bottom outliers in product-year price differences. The density plot weights each product-year price difference with the sales share of that product in a given year.

manufacturers in the introductory discussion, the differences in the price of the product also reflected the poor quality of Eastern products (Mertens and Müller, 2022). Our theoretical model will account for these various margins and generate an overall price behavior that is consistent with the data.

Fact 4: R&D expenditures have been much lower in the East. Consistent with persistently lower quality in East, R&D investment (as a fraction of the regional output) has been much lower than in the East, as shown in Figure 8. The effort by private businesses has been particularly lackluster, with the gap between the Eastern and Western firms widening even further over the sample period. These observations indicate a lack of effort in the East to close the technological gap with the West. Our theory will provide an explanation for the deficient R&D incentives of Eastern firms based on their initial technological disadvantages.

Fact 5: Firms' R&D effort is inversely associated with their (price) distance from the industry leader. An important feature of the data that guides our theoretical framework is a negative relationship between firms' position in the market relative to the industry leader and their R&D activity. We explore this relationship utilizing the granular German firm-product-level data that report prices of firms' individual products. Consistent with the theoretical model we will adopt, we define the variety with the highest price as the industry leader for each nine-digit product industry j and year t. We compute the (inverse) price gap between the leader variety in j at time

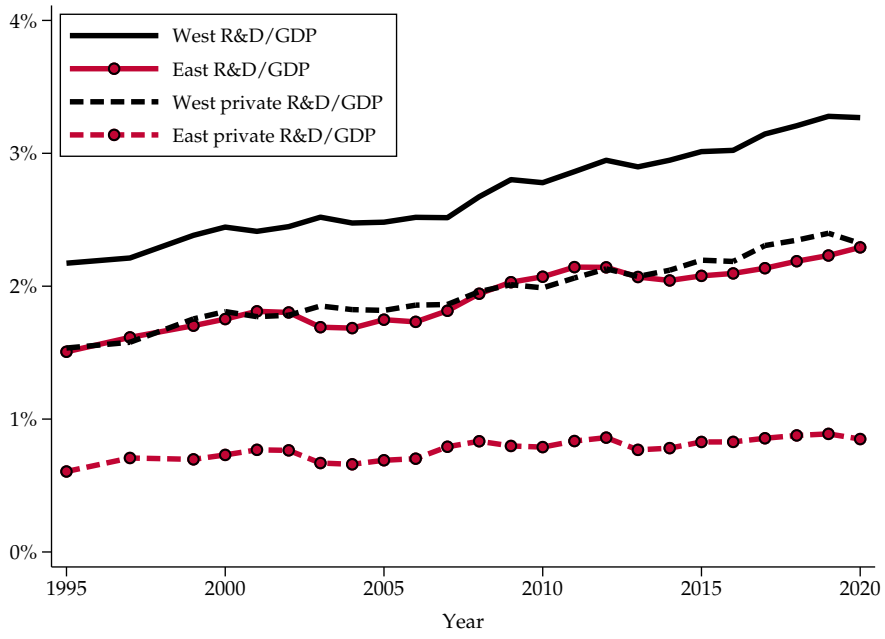


Figure 8: R&D expenditures in East and West Germany.

Notes: Total and private R&D expenditures over GDP for East and West Germany (1995-2020). We impute R&D expenditures for 1996 and 1998. Berlin is excluded. Source: Destatis.

t (P_{jt}^{Max}) and all other varieties within the same industry produced by different firms denoted by i (P_{ijt}) as the ratio $Gap_{ijt} = P_{ijt}/P_{jt}^{Max} \in (0,1)$. This measure is larger when the price distance is smaller. For firms that produce multiple products (78% of firms), we aggregate the product-level measures to the firm level, weighting them using sales shares, because information on R&D activity is available at the firm level. As such, the firm-level gap $Gap_{it} = \sum_j s_{ijt} Gap_{ijt}$ defines the weighted average of the price gap for a multi-product firm, where s_{ijt} denotes the share of total firm revenue accounted for by sales of the variety in product j.

We measure firms' R&D effort by the share of R&D workers in the firm's total workforce given by $RDI_{it} = \ln(L_{it}^{R\&D}/L_{it})$. We focus on firms that engage in R&D activity and therefore on the intensive margin, as initiating R&D involves significant fixed costs (e.g., establishing a R&D department), making the extensive margin less sensitive to changes in the competitive environment. We then estimate the following firm-level regression to uncover the response of firms' R&D effort to the variation in the average (price) distance of the firm from the leaders of the industries in which the firm operates:

$$RDI_{it} = \beta Gap_{it-1} + \nu_i + \nu_t + \epsilon_{it}, \tag{1}$$

where ν_i and ν_t denote firm and year fixed effects. We use lagged values (Gap_{it-1}) to account

for adjustment lags in firms' R&D decisions. We present the results for the East German sample given the focus of the analysis and report the results for all firms in the Appendix (Table A.1).

Table 1: R&D intensity and price gaps

	RDI_{it}	
	All East firms	Single-product East firms
	(1)	(2)
Gap_{it-1}	0.199***	0.170*
	(0.067)	(0.087)
Year FE	yes	yes
Firm FE	yes	yes
Observations	9,918	2,994
R^2	0.867	0.884

Notes: The table reports the results from estimating equation (1) using the sample of East German firms in the German firm-product-level data. RDI_{it} is R&D intensity defined as R&D employment share in total employment. Gap_{it} measures the sales-weighted average price ratio between a firms' products and the highest priced products within an industry and year. Standard errors are clustered at the firm level. (***, **, *) denote significance at 1%, 5%, and 10%, respectively.

Table 1 presents the results. The first column uses all available East German firm observations with positive R&D employment, while the next focuses on single-product firms as a robustness check. Overall, the coefficients imply that a decrease in firms' product price gaps vis-à-vis the industry leaders by 10 basis points is associated with a 1.7–2.0 percent increase in firms' R&D effort. This supports the idea that firms catching up with (falling behind) their competitors become incentivized to invest (discouraged from investing) in R&D. As we shall see, such a relationship arises endogenously in the theoretical framework we employ in our analysis. Price differences between rivals reflect (in part) the difference between their technologies and hence the degree of competition between them. As firms get closer to their rivals, competition stiffens, and firms intensify their R&D effort to outpace their rivals, in accordance with the empirical relationship identified in this section. In Section 5.2, we discuss how the implications of the simulated model align with the empirical relationship described here.

Summary. The empirical analysis documents a tepid pace of economic convergence between the East and West that has persisted for decades, characterized by Eastern firms that were ailed by technological and competitive deficiencies resulting in relatively lower productivity, output prices, and market shares and invested little in R&D to improve their technology. Next, we present a theory that is consistent with this depiction of the German economy. It accounts for differences across firms in terms of productivity, product quality, and labor costs and links

the heterogeneity in these factors to firms' market performance, which, in turn, affects firms' forward-looking decisions to invest in R&D and technology upgrading. The model mimics the observed pace of regional convergence at the macro level along with persistent regional price gaps that reflect persistent technological differences between Western and Eastern firms. The model provides a rationale for sustained technological gaps based on initial technological differences that feed into endogenous R&D decisions. The strategic investment behavior of firms based on their technological and competitive position in the market vis-à-vis their competitors also helps the model generate firm dynamics that conform with the data, with firms ramping up their R&D effort as they improve in the competitive race with the market leader as reflected by higher relative prices.

4 Model

We build an endogenous growth model of market competition and R&D race between firms that can mimic the dynamics of economic convergence between the two regions of Germany and average relative prices among producers of the two regions as observed in the micro data. In our model, Germany as a whole is analyzed as a closed economy that consists of two regions, West and East, denoted by $r \in \{w, e\}$. Both regions admit a measure of representative households that consume a basket of tradable (between the two regions) and nontradable goods and supply labor regionally. While the population size of Germany is normalized to one at all times, the regional sizes move exogenously, mimicking the data to capture the changes in the region-specific labor force over time for various reasons including cross-border migration.

The centerpiece of the model is a unit measure of tradable goods. Each tradable good is produced by two incumbent firms—one from each region—that produce the varieties of the same good but with different product qualities. The firms also differ in terms of production efficiency—a region-specific variable moving exogenously—and production costs (wages), that are determined endogenously at the regional level. These firms sell their products in both regions without any frictions and additional costs and compete à la Bertrand in their product markets. To increase their product quality and market share, firms invest in R&D, which improves qualities in a step-by-step fashion (Acemoglu and Akcigit, 2012; Akcigit and Ates, 2023), and, as is standard in these models, firms' R&D investments responds to the technology (quality) difference between the two firms in a product line. Knowledge spillovers that occur at an exogenous rate complement this process, helping technologically laggard firms learn from the frontier. As such, the product market outcomes reflect product quality, production efficiency, and production cost differences across firms, while firms strive to improve quality of their products via strategic R&D decisions. As a result, the main channels driving the dynamics of the model will be the evolution of the relative efficiency level in the regions and the product qualities, with the latter

being determined by endogenous firm investments and knowledge spillovers.

4.1 Preferences

Each region is populated by a measure of representative households—denoted by $L_r(t)$—who derive utility from consumption of tradable and nontradable goods, and supply labor inelastically. The demand system is characterized by nested constant elasticity of substitution (CES) preferences as follows:

$$\max_{\{c_{ij}^r(t), C_r^{NT}(t)\}} \int_{T_0}^{\infty} e^{-\rho(t-T_0)} \log C_r(t) dt$$

$$\text{s.t. } \dot{Z}_r(t) = r_r(t) Z_r(t) + w_r(t) L_r(t) + \Pi_r(t) + T_r(t) - E_r(t)$$

$$E_r(t) \equiv \int_0^1 \left(p_{wj}^r(t) c_{wj}^r(t) + p_{ej}^r(t) c_{ej}^r(t) \right) dj + P_r^{NT}(t) C_r^{NT}(t)$$

$$C_r(t) \equiv \left(\frac{1}{\beta} \exp \left[\int_0^1 \log \left(\sum_{k \in \{e,w\}} \left(q_{kj}(t) c_{kj}^r(t) \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} dj \right] \right)^{\beta} \left(\frac{Q_r^{NT}(t) C_r^{NT}(t)}{1-\beta} \right)^{1-\beta}$$

In this expression, $\rho > 0$ denotes the time preference, $\beta \in (0,1)$ denotes the aggregate share of tradable goods, and $\sigma > 1$ denotes the elasticity of substitution actoss varieties in each product line. These parameters are common across regions. A consumer in region r consumes tradable good $j \in [0,1]$ produced in region k, $c_{kj}^r(t)$, with the associated quality $q_{kj}(t)$. The price of the variety is $p_{kj}^r(t)$; yet, the price of a specific variety is equalized across regions owing to costless trade of goods between the regions—i.e., $p_{kj}^e(t) = p_{kj}^w(t)$ holds in equilibrium. We define the average quality of products produced by firms in region r as

$$Q_r^T(t) \equiv \exp \left\{ \int_0^1 \log q_{rj}(t) dj \right\}. \tag{2}$$

Households also consume $C_r^{NT}(t)$ amount of a nontradable good that is region specific, homogeneous, and produced by regional firms in perfectly competitive markets. For the sake of tractability, we assume that the quality of the nontradable good in a region scales with the average quality of tradable goods produced in that region—i.e., $Q_r^{NT}(t) = Q_r^T(t)$.

Households finance their total consumption expenditure, $E_r(t)$, with income earned on labor, profits rebated from the regional firms they own, returns on assets, and government transfers (if any). In the budget constraint, $L_r(t)$ denotes labor, $\Pi_r(t)$ denotes dividends from firms (operational profits net of R&D spending), $Z_r(t)$ denotes assets that households hold (equaling the total stock value of firms net of dividends), and $T_r(t)$ denotes any lump-sum government transfers

or taxes, with $w_r(t)$ and $r_r(t)$ denoting the region-specific wage and interest rates, respectively.[14] Markets are incomplete in the sense that households from different regions cannot write debt contracts with each other; however, households within a region can do. Consistent with financial autarky at the regional level there is home bias in assets: firms in a region are owned by the inhabitants of that region. Therefore, $\Pi_r(t)$ is the sum of dividends distributed by firms that produce in region r. The immediate implication of the financial autarky assumption is that trade is balanced at all times between the regions when government transfers and subsidies are absent. Moreover,in equilibrium, the value of the financial portfolio, $Z_r(t)$, equals the total market value of the firms that are located in region r, and the rate of return on this portfolio, $r_n(t)$, is region specific in equilibrium.[15]

Regional population sizes $L_r(t)$ are time-varying to account for changes in the size of the regional labor force observed over the period of interest due to factors such as migration.[16] We postulate that the following functional form governs this variable:

$$L_r(t) = L_{r,bgp} + (L_{r,t_0} - L_{r,bgp})e^{-\nu^L(t-t_0)}. \tag{3}$$

We normalize the total German population to one, i.e., $L_w(t) + L_e(t) = 1$ at all times. Then, $L_r(t)$ corresponds to population shares, with L_{r,t_0} and $L_{r,bgp}$ denoting the initial and BGP values, respectively, and ν^L is a curvature parameter common across regions. Section 5 details the calibration of the process, which produces a near perfect fit to the data.

4.2 Production

Labor is the only factor of production in the model and is used in the production of both tradables and the nontradable good (also in R&D, as detailed later). Importantly, region-specific labor produces at a regional efficiency rate $A_r(t)$.

Tradable goods. In every sector $j \in [0, 1]$, West and East firms produce differentiated varieties under a linear production function:

$$y_{rj}(t) = A_r(t) l^T_{rj}(t),$$

[14] Positive (negative) $T_r(t)$ means lump-sum government transfers to (taxes collected from) the households in r.

[15] The financial autarky assumption allows us to abstract from trade imbalances and ease the computation of the model. Evidently, the East maintained a net trade deficit vis-à-vis the West, especially in the early years of unification. In the model, we capture this phenomenon via voluminous government transfers and subsidies from West to East, in reflection of the actual policies that provided cross-regional support. We provide the details in Section 5.

[16] While this formulation would help the model capture migration-related flows, it is worth noting that emigration from the East was more prevalent in the early years of the reunification predating the period of our analysis.

where $l_{rj}^T(t)$ denotes labor used by the firm of region r in product line j, and $A_r(t)$ denotes the region-specific efficiency level. As will be discussed shortly, we posit that $A_r(t)$ varies over time along an exogenous path, that will be determined by the data in the calibration of the model. Accordingly, firms differ in three margins: (i) firm-specific product quality, (ii) region-specific production efficiency, and (iii) region-specific input cost (wages). Engaging in Bertrand competition with its rival, the firm that has the highest quality relative to efficiency-adjusted production cost obtains an advantage in the market, capturing a larger share of it.

Nontradable goods. A homogeneous nontradable good specific to a region $r = \{w, e\}$ is produced by perfectly competitive firms in the region. Production technology is linear in labor, $y_r^{NT}(t) = A_r(t) l_r^{NT}(t)$.

Production efficiency $A_r(t)$. At the time of reunification, the two regions differed in various technological aspects, which contributed to the large regional income gap initially and also influenced the subsequent dynamics of regional economic convergence. In the model, endogenous technology dynamics will reflect firms' investment in product quality improvements, but ideally we would like the model also to capture other technological factors that could have affected the convergence dynamics. Although this regional difference in productive efficiency may reflect various mechanisms that are beyond the focus of our analysis, we would nonetheless like the model to incorporate these aspects of the data in an effort to avoid attributing all convergence dynamics to a single quality margin.

We capture the technological dynamics other than the product quality margin with the following exogenous, parametric process, whose parameters we discipline in the model calibration:

$$A_r(t) = A_{r,bgp} + \left(A_{r,t_0} - A_{r,bgp}\right) e^{-\nu_r^A (t - t_0)}, \tag{4}$$

where A_{r,t_0} and $A_{r,bgp}$ denote the initial and BGP levels, respectively, and ν_r^A governs the speed of convergence of $A_e(t)$ to its BGP level. Given our specific focus on convergence, we normalize the Western aggregate productivity to be one in all periods, i.e., $A_w(t) = 1$ for all $t \geq T_0$. Motivated by empirical findings, we posit that the Eastern production efficiency $A_e(t)$ was initially lower than its Western counterpart (as is implied by the calibration results) and allow it to vary over time according to the exogenous path defined in equation (4). Notice that $A_e(t)$ also corresponds to the relative level given that $A_w(t) = 1$.

This time-varying structure of relative efficiency levels may reflect various technological changes other than product quality adjustments that could have influenced economic progress in the East. One such factor could be the proliferation of new companies in the East and the intra-regional reallocation of Eastern workers to more productive units (Heise and Porzio, 2022).

This structure could also reflect potential spillovers from the established Western production techniques within the capitalist market economy to Eastern production units as they integrated into the Western system. These spillovers could, for example, have been facilitated by Western managers taking over management of some Eastern firms (Mergele et al., 2020). Labor efficiency may also have improved due to rapid capital upgrading facilitated by the large investment flows in the immediate aftermath of reunification. However, emigration of skilled people initially could have hampered average labor efficiency in the East. In fact, the average physical productive efficiency (TFPQ) among Eastern firms was persistently lower than the corresponding Western level, as documented in the Online Appendix (Figure A.1). In addition to allowing the model to speak to such diverse factors, this feature will also be an important element in the identification of product quality differences through the use of product-level price data, as relative prices reflect not only product qualities, but also production efficiency and cost differences.

4.3 Innovation and knowledge spillovers

In each product line, incumbent firms differ in the quality of their products. We call the firm from r the market leader (follower) in j if $q_{rj} > q_{-rj}$ ($q_{rj} > q_{-rj}$) for $r, -r \in \{e, w\}$ and $r \neq -r$. Firms are called neck-and-neck if $q_{rj} = q_{-rj}$. We normalize initial productivity levels to unity such that $q_{rjt_0} = 1$.

Firms invest in R&D to improve their product quality. A successful innovation improves the quality of a product proportionally by a factor $\lambda > 1$, which stands for the innovation step size. In other words, $q(t + \Delta t) = \lambda q(t)$ upon successful innovation, with Δt denoting an infinitesimal change in time.

Product qualities evolve also with knowledge spillovers that flow from the technologically superior firm (frontier or leader firm) to the inferior one (laggard firm). Follower firms receive spillovers from the technology leaders with a Poisson rate $\delta \geq 0$. Technology spillovers occur in heterogeneous sizes; the number of steps with which it improves the follower quality is drawn from a Pareto distribution with shape parameter $\theta_{\text{shape}} = 0.01$ and location parameter $\theta_{\text{location}} = 1$. That is, the minimum possible improvement is one step, whereas the maximum quality spillover enables the follower to catch up with the market leader. This construct rules out leapfrogging.

This structure of quality improvements implies that a certain number of technology steps separate the leader and the follower in a given product line. This difference, which we call the technology or quality gap, captures the difference between the total number of technology rungs that determine these firms' product qualities. If, in line j, the product qualities of the firms from r and $-r$ build on $N_{rj}(t)$ and $N_{-rj}(t)$ past improvements, respectively, we measure the technology gap between these firms as $m_{ij}(t) \equiv N_{rj}(t) - N_{-rj}(t) \in \mathbb{N}$. Then the relative quality level is a

function of $m_{rj}(t)$:

$$\frac{q_{rj}(t)}{q_{-rj}(t)} = \lambda^{N_{rj}(t)-N_{-rj}(t)} = \lambda^{m_{rj}(t)}. \tag{5}$$

To render the state space finite, we set an upper bar on the size of the technology gap that can separate two competitors, denoted by $\bar{m}$, such that $|m_{rj}(t)| < \bar{m}$. As will be clear, $m_{rj}(t)$ sums up all the industry-specific information that is relevant to the firm's payoff. Therefore, we discard industry subscript j when $|m_r(t)| \in \{0, ..., \bar{m}\}$ concerns a firm-specific value. We adopt the notation $m_j(t) \in \{0, ..., \bar{m}\}$ to denote the technology gap between competitors in a specific sector j. Lastly, when we say the leader is m steps ahead or, reciprocally, the follower is m steps behind, it means m technology steps separate the two rivals—i.e., the follower needs to improve its quality m steps more than the leader to catch up with the technology leader. When firms have the same quality level ($m_j(t) = 0$), we call the firms are "neck-and-neck."

Firms conduct R&D by hiring labor. A firm in region r that employs $h_{rj}(t)$ researchers can generate a Poisson arrival of rate of innovation $x_{rj}(t) = \left(\gamma \frac{h_{rj}(t)}{\alpha_r}\right)^{\frac{1}{\gamma}}$, with γ denoting the (inverse) elasticity of R&D with respect to R&D input. Conversely, denoting the R&D expenditure by $R_{rj}(t)$, the convex cost of generating the arrival rate of $x_{rj}(t)$ is given by $R_{rj}(t) = \alpha_r \frac{x_{rj}(t)^\gamma}{\gamma} w(t)$, with $w(t)$ standing for the wage rate. Although we consider the curvature parameter γ to be common across regions, we allow the scale parameter α_r to be region-specific, capturing potential differences across the two regions in the productivity of researchers.

4.4 Equilibrium

In this section, we characterize the dynamic general equilibrium of the model where the firms' strategies are a function of the payoff-relevant state variable m. We start with the static equilibrium. Then, we describe firms' value functions, their forward-looking innovation decisions, and the resulting dynamics of the aggregate economy.

Households. To start, the life-time utility maximization of the households implies the standard Euler equation:

$$\frac{\dot{E}_r(t)}{E_r(t)} = r_r(t) - \rho. \tag{6}$$

The representative household in region $r = \{w, e\}$ allocates expenditures E_r to tradable and

nontradable goods based on static maximization in each period[17]

$$\max_{\left\{c_{ej}^r, c_{wj}^r, C_r^{NT}\right\}} \log\left\{\left(\frac{\exp\left\{\int_0^1 \log\left(\left(q_{wj}c_{wj}^r\right)^{\frac{\sigma-1}{\sigma}} + \left(q_{ej}c_{ej}^r\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} dj\right\}}{\beta}\right)^{\beta}\left(\frac{Q_r^{NT}C_r^{NT}}{1-\beta}\right)^{1-\beta}\right\}$$

$$\text{s.t. } \int_0^1 \left(p_{wj}c_{wj}^r + p_{ej}c_{ej}^r\right) dj + P_r^{NT}C_r^{NT} = E_r.$$

Taking first order conditions and organizing terms yields the following demand functions for the non-tradable good and tradable goods:

$$P_r^{NT}C_r^{NT} = (1-\beta)\, E_r, \tag{7}$$

$$p_{kj}c_{kj}^r = \frac{\left(\frac{q_{kj}}{p_{kj}}\right)^{\sigma-1}}{\left(\frac{q_{wj}}{p_{wj}}\right)^{\sigma-1} + \left(\frac{q_{ej}}{p_{ej}}\right)^{\sigma-1}}\beta E_r \qquad \text{for } k = w, e. \tag{8}$$

Demand function (8) states that the representative household spends β fraction of her resources on each tradable sector j. Furthermore, she splits these expenditures between Western and Eastern varieties depending on the varieties' relative price-adjusted quality. If the relative quality of a good, q_{rj}, increases, households demand more of it and allocate a larger fraction of their spending toward that good, everything else being equal.

We now define a number of indices that will come in handy in our analysis. Starting with the quantities of consumption, the total consumption of good j by consumers in region r, their total consumption of tradable goods, and their aggregate consumption basket are respectively defined by the following expressions:

$$c_j^r(t) \equiv \left[\left(\tilde{q}_{wj}(t)c_{wj}^r(t)\right)^{\frac{\sigma-1}{\sigma}} + \left(\tilde{q}_{ej}(t)c_{ej}^r(t)\right)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

$$C_r^T(t) \equiv \exp\left\{\int_0^1 \log c_j^r(t) dj\right\},$$

$$C_r(t) \equiv \left(\frac{C_r^T(t)}{\beta}\right)^{\beta}\left(\frac{C_r^{NT}(t)}{1-\beta}\right)^{1-\beta},$$

where $\tilde{q}_{rj}(t) \equiv \frac{q_{rj}(t)}{q_j(t)}$ in the first line represents the quality of tradable good j produced in r relative to the quality index in that sector as defined by $q_j(t) \equiv \left[q_{wj}(t)^{\frac{\sigma-1}{\sigma}} + q_{ej}(t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$. These indices

[17] The time argument t is removed to save on notation in the formulation of the problem.

will prove useful when calculating welfare of households.

This price indices corresponding to the quantities above are given as follows:

$$
\begin{aligned}
p_j(t) &\equiv \left[\left(\frac{p_{wj}(t)}{\tilde{q}_{wj}(t)} \right)^{1-\sigma} + \left(\frac{p_{ej}(t)}{\tilde{q}_{ej}(t)} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \\
P^T(t) &\equiv \exp\left\{ \int_0^1 \log p_j(t) dj \right\}, \\
P_r(t) &\equiv \left(P^T(t) \right)^{\beta} \left(P_r^{NT}(t) \right)^{1-\beta},
\end{aligned}
$$

with the total expenditure in region r being $E_r(t) = P_r(t)C_r(t)$. We take the total expenditure in Germany, which corresponds to the total nominal GDP, as the numeraire. Notice that the first two expressions are common across regions in the absence of any costs associated with trade between the two regions. The aggregate price index in the third expression is region-dependent owing to the non-tradable prices.

Given that the dynamics of product qualities is at the center of our analysis, we also define the following indices:

$$
\begin{aligned}
q_j(t) &\equiv \left[q_{wj}(t)^{\frac{\sigma-1}{\sigma}} + q_{ej}(t)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \\
Q^T(t) &\equiv \exp\left\{ \int_0^1 \log q_j(t) dj \right\}, \\
Q_r(t) &\equiv \left(Q^T(t) \right)^{\beta} \left(Q_r^{NT}(t) \right)^{1-\beta}.
\end{aligned}
$$

where $q_j(t)$ is the sector-specific quality index as described before. $Q^T(t)$ corresponds to the aggregate quality of all tradable goods while $Q_r^{NT}(t)$ is the quality of the nontradable good in region r as defined earlier. A geometric average of these indices obtains the quality index associated with the consumption basket consumed by households in r.

Nontradable sector. Turning to the firms, the nontradable-good firms solve the following static problem at each instant:

$$
\max_{l_r^{NT}(t)} P_r^{NT}(t) A_r(t) l_r^{NT}(t) - W_r(t) l_r^{NT}(t)
$$

by taking prices $P_r^{NT}(t)$ and wages $w_r(t)$ as given. Given that the representative household spends $1-\beta$ fraction of their total expenditure on nontradable goods, labor allocated for nontradable good production is given by $l_r^{NT}(t) = (1-\beta)\, E_r(t)/w_r(t)$.

Tradable sector. Turning to the tradable sector, profit maximization of a tradable-good producer is characterized by

$$\max_{p}\left[p-\frac{w_r(t)}{A_r(t)}\right]y\left(p\right),$$

facing the demand of the consumers defined in equation (8). Denoting the market (revenue) share of the firm by $s_{rj}(t)\in[0,1]$, the solution to this maximization problem yields the following optimal pricing rule as a time-varying markup over marginal cost:

$$p_{rj}(t)=\mu\left(s_{rj}(t)\right)\frac{w_r(t)}{A_r(t)}=\frac{\varepsilon(s_{rj}(t))}{\varepsilon(s_{rj}(t))-1}\frac{w_r(t)}{A_r(t)}, \tag{9}$$

where the markup $\mu(s_{rj}(t))$ can be written as a function of the residual demand elasticity for the firm from r, $\varepsilon(s)=s+(1-s)\,\sigma$, which declines in firm size as measured by the firm's market share. As the size of the firm increases, the demand that the firm faces gets more inelastic, which allows the firm to charge higher markups. Indeed, the price elasticity of demand is a weighted average of the cross-sector elasticity (equal to one) and the within-sector elasticity $\sigma>1$, with weights being the firm's market share. As s increases, this average declines and the markup of the firm increases. Lastly, the market share of the firm is given by

$$s_{rj}(t)=\frac{p_{rj}(t)\left(c^{w}_{rj}(t)+c^{e}_{rj}(t)\right)}{\beta E(t)}=\frac{\left(\frac{q_{rj}(t)}{p_{rj}(t)}\right)^{\sigma-1}}{\left(\frac{q_{wj}(t)}{p_{wj}(t)}\right)^{\sigma-1}+\left(\frac{q_{ej}(t)}{p_{ej}(t)}\right)^{\sigma-1}}, \tag{10}$$

where $E(t)=E_w(t)+E_e(t)$ measures the total expenditure by German households. Equations (8)-(10), with the fact that the market shares of two rivals sum to 1 (i.e., $s_{rj}(t)+s_{-rj}(t)=1$), uniquely characterize the optimal production of tradable varieties, their prices, and the market share of tradable-good producers.

The ratio of the market shares of two rivals provides valuable insights about the drivers of firms' competitiveness in a market and the overall income a region could earn in the tradable sector. To illustrate that, we combine equations (9) and (10) to obtain

$$\frac{s_{rj}(t)}{1-s_{rj}(t)}=\left(\frac{q_{rj}(t)}{q_{-rj}(t)}\right)^{\sigma-1}\left(\frac{\mu\left(s_{rj}(t)\right)w_r(t)/A_r(t)}{\mu\left(1-s_{rj}(t)\right)w_{-r}(t)/A_{-r}(t)}\right)^{1-\sigma}. \tag{11}$$

Defining $\bar{s}=\frac{s}{1-s}$, further algebraic modifications yield the following expression:

$$\Gamma\left(\bar{s}\right)=\left[\frac{q_{rj}(t)}{q_{-rj}(t)}\frac{A_r(t)}{A_{-r}(t)}\left(\frac{w_r(t)}{w_{-r}(t)}\right)^{-1}\right]^{\sigma-1}, \tag{12}$$

where $\Gamma(\bar{s}) = \bar{s}^{\sigma}(\bar{s}+\sigma)^{\sigma-1}(1+\sigma\bar{s})^{1-\sigma}$ defines an increasing function of $\bar{s}$ and thus s. Equation (12) highlights the factors that determine the relative market shares: (i) the relative product quality of the firm, (ii) the relative region-specific production efficiency, and (iii) the relative region-specific wage. A higher relative production efficiency boosts the market share of a firm, whereas a higher wage rate relative to the other region hurts the competitiveness and the market share of firms operating in that region. Importantly, this expression relates the market share of a firm to its technology in terms of product quality—a higher relative quality level implies higher market share. Forward-looking firms invest in quality-improving innovation to attain a larger share of the market.

Finally, profits and the labor demand of the tradable-good firm are derived as

$$\pi_{rj}(t) = \left[1-\mu\left(s_{rj}(t)\right)^{-1}\right] s_{rj}(t)\beta E(t),$$
$$l^{T}_{rj}(t) = \frac{\frac{s_{rj}(t)}{\mu\left(s_{rj}(t)\right)}\beta E(t)}{w_r(t)}.$$

Firm values. Let $V_r(m,t)$ denote the discounted value of future cash flows of a firm located in region r separated by $m \in \{-\bar{m},\ldots,\bar{m}\}$ steps from its competitor. The Hamilton-Jacobi-Bellman equation can be written as follows:

$$\begin{aligned} r_r(t)V_r(m,t) = &\left[1-\mu\left(s_r(m,t)\right)^{-1}\right] s_r(m,t)\beta E(t) \\ &+ \max_{x_r}\left\{-\left(1-\zeta^{R}_{r}(t)\right) w_r(t)\alpha_r\frac{x_r^{\gamma}}{\gamma} + x_r\left[V_r(m+1,t)-V_r(m,t)\right]\right\} \\ &+ x_{-r}(-m,t)\left[V_r(m-1,t)-V_r(m,t)\right] \\ &+ \mathbf{1}_{\{m\neq 0\}}\delta\sum_{n=1}^{|m|} f\left(|m|,n\right)\left[V_r(m+\kappa(m)n,t)-V_r(m,t)\right] + \frac{\partial V_r(m,t)}{\partial t}, \end{aligned} \tag{13}$$

where $\kappa(m) = (-1)^{\mathbf{1}\{m>0\}}$ is an indicator function that takes the value -1 (1) if $m > 0$ ($m < 0$).

The left-hand side of equation (13) represents the safe return to selling the firm and investing the proceeds at the prevailing interest rate, which, in equilibrium, equals the return from owning the firm. The first line of the right-hand side is the flow rate of profits. The second line defines the R&D decision. The firm chooses the optimal innovation flow rate, whose cost is given by the first term, and the return—the second term—is the increase in firm value from improving the quality gap from m to $m+1$. Region-specific R&D subsidy rate is given by $\zeta^{R}_{r}(t) \in [0,1]$. The third line captures the expected loss in firm value in case of a successful innovation by the competitor. In that case, the gap of the firm deteriorates from m to $m-1$. The fourth line is the expected change in firm value in case of knowledge spillovers, which occurs when there is a nonzero

gap between the firms. The spillover can generate quality improvements of heterogeneous sizes, and the expected size depends on the position of the firm on the quality ladder. In particular, $f(|m|, n)$ gives the probability of jumping by n steps if the absolute gap between the firms is $|m|$. If the firm is laggard, then spillover increases firm value. On the other hand, if the firm is the leader in the market, then spillover decreases firm valuation. Finally, the last term represents the change in firm value due to time variation in aggregate variables.

The first-order condition of the firm's dynamic optimization problem implies the following optimal innovation rate:

$$x_r(m,t) = \left[\frac{V_r(m+1,t) - V_r(m,t)}{(1-\zeta_r^R(t))\,\alpha_r w_r(t)}\right]^{\frac{1}{\gamma-1}}. \tag{14}$$

The step-by-step innovation structure introduces strategic motives that shape the innovation decisions of rivals in a sector. The technology gap between the rivals determines their market shares and the return to innovation, which influences the optimal R&D decision. Firms close in technology and market shares intensify their R&D effort to improve their quality a bit more and steal a significant market share from the rival—a reflection of the "escape-competition" effect inherent in this class of models (Aghion et al., 2005). Conversely, there exists a "discouragement" effect: followers that are too technologically laggard need many innovations to catch up, and the farther they are, the lower the chances to accomplish it, discouraging those followers from investing much in R&D. This effect plays a key role in our quantitative investigation of the convergence dynamics in the East in light of the fact that most firms in the East started to compete with Western counterparts from a technologically laggard position in the aftermath of the reunification.

Given the central role of technology gaps in driving the dynamics of the model, a key object to keep track of is the distribution of quality gaps across sectors. This aggregate state of the model moves endogenously over time, with its law of motion being determined by the rates of innovations chosen by the firms and quality spillovers. Let $\psi(m,t)$ denote the share of sectors in which Western firms are at position $m \in \{-\bar{m}, \ldots, \bar{m}\}$ ($m > 0$ (< 0) implies the Western firm leads (lags) by m steps), with the total mass being $\sum_{n=-\bar{m}}^{\bar{m}} \psi(n,t) = 1$, $\forall t$. Correspondingly, the mass of sectors in which East firms command a gap of m equals $\psi(-m,t)$. The inflows and outflows of the sectors to and from a certain quality gap level shapes the Kolmogorov forward equations for $m = -\bar{m}+1, \ldots, \bar{m}-1$ as follows:

$$\begin{aligned}\dot{\psi}(m,t) = {} & \psi(m-1,t)x_w(m-1,t) + \psi(m+1,t)x_e\left(-(m+1),t\right) \\ & + \delta\left[\sum_{n=1}^{\bar{m}-|m|} \mathbf{1}_{\{m\geq 0\}} f(m+n,n)\psi(m+n,t) + \mathbf{1}_{\{m\leq 0\}} f\left(|m-n|,n\right)\psi(m-n,t)\right] \\ & - \psi(m,t)\left[x_w(m,t) + x_e(-m,t) + \mathbf{1}_{\{m\neq 0\}}\delta\right].\end{aligned} \tag{15}$$

The change in the mass of sectors where Western firms are at position m equals inflows minus outflows. In particular, the first line describes the inflow—the technology gap in a sector reaching m—due to innovations by an Eastern or Western firm. The second line represents the inflow due to knowledge spillovers. Spillovers may help a laggard Western firm reach $m < 0$ from a previously worse position or cause a leading Western firm to lose its advantage seeing it deteriorate to $m > 0$, when its Eastern rival benefits from spillovers. Finally, the last line denotes the total outflow as innovations and knowledge spillovers occur in sectors with gap m.[18]

Closing the model. To ease notation, we define region-specific quality gap distributions $\psi_w(m,t) \equiv \psi(m,t)$ and $\psi_e(m,t) \equiv \psi(-m,t)$, where $\psi_i(m,t)$ denotes the mass of sectors in which the firm from region i has a quality gap of m.

Labor and asset markets in each region are cleared in every period. The market clearing condition for labor, which is used in tradable production, nontradable production, and R&D, is

$$L_r(t) = \left(\sum_{m=-\bar{m}}^{\bar{m}} \psi_i(m,t) \frac{s_i(m,t)}{\mu\left(s_i(m,t)\right)} \right) \frac{\beta E(t)}{w_r(t)} + (1-\beta)\frac{E_r(t)}{w_r(t)} + \sum_{m=-\bar{m}}^{\bar{m}} \psi_r(m,t)\alpha_r \frac{x_r(m,t)^\gamma}{\gamma} \tag{16}$$

for region $r = \{w, e\}$. The first component on the right-hand side of this equation is the demand for labor in tradable production, the second term is the demand for nontradable production, and the third one stands for the demand in R&D activity. Asset market clearing condition combined with the assumption of financial autarky implies that total expenditures of a region on consumption goods equals the total income. That is,

$$E_r(t) = w_r(t)L_r(t) + \Pi_r(t) + T_r(t), \tag{17}$$

with $\Pi_r(t) = \int_0^1 \left(\pi_{rj}(t) - \alpha_r \gamma^{-1} x_r(m,t)^\gamma w_r(t)\right) dj$ denoting total profits (net of R&D) generated by the firms of the region and $T_r(t)$ denoting lump-sum government taxes/transfers.

Asset market clearing condition (17) can be further utilized to derive expressions for total expenditures, $E_r(t)$, and GDP of a region, $Y_r(t)$, in terms of average market shares of region's firms and net transfers to the region. Total GDP of a region is defined as the sum of total value added generated by both tradable and nontradable firms:

$$Y_r(t) \equiv (1-\beta)\, E_r(t) + \sum_{k\in\{w,e\}} \left(\sum_{m=-\bar{m}}^{\bar{m}} s_r(m,t)\psi_r(m,t) \right) \beta E_k(t).$$

[18] Kolmogorov forward equations in boundary cases $\bar{m}$ and $-\bar{m}$ can be derived as

$$\dot{\psi}(\bar{m},t) = \psi(\bar{m}-1,t)x_w(\bar{m}-1,t) - \psi(\bar{m},t)\left[x_e\left(\bar{m},t\right)+\delta\right],$$
$$\dot{\psi}(-\bar{m},t) = \psi(-\bar{m}+1,t)x_e(\bar{m}-1,t) - \psi(-\bar{m},t)\left[x_w(-\bar{m},t)+\delta\right].$$

Recall that regional governments can send/receive funds to/from the other region. Let $\mathcal{T}_r(t) \equiv G_r(t) + T_r(t)$ denote the net inter-regional flow of funds to or from region r. Defining $G_r(t)$ as the expenditure of regional government in r on local industrial policy, a negative (positive) $\mathcal{T}_r(t)$ implies outflows from (inflows to) region r.[19] In addition, we define the average market share of firms from r as

$$S_r(t) \equiv \sum_{m=-\bar{m}}^{\bar{m}} s_r(m,t)\psi_r(m,t). \tag{18}$$

Given these definitions, we can derive the following expressions:

$$E_r(t) = S_r(t) + \frac{1}{\beta}\mathcal{T}_r(t), \tag{19}$$

$$Y_r(t) = S_r(t) + \frac{1-\beta}{\beta}\mathcal{T}_r(t). \tag{20}$$

Finally, the federal German government does not borrow to finance its expenditures. Accordingly, the sum of inter-regional transfers equals to zero at all times, $\mathcal{T}_w(t) + \mathcal{T}_e(t) = 0$.

5 Calibration

In this section, we present the details of the model calibration, which focuses on the period between 1995 and 2015 (i.e., $t_0 = 1995$). We also discuss key mechanisms that the shape dynamics of convergence between the East and West in the model.

5.1 Calibration

We start with the description of externally set parameters listed in Table 2. We set the time discount rate to 2.5 percent. We set the share of tradable goods in final output to 25 percent as observed in the data. The curvature parameter of the R&D cost function (γ), which governs the elasticity of innovative output to R&D, is set to two following the conventional estimates in the literature (Hall and Ziedonis, 2001; Blundell et al., 2002; Acemoglu et al., 2018).

To capture the sizable support provided by the West to Eastern consumers, we include a lump-sum consumption subsidy from the West to the East. In the data collected from German data sources, this subsidy amounts to approximately 1.4 percent of German nominal GDP over the period 1991-2009, although we lack information on the annual decomposition.[20] We assume that the subsidy rate in the model follows a smooth, declining curve, shaped by the starting level

[19] Recall that $T_r(t) < 0$ ($T_r(t) > 0$) implies net tax collection from (transfers to) the households in region r. In addition, $G_r(t) = \zeta_r^R(t)W_r(t)L_r^R(t)$ holds in the baseline—i.e., the only industrial policy a regional government finances is the R&D subsidies—given that we set production subsidies to zero in the calibration, as explained in Section 5.

[20] We detail the steps of constructing the series of consumption transfers and R&D subsidies in Appendix C.

Table 2: Externally Set Parameters

Parameter	Description	Value
ρ	Time discount rate	0.025
γ	R&D curvature	2
β	Tradable sector expenditure share	0.25
θ	Pareto distribution shape parameter for δ	0.01
$L_{wt} + L_{et}$	Total labor of Germany $\forall t$	1
$L_{e,1995}$	Initial East labor	0.168
$L_{e,bgp}$	East labor in BGP	0.133
$\nu^L(\times 10^2)$	Half-life of labor	6.583
$\zeta^P_{w,t}$, $\zeta^P_{e,t}$	Production subsidy rate $\forall t$	0
$T_{e,1995}$	Initial East lump-sum transfer (1995)	0.022
$\nu^T_e(\times 10^2)$	Half-life of East lump-sum transfer	6.931

and a parameter governing its curvature, such that the total amount of consumption subsidy over the same period matches the corresponding value in the data.[21] Due to dearth of data, we set the production subsidy rate in both regions to zero in the baseline.

The total labor for the German economy is normalized to one. By fitting equation (3) via nonlinear least squares to the empirical aggregate employment series for East Germany, we obtain the parameters $L_{e,1995}$, $L_{e,bgp}$ and ν^L, and using the normalization for the total labor size, we back out the corresponding values for the West. As presented in Figure A.2 in the Appendix, this procedure obtains a great fit to the data, supplying us with a sensible and parsimonious functional form that we can use in out-of-sample counterfactual policy analysis.

We estimate the remaining parameters by matching the moments listed in Table 3 and the relative price distribution in 1995. The procedure centers on the transition path of the economy to determine the parameters that help the model replicate the observed time variation in the relevant empirical moments after determining the initial state of the economy consistent with the data. The key insight behind the estimation procedure is the observation that, while both quality and efficiency improvements increase average market shares of firms and aggregate income of a region, they affect the relative prices in opposite direction. Consider the following expressions:

$$\hat{p}_{rj}(t) = \hat{\mu}(\hat{s}_{rj}(t)) + \hat{w}_e(t) - \hat{A}_e(t),$$
$$\hat{s}_{rj}(t) = (\sigma - 1)(\hat{q}_{rj}(t) - \hat{p}_{rj}(t)),$$

where $\hat{x}_{rj}(t) \equiv \log(x_{rj}(t)/x_{-rj}(t))$ for $r = \{e, w\}$ and $r \neq -r$, and recall that a higher market share improves the regional income (see equation 20). Once the relative average wage rate is controlled, as observed from the national accounts, higher regional efficiency decreases the relative price of

[21] The specific path of the annual level of consumption subsidies flowing to the East is assumed to take the form $T_e(t) = T_{e,1995}e^{-\nu^T_e(t-1995)}$, which also corresponds to the subsidy rate, as the nominal GDP is normalized to one, allowing us to determine it externally.

good j in region r, which, in turn, increases the market share. By contrast, higher relative quality of a product in r raises both the relative price and the market share in favor of the producer in r. As such, the joint dynamics of relative wages, incomes, and prices are informative about the relative importance of quality and efficiency improvements in shaping the convergence of the East to the West. Guided by this intuition, the set of calibration targets include the initial level of relative wage levels, relative (per capita) output levels, and relative prices in the two regions as well as their evolution over time.[22] These targets discipline the model parameters in a way that is consistent with the underlying technology and labor efficiency dynamics implied by the data.

Table 3: Targeted Moments and Model Fit

Panel A: Parameter estimates			**Panel B: Moments**		
Parameter	Value	Description	Moment	Model	Data
λ	1.148	Innovation step size	East relative GDP per worker in 1995	0.632	0.643
σ	105.7	Elasticity of substitution	East relative GDP per worker in 2015	0.790	0.784
δ	0.163	Quality diffusion	East relative wage in 1995	0.750	0.737
α_w	1.586	West R&D cost	East relative wage in 2015	0.806	0.812
α_e	5.652	East R&D cost	East average log price gap in 2015	-0.213	-0.213
$A_{e,1995}$	0.285	East efficiency in 1995	West average R&D between 1995-2015 (%)	1.638	1.638
$\nu_e^A(\times 10^2)$	4.883	Half-life of efficiency	East average R&D between 1995-2015 (%)	0.085	0.085
$\zeta^R_{w,1995}$	0.100	West R&D subsidy rate	West R&D subsidy in 1995 (%)	0.135	0.135
$\nu_w^R(\times 10^2)$	6.982	Half-life of West R&D subsidy rate	West R&D subsidy in 2015 (%)	0.044	0.044
$\zeta^R_{e,1995}$	0.249	East R&D subsidy rate	East R&D subsidy in 1995 (%)	0.038	0.038
$\nu_e^R(\times 10^2)$	4.248	Half-life of East R&D subsidy rate	East R&D subsidy in 2015 (%)	0.005	0.005

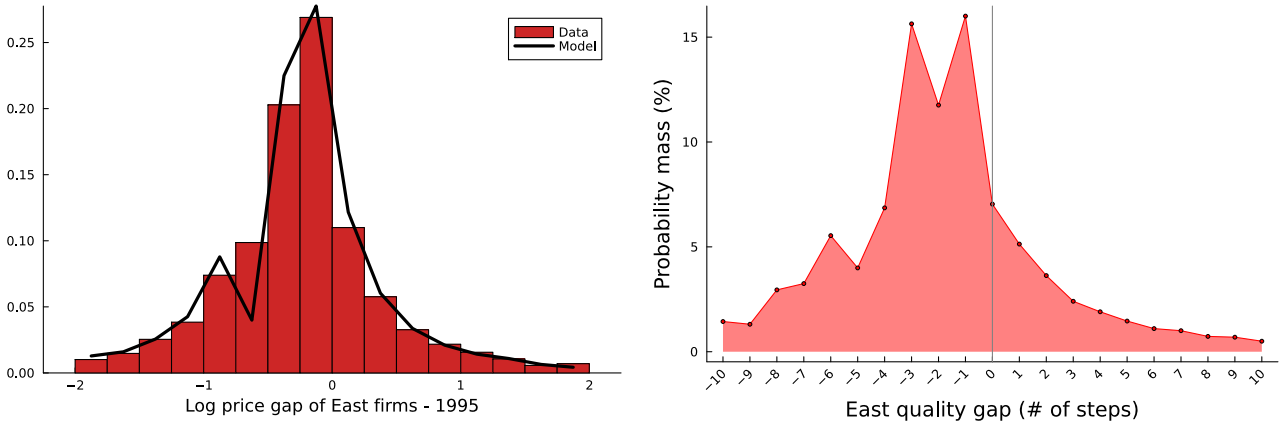
While the set of parameters in Table 3 are calibrated jointly, let us provide a heuristic explanation of how certain moments influence specific parameters. Consider first the parameters $\{\lambda, \sigma, \delta, \nu_e^A, A_{e,1995}\}$, while keeping fixed the parameters that define the R&D process, whose calibration we discuss shortly. Given these parameters, the initial relative price distribution implies a certain quality gap distribution over m determining the initial state of the economy. Given this implied distribution of quality gaps, the initial levels of relative income and wages are informative about the initial efficiency level ($A_{e,1995}$) and the elasticity of substitution between goods (σ).[23] Yet, the transition of the model needs to mimic the empirical change of relative incomes, wages, and the mean log price gap, which are influenced by the size of quality improvements (λ), half-life of labor efficiency in the East (ν_e^A), and the magnitude of technology spillovers (δ), and thus, help discipline these parameters.

Turning to the R&D process, regional R&D-to-GDP ratios help discipline the R&D cost scale

[22] As such, the estimation procedure shares the spirit of Akcigit et al. (2018), in that it is disciplined by the transitional dynamics of the model, with the initial state of the economy—the quality gap distribution, in particular—being determined by detailed micro-level data.

[23] We set $A_{e,bgp} = 1$, i.e., the Eastern productivity fully converges to the Western level in the very long run.

parameters, together with the regional R&D subsidy rates, which are calibrated to match the empirical counterparts. The paths of R&D subsidy rates (funded regionally) are assumed to follow a smooth, declining path shaped by an initial rate and a half-life parameter akin to the consumption subsidy rate.



A) Price gap distribution, model vs. data

B) Implied quality distribution

Figure 9: Price and quality gap distributions in 1995

The model closely matches the empirical targets. In particular, the model-implied initial price distribution mimics the empirical counterpart well (Figure 9a), with the implied quality gap distribution shown in Figure 9b. Not surprisingly, in most products, the Western producers command a technological advantage over their Eastern rivals in the initial year. Starting from this initial state, the calibrated economy reproduces the variation over time in important empirical targets such as the change in GDP per capita, relative wages, and the sustained disparities between the prices of Eastern and Western producers, which play an integral role in disciplining key margins in the model (Table 3).

5.2 Equilibrium Properties

Model mechanism in the data. As discussed in Section 3, Table 1 documented a positive relationship between (inverse) price gaps and the R&D effort of German firms. We next discuss how the model conforms with this empirical relationship.

Owing to its step-by-step innovation structure, a salient feature of our framework is that a laggard firm's innovation intensity increases as its technology gap with the leader shrinks. This relationship, illustrated in Figure 10, reflects the strategic behavior of the forward-looking firm: a higher chance of catching up with and taking over the market leader provides the opportunity to dramatically increase the firm's market share, incentivizing it to invest more in R&D. A shrinking technology gap also translates to a decreasing price gap between the two firms, allowing the

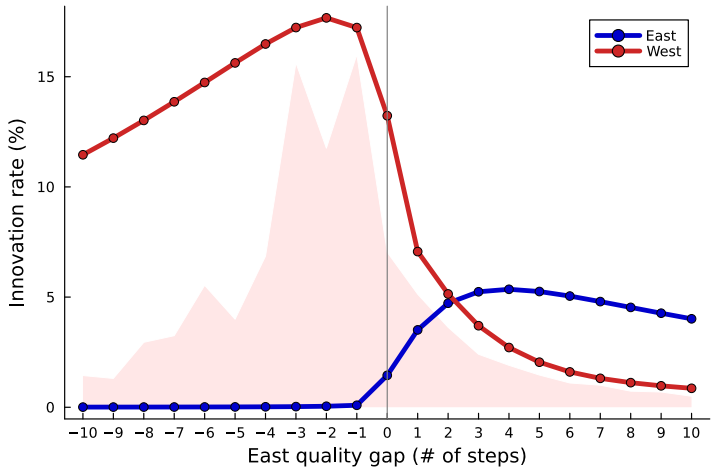


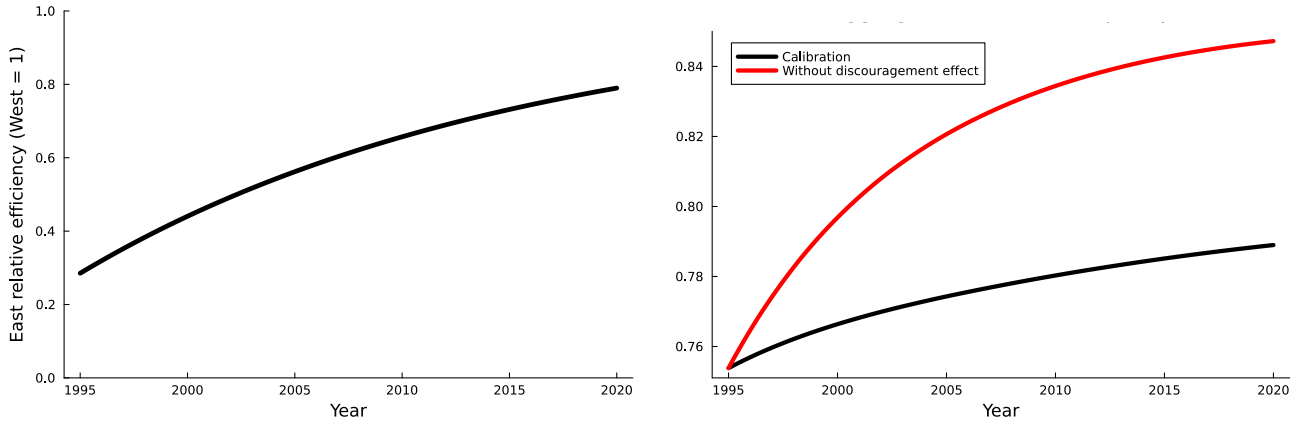
Figure 10: Innovation effort in the model

model to replicate the negative relationship between a diminishing price gap and higher R&D effort. Indeed, running the regression given by equation (1) on a set of firms simulated in the model's balance growth path obtains the coefficients 1.186 and 0.832 for the samples of Eastern firms and all German firms, respectively, both statistically significant at one percent level.

Convergence and the discouragement effect. In the calibrated economy, two main drivers shape the income convergence between the two regions. The first one, the quality channel $(\log Q_{et})$, captures the average level of technology (equivalently, product qualities), which evolves endogenously based on firms' forward-looking R&D decisions and knowledge spillovers. The second one is the exogenous production-efficiency channel (A_{et}). Improvements in each of these margins would help the average Eastern incomes approach Western levels. We now examine the evolution of these two important margins.

Figure 11a shows the evolution of the relative efficiency in the East in the calibrated economy. The calibrated path implies a sustained improvement in the average efficiency of Eastern labor force relative to the West, closing the gap steadily. By contrast, the calibrated path of relative average quality of Eastern products, shown by the black line in Figure 11b suggests only a slight gain, limiting the regional income convergence. Therefore, based on the dynamics of the calibrated economy, it is straightforward to conclude that income convergence between the East and the West was mostly supported by the relative productive efficiency gains in the East, with the product quality improvements contributing little to the process.

Further inspection suggests that the reason why Eastern firms do not improve their product quality faster, causing the technology gap with the West to widen, is the lack of sufficient competitive forces that incentivize them to do so. At the time of unification, most Eastern firms are technologically behind their Western rivals and many to a large degree (Figure 10). As a result,



A) Efficiency channel

B) Quality channel and discouragement

Figure 11: Innovation effort and markups in the model

Eastern firms' prospects of sufficiently upgrading their technology, such that they can catch up and or even surpass their Western rivals are slim, discouraging them from investing in R&D.

This result is a reflection of the key role strategic forces play in driving firms' endogenous forward-looking decisions in step-by-step innovation models. Firms intensify innovation effort when in close competition with their rivals (the neck-and-neck level)—dubbed as the "escape-competition" effect—but reduce it when they fall behind their rivals—the "discouragement" effect—and it grows as the technology gap widens. In fact, comparing the dynamics in the baseline economy to a counterfactual one in which both Eastern and Western firms are assumed to exert the maximum effort at every point in time provides an idea about the magnitude of the discouragement effect.[24] Figure 11b demonstrates that the impact of this discouragement effect is substantial. In the counterfactual economy, the Eastern firms indeed innovate more intensively—enough to ensure that the technological gap with the West closes over time. Consequently, the average quality level in the East relative to the West (the red line) rises markedly over the calibration period, which contrasts with the declining pattern observed in the calibrated baseline economy (the black line). The difference between the two lines suggests that by 2015, the relative average product quality in the East would be six percentage points higher in the absence of the discouragement effect, lending notably greater support to convergence. As such, the theory provides an intuition as to how initial technological disparities could perpetuate regional economic gaps by feeding into forward-looking R&D decisions of firms.

[24]The thought experiment is equivalent to assuming that firms are neck-and-neck at each point in time giving optimal innovation responses, with the optimal decisions being determined by the policy functions obtained in the baseline calibration along the transition.

6 Policy Analysis

In this section, we evaluate several alternative policy settings in terms of their implications for the technological catch-up between the two German regions and consumer welfare. We first explore whether delaying the unification process could have potentially dampened the discouragement effect that hurt Eastern firms' incentives. Then, we analyze alternative subsidies—R&D subsidies, production subsidies, and outright consumption support—that were considered or part of the policy kit back at the time. Finally, we entertain a policy that would encourage technology flows from the frontier Western firms to the East via licensing. The costs of all policy schemes we consider are borne by agents in the West, funded in a lump-sum fashion.

To be sure, our goal here is not to evaluate actual policies adopted in Germany back then; rather, it is to comprehend the implications of various policy options in order to assess the best possible practices that could have sped up technological and income convergence between the East and the West.

Welfare. We analyze the variations in consumption-equivalent welfare (CEQW) triggered by policy changes. We assume policies take effect in the initial period representing the year 1995. Let $U_r(T)$ denote the total discounted utility the representative household in region r derives from consumption over a period of length T starting from 1995:

$$U_r(T) \equiv \int_{1995}^{1995+T} e^{-\rho(t-1995)} \log C_r(t) dt.$$

Let $U_r^{policy}(T)$ denote the value under a new policy regime. The change in CEQW under the new policy for a horizon of T, denoted by $\gamma_r(T)$, then follows from the following equality:

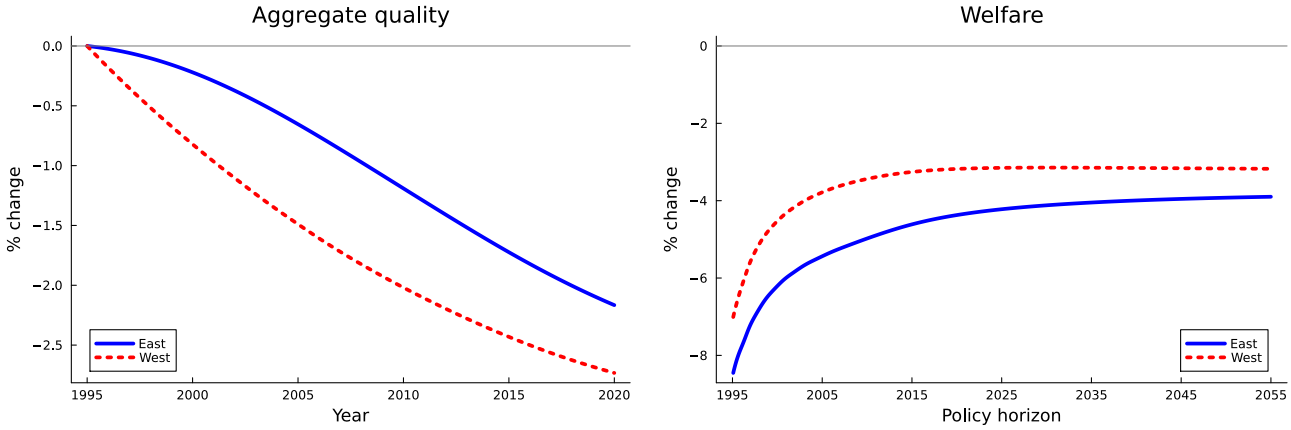
$$\int_{1995}^{1995+T} e^{-\rho(t-1995)} \log \left[C_r^{\text{cal}}(t) \left[1 + \gamma_r(T) \right] \right] dt = U_r^{\text{policy}}(T),$$

where $C_r^{\text{cal}}(t)$ refers to the consumption path that would arise in the calibrated economy in the absence of policy changes. A positive $\gamma_r(T)$ means that the consumer is better off under the new policy, with a $\gamma_r(T)$ percent increase in CEQW over a horizon of T years. Conversely, a negative $\gamma_r(T)$ implies a $|\gamma_r(T)|$ percent decline in CEQW.

6.1 Delayed unification

Given the discouragement effect on Eastern firms exerted by Western ones in the post-unification economy—as examined in Section 5.2—a sensible follow-on question is if delaying unification could have helped Eastern firms and incomes. Indeed, some policy makers at the time pushed for a delayed or phased integration, a perspective that is still debated today (Rödder, 2016; Burda,

2020). We now assess this idea in a counterfactual economy, in which excessively high tariff rates imposed by the East on imports from the West effectively prohibit access of Western goods into the East, fully protecting Eastern firms initially and declining gradually over time thereafter.[25]



A) Change in aggregate qualities

B) Consumption equivalent change in welfares

Figure 12: Delayed unification

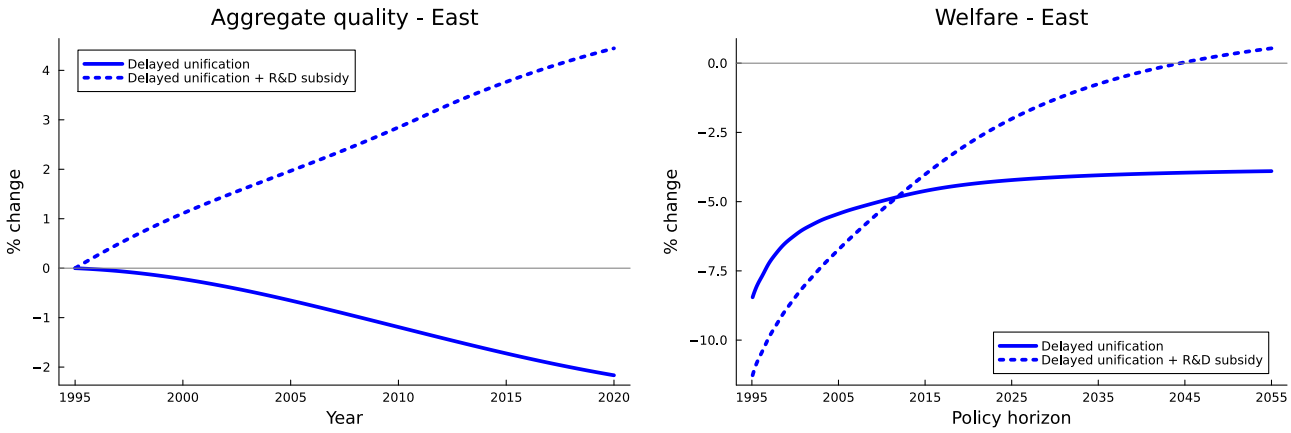
Figure 12 shows the path of regional average qualities and changes in consumption-equivalent welfare over different horizons.[26] Figure 12a indicates that that regional average qualities are lower than their baseline paths, and the losses grow over time. While the dynamic loss is larger in the West in proportional terms, implying that, in relative terms, the Eastern average technology is closer to the West in the delayed unification scenario when compared with the baseline, this seemingly improved Eastern technological position relative to the West clearly occurs at the expense of overall technological deterioration. As shown in Figure 12b, these dynamics lead to substantial welfare losses in both regions.

The main reason for dynamic losses in average quality is the reduced innovation incentives of firms caused by higher trade barriers, akin to the results in Akcigit et al. (2018). While higher trade costs on Western imports shrink the export market size for Western firms, they also reduce the competitive pressure from Western rivals that many technologically laggard Eastern firms previously faced in their domestic market. Moreover, while tariffs are raised unilaterally by the East, hurting exporters from the West, the demand from the West for Eastern products also diminishes reciprocally—recall that trade is balanced—hurting Eastern exporters' profits and their innovation incentives. Overall, the delayed unification depresses overall technological

[25]Figure A.3 in the Appendix exhibits the path of the tariff rates. The experiment restricts only the flow of goods, with spillovers or efficiency convergence remaining unaffected. Clearly, impediments to those margins stemming from weaker trade linkages would aggravate the costs associated with delaying the unification.

[26]In the policy analysis, we focus on the path of the average product quality across regional producers.

development, weighing on incomes and consumer welfare.[27]



A) Change in East aggregate quality

B) Consumption equivalent change in East welfare

Figure 13: Delayed unification with R&D subsidies to the East

In light of these findings, an alternative policy design could be providing support to R&D in the East in conjunction with delaying the unification to weather its negative effects on innovation incentives. To entertain this alternative, we consider the same path of increased import tariffs as above, but with the tariff revenue collected in the East being used to subsidy R&D activity of Eastern firms. Figure 13 compares the implications for the average quality and welfare in the East with the previous case—delayed unification without R&D subsidy. As can be expected, the average quality path is higher with the help of additional support to R&D. In fact, it even exceeds the path of the calibrated baseline economy (note that the change is relative to the baseline, and the dashed line is in the positive territory). However, this policy still implies lower welfare in the East relative to the baseline for about half a century. While R&D support helps correct the negative innovation effects of higher trade barriers and make Eastern consumers better off in the longer run, those consumers are indeed worse off initially compared to the "delayed unification" scenario. The reason is that the tariff revenue is spent on R&D subsidies instead of consumption, with the benefits materializing only gradually over time.

6.2 Subsidy Policies

Subsidies to the East. Following the reunification, the German government established several schemes to lift up the Eastern economy, including direct transfers to households and producers

[27]The magnitude of the welfare loss in the West is smaller than in the East despite the larger dynamic losses in average quality because the size of the regional Western market is much larger than the Eastern market for Western exports. Therefore, the income loss from reduced exports is proportionally less detrimental in the West. In addition, we assume that the West decreases the amount of the transfers that were calibrated in the baseline economy, as the East starts collecting revenue from the tariffs imposed on Western products.

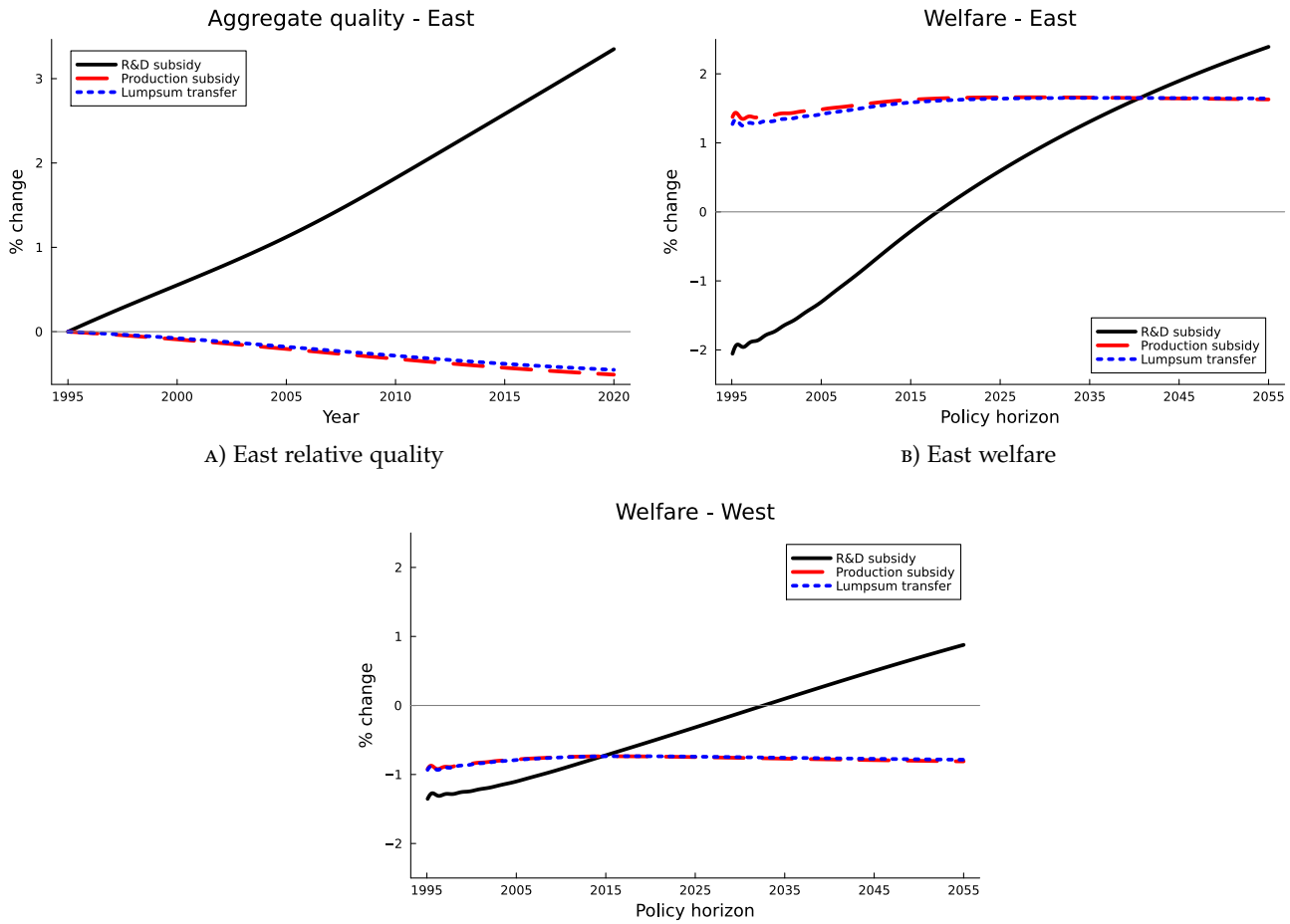
in the East funded by taxpayers living in the more affluent West German states (Uhlig, 2008; Paqué, 2009). In this part, we evaluate how various transfer policies could have helped the Eastern economy in the aftermath of the unification. We start by comparing Western support through (i) R&D subsidies to Eastern firms, (ii) production subsidies to Eastern firms, and (iii) lump-sum transfers to Eastern consumers. In each case, the change in transfers lasts permanently and amounts to 0.3 percent of the German GDP over that period.

As shown in Figure 14a, consumption and production subsidies lead to a slight decline in the average quality of Eastern products relative to the baseline. That said, both policies are effective in boosting the welfare of Eastern households, as shown in Figure 14b. Not surprisingly, consumption subsidies provide windfall gains to the consumers in the East, while production subsidies lower the effective cost of production in the East, supporting production, income and consumption in that region.[28]

A plausible question is then whether the same amount of resources used in the previous subsidy counterfactuals could be spared for R&D subsidies, potentially boosting technological convergence and raising incomes and welfare. Figure 14 confirms this conjecture, though with some important nuances. To start, R&D subsidies prove very effective in supporting technological convergence, improving the average quality path notably relative to the baseline (the solid line in Figure 14a). However, this acceleration in product qualities does not immediately translate to welfare gains. Indeed, R&D subsidies create welfare losses in the East for horizons up to two decades, and it takes about four decades for the Eastern consumers to enjoy similar gains as in the case of consumption and production subsidies. The reason is that substantial R&D support raises labor demand for this activity, putting pressure on wages and production workforce, eroding Eastern firms competitiveness vis-à-vis their Western counterparts. Therefore, while it is true that R&D subsidies generate dynamic persistent welfare gains, these gains materialize with considerable lags, and production or consumption subsidies turn out to be more beneficial options when the policy maker's horizon is shorter than four decades.

Turning to the implications of these alternative policies for Western consumers, Figure 14b shows that all these schemes to provide additional support to the East reduce welfare in the West, except in the very long run in the case of R&D subsidies. The benefits from improved product quality eventually dominate the welfare gains for the Western consumer, making them better off, but only when a horizon of at least four decades is considered.

[28]The increased demand for production workers and higher wages also raise the cost of doing R&D in the production-subsidy counterfactual. Similarly, consumption transfers raise the demand for nontradables as well, increasing the demand for workers in that sector, pushing up wages. As a result, the relative quality path in these experiments (the dashed and dotted lines in Figure 14a) are slightly worse than in the baseline.



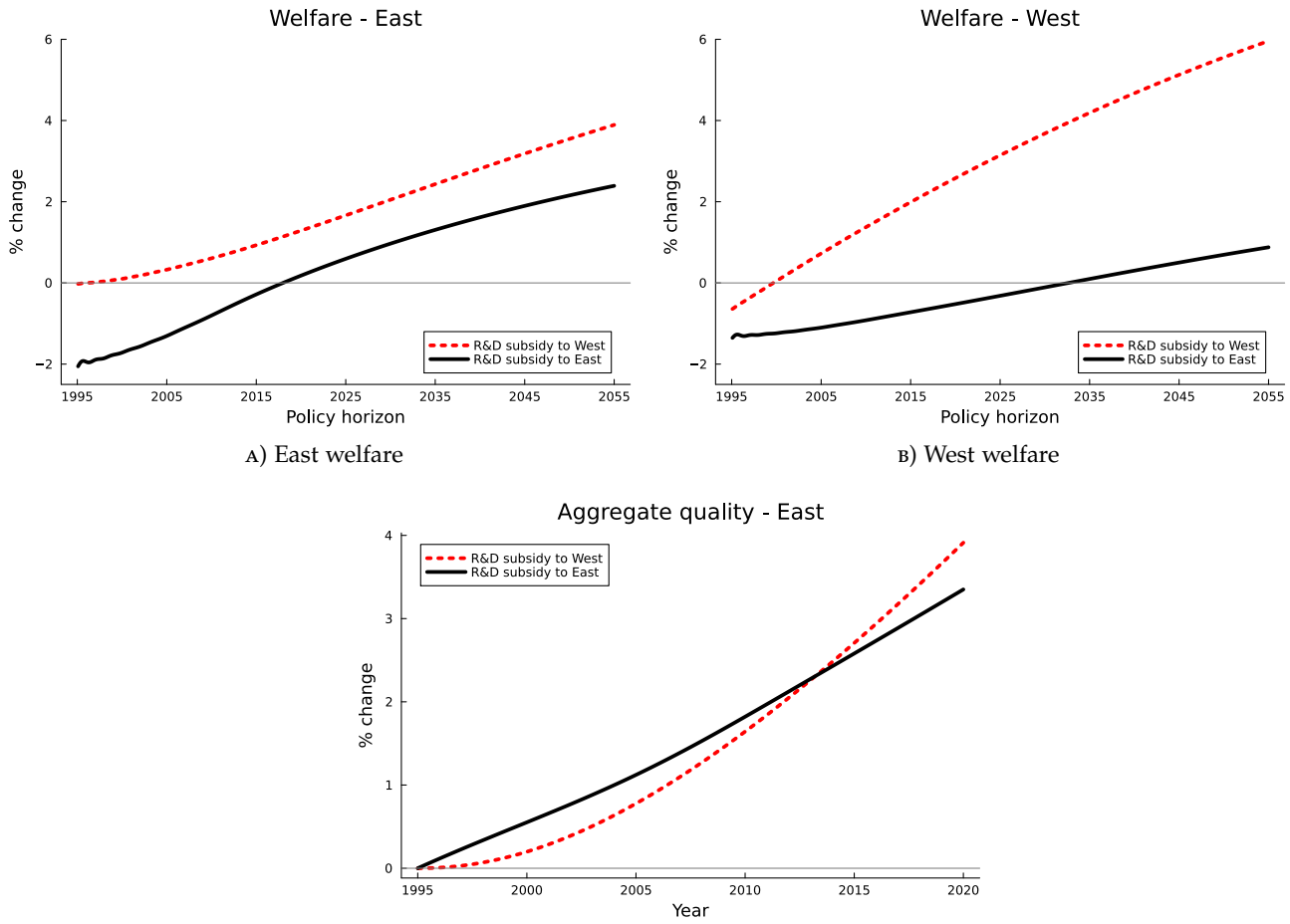
A) East relative quality

B) East welfare

C) West welfare

Figure 14: Comparison of subsidy policy counterfactuals

R&D subsidy in the West. The previous investigation revealed that among the analyzed subsidy schemes, only R&D subsidies bolster technological advancement in the East, though at the expense of consumers' welfare in both regions. An alternative scheme could be using the same amount of resources to support R&D in the West, given that Western firms are more efficient in doing R&D—the cost of obtaining the same rate of innovation is lower in the West—and the East could still benefit from faster technological improvements through knowledge spillovers. Indeed, as shown in Figure 15a, Eastern average quality starts to benefit from this policy via spillovers before long, even surpassing the path that emerges in the case of increased R&D transfer to the East in about two decades, and without much loss prior to that. In addition, welfare in both regions improve (except for the immediate horizons in the West) owing to improved quality of products sourced from both regions. As such, spending the resources on supporting R&D activity in the more productive region helps technological development and incomes in both regions as long as the Eastern agents are able to rely on technology spillovers from the West to a reasonable degree.



A) East welfare

B) West welfare

C) East relative quality

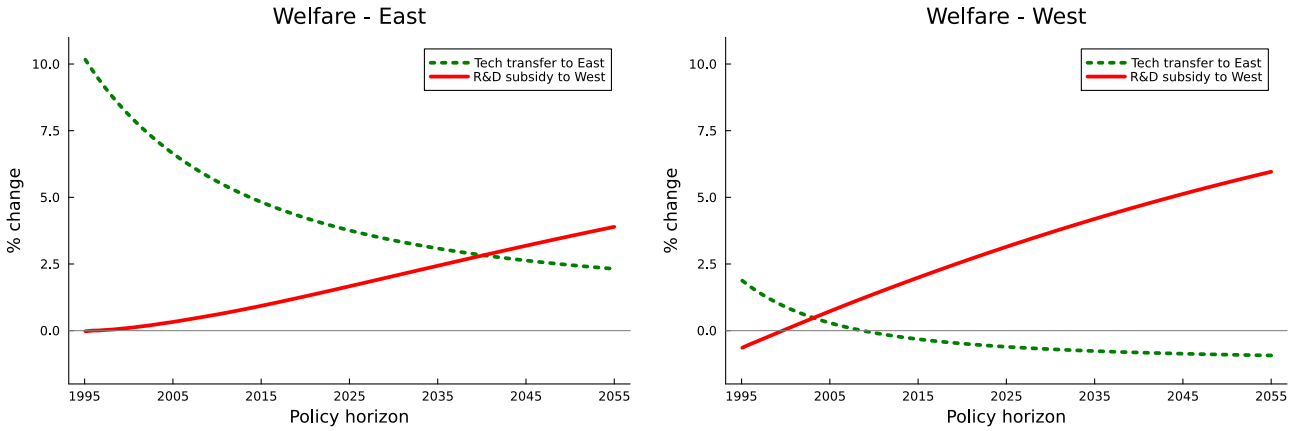
Figure 15: Implications of subsidizing Western R&D

6.3 Licensing Western Technologies

Next, we consider an alternative policy that facilitates the flow of technology to the laggard region; that is, incentivizing West German firms to share their frontier technologies with laggard Eastern firms in their sectors. The rationale behind this alternative is to reduce the initial technological laggardness of the Eastern producers, which, as explicated in Section 5.2, hurts their competitiveness in the market and discourages them from innovating. The thought experiment is that, at the time of integration, Western frontier firms transfer their technology to Eastern competitors via licensing, though it is unlikely that it can fully be absorbed by Eastern producers. We assume that Eastern firms enter the integrated economy at a better position than they would in the calibrated economy, such that their initial position is, on average, a number of technology steps closer to the Western firms.

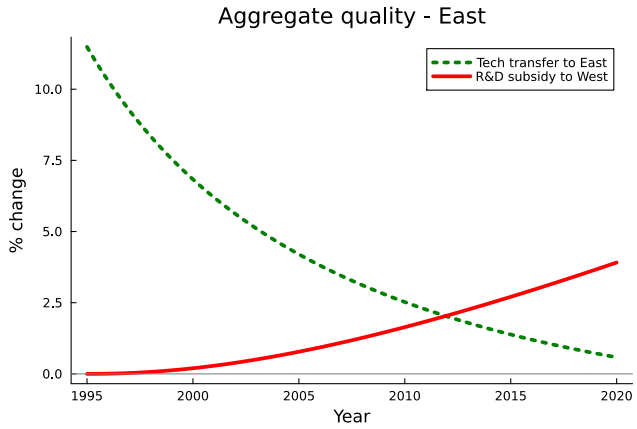
To draw comparisons to the previous exercises, we determine the magnitude of step gains

from licensing in a way that the cost of this policy on the Western side is of similar magnitude as in the previous cases. The cost of this policy is the loss in future profit stream for Western firms as a result of closer competition, translating into lower firm valuations in 1995 in net present discounted terms. We pick the average step gain for Eastern laggards such that the total loss in Western firms' values is of similar magnitude to the output losses in West Germany in the previous exercises.[29] Accordingly, we set the size of the gain via licensing to be two.[30]



A) East welfare

B) West welfare



C) East relative quality

Figure 16: Implications of technology licensing

[29] In the previous exercises, the total amount of (permanent) subsidies equals 0.3 percent of German GDP, which, in present discounted value terms, corresponds to about 15.8 percent of total German GDP in 1995. We consider a within-sector technology transfer from leader Western firms to laggard Eastern firms in terms of fixed quality steps, such that the average value loss of Western firms relative to German GDP in 1995 is of similar magnitude. The maintained technology transfer that leads to a gain of two steps for the Eastern firms generates a loss of about 14.4 percent of German GDP in Western firm values—a cost on the budget of the Western households, who own the firms, that is comparable to the amount of subsidies to the East they are assumed to fund in the other exercises.

[30] We do not allow follower East firms to leapfrog Western leaders after the technology transfer (in case the initial lag of the Eastern firm in a sector is less than the number of steps of the technology transfer). They can at most become neck-and-neck with their competitors. We also do not change an Eastern firm's position if it already has a

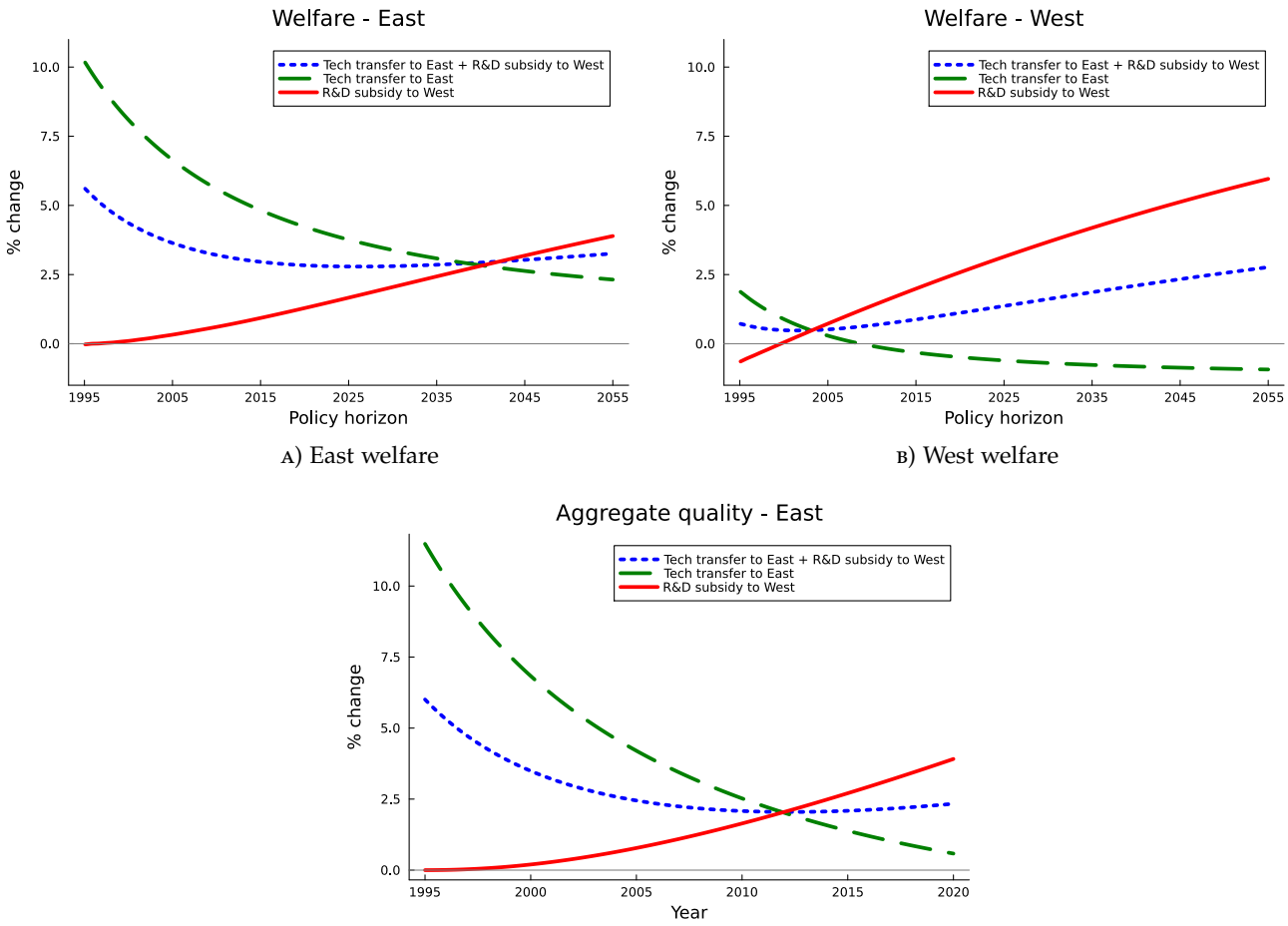
To start, licensing has an immediate large impact on the relative technology level of Eastern firms, as shown in Figure 16c. Given that the support is assumed to be one time at the outset of integration, the relative technology level of Eastern firms starts to regress after the initial jump, though always remaining at levels materially higher than the path arising in the calibrated economy. Second, the technologically improved position of Eastern firms translate into higher market shares, incomes, and considerable permanent welfare gains, especially over shorter horizons (Figure 16a). In addition, welfare in the West also improves in the short term owing to the expanded production of better-quality goods with Eastern products benefiting from licensing, a distinguishing implication of licensing compared to previously analyzed subsidies (Figure 16b). That said, the loss of income to Eastern firms becomes the dominant force when longer horizons are considered, leading to small declines in the welfare of Western consumers. Hence, when compared with the scenario of increased R&D subsidies to the Western firms, this policy appears to shuffle welfare gains across time and space: toward earlier periods and Eastern consumers.

Combining best policies. The previous analysis suggests that relying on the Western frontier technology and creating schemes to make the Eastern producers benefit from it produce the best welfare outcomes, albeit with some nuances as to who happens to benefit more and when. We then ask, is there a way to achieve a more balanced welfare improvement across time and space mixing the most effective policies—subsidizing R&D by Western firms and initial licensing of Western technology to the East? We now examine this policy mix, with the total resources spent remaining the same as in previous experiments, being split equally to fund each policy.

Figure 17 demonstrates the Eastern average quality under this scenario. As could be expected, the path lies in between the ones obtained separately in each scenario, implying still a notable improvement relative to the baseline. The welfare gains also follow similar patterns, with Western consumers now experiencing an improvement relative to the baseline over any horizon, though at a lower rate than in the case of subsidizing Western R&D alone.

In summary, our results indicate that it would be possible to accelerate technological advancement in the East in a way that is beneficial to all consumers over any policy horizon by initially licensing Western technologies and compensating the West for potential income losses via subsidies to Western R&D. The distinct feature of this policy is that it focuses on ensuring the flow of frontier technology flows to the East, instead of forcing the technologically laggard Eastern firms to reinvent the wheel. To be sure, policies that could reduce the comparative disadvantage of the East in R&D as captured by the high value of α_e could have improved the effectiveness of R&D subsidies to Eastern firms and should be entertained as part of the policy tool. However, these differences could arise from deep-rooted issues, such as organizational or institutional factors, that could take time to be meaningfully altered. Our analysis highlights

lead over its competitor in 1995.



A) East welfare

B) West welfare

C) East relative quality

Figure 17: Implications of the policy mix

that, given these factors, relying on the transfer of frontier technology to the East to prop up their technology and competitiveness produces the best welfare outcomes.

7 Conclusion

In this study, we attempt to contribute to the perennial debate on the persistent income and technology gaps between the two regions of Germany—the West and the East. Motivated by similar observations at granular product-level data, we propose a theory that links firms' endogenous innovation incentives, which drive aggregate dynamics of technological development and income, to their positions in market competition, which, in turn, reflects the level of technology they command relative to their rivals. We quantify the key features of this model—notably, the dynamics of relative product qualities—relying on a novel dataset of firm-level prices over narrowly defined products.

Our quantitative analysis provides various insights regarding technological convergence between the two regions and policy implications. To start, the results point to a novel technological factor coupled with the dynamics of market competition as the root cause of persistent product quality disparities between the East and the West and the slow pace of economic convergence. Policies that aim at boosting technology upgrading of Eastern firms could alleviate this problem. That said, our results emphasize that standard support schemes such as R&D subsidies to Eastern firms would not be welfare-improving over the relevant policy horizons in light of the estimated high cost of doing R&D in the East. More effective use of resources would need to rely on technology transfers from Western firms via licensing while supporting their innovative activity, respecting their comparative advantage and ensuring the flow of knowledge spillovers.

Certainly, our analysis bears broader relevance to topics concerning economic development. A central theme in macroeconomics is the design of appropriate policies to support the convergence of developing economies to high-income levels. The fact that economic convergence could drag for decades even among two regions that share a common language, common cultural backgrounds, and common borders only adds to the intricacies of economic development and optimal design of industrial policies to support it. Our study could potentially shed light on underexplored technological factors that could perpetuate and impinge upon economic convergence and the most effective policies to overcome these challenges.

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Online Appendix

A Additional Empirical Results

Table A.1: R&D intensity and price gaps, including West-German firms.

	RDI_{it}			
	All firms	All single-product firms	West firms	West single-product firms
	(1)	(2)	(3)	(4)
Gap_{it-1}	0.049**	0.070**	0.041*	0.059
	(0.022)	(0.034)	(0.024)	(0.037)
Year FE	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
Observations	81,409	22,353	70,016	18,802
R^2	0.879	0.884	0.881	0.883

Notes: This tables reports results from estimating equation (1) using different firm samples. R&D intensity (RDI_{it}) is defined as R&D employment share in total employment. Gap_{it} measures the sales-weighted average price ratio between a firms' products and the highest priced products within an industry and year. Standard errors are clustered at the firm level. Significance: 0.01***, 0.05**, 0.1*. German firm-product-level data. East-German firms.

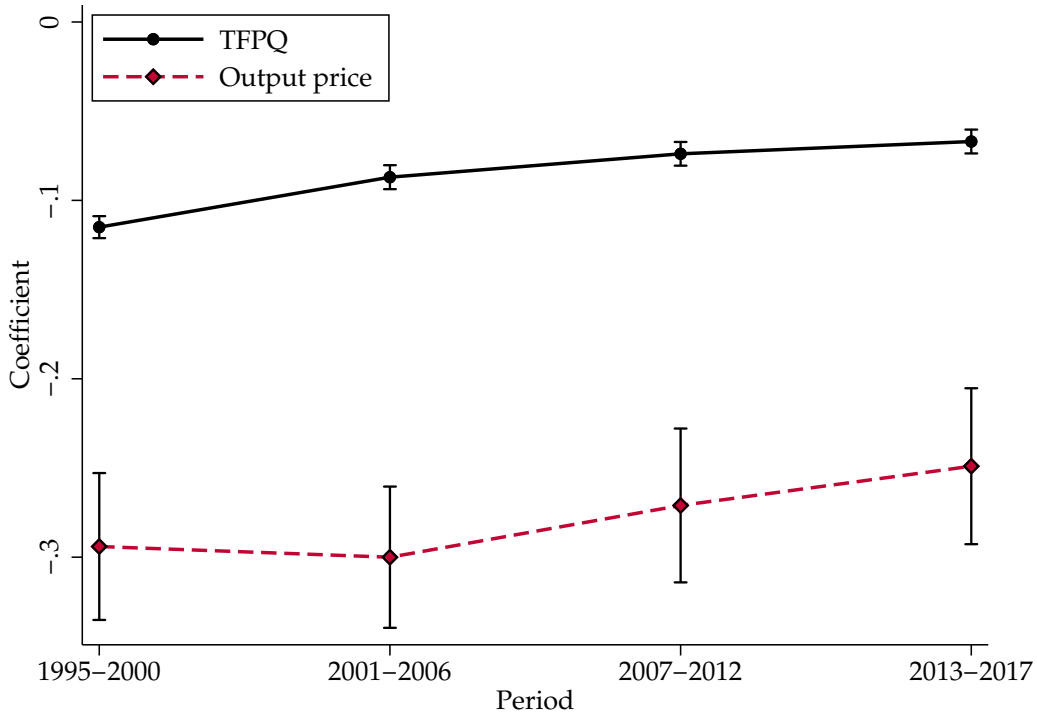


Figure A.1: Firm-level productivity and output prices.

Notes: East-dummy coefficients and 95% confidence intervals from regressing firm-level TFPQ (quality-adjusted total factor quantity-productivity) and output prices on a dummy indicating East-German firm location. For multi-product firms, we use the output price of the core-product (product with highest sales share). The regressions control for year times core-product fixed effects. TFPQ is derived from a translog production function estimation routine following Mertens (2022) and Mertens and Schoefer (2024). This routine projects firms' gross output on a polynomial in labor, intermediates, and capital while controlling for a productivity control function and an input price control function. The productivity control function is derived from inverting firms' demand function for raw materials, product components, and energy (similar to Levinsohn and Petrin, 2003). We include location and industry dummies, an export dummy, the number of products a firm produces as well as wages (a serially correlated input price) into the productivity control function. The firm-level input price control function includes a firm-level output price index and product market shares(similar to the product-level approach in De Loecker et al., 2016). Gross output is deflated with a firm-level price index as in Eslava et al. (2004) to purge firm-specific price variation from firm output. The production function is estimated separately by NACE rev. 1.1 industries using a one-step approach as in Wooldridge (2009). The estimation also controls for year dummies. TFPQ is computed as the sum of the residuum from the production function, year dummies, and the productivity control function. As discussed in De Loecker et al. (2016), the inclusion of the input price control function controls for quality differences between firms. German manufacturing sector firm-product-level data spanning 1995-2017.

B Additional Quantitative Results

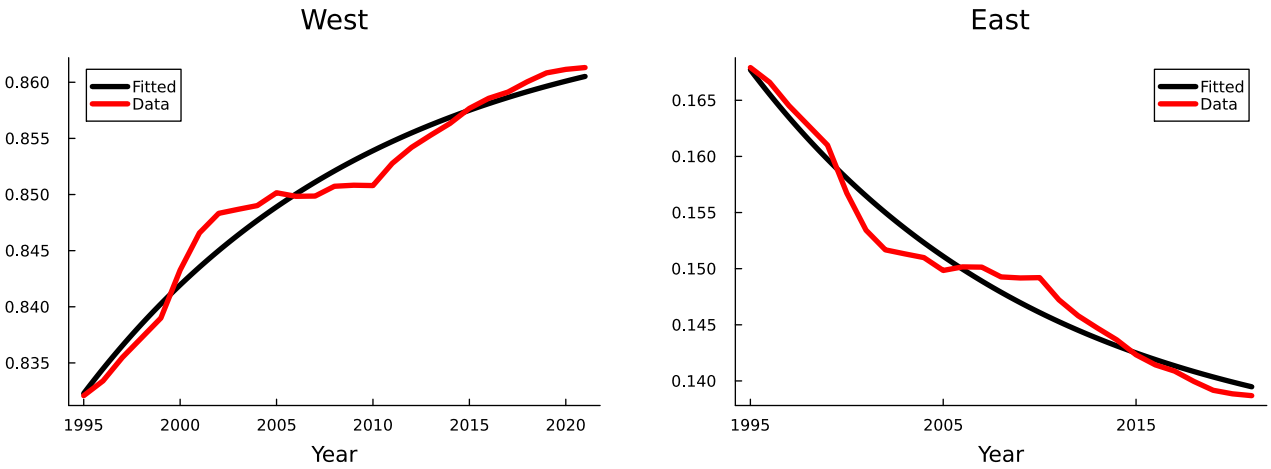


Figure A.2: The fit for the regional labor force sizes

Notes: Total labor force in Germany is normalized to one in all periods. Regional labor forces sum up to one. East parameters $L_{e,1995}$ and $L_{e,bgp}$ and the common half-life parameter ν^L are estimated via fitting equation (3) to East normalized labor force with nonlinear least squares. West parameters are recovered from the relationship $L_{w,1995} = 1 - L_{e,1995}$ and $L_{w,bgp} = 1 - L_{e,bgp}$.

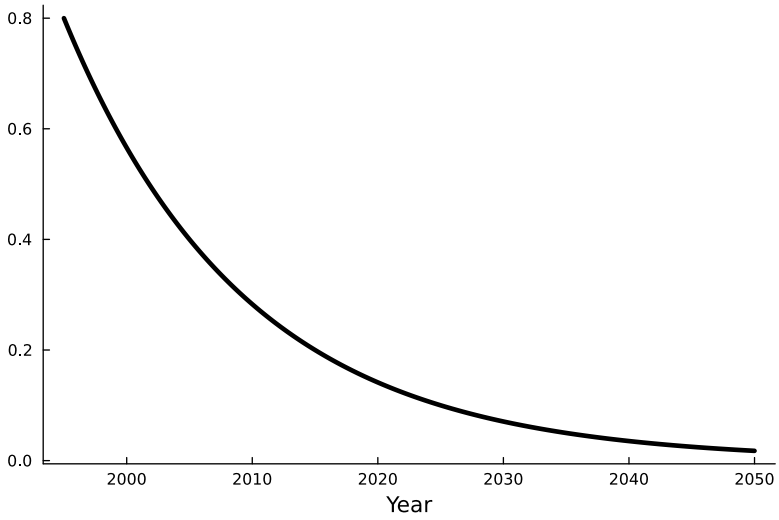


Figure A.3: Tariff rate by the East imposed on Western goods

C Construction of Subsidy and Transfer Series

We construct the series for R&D subsidies and consumption transfers from several data sources. In the following, we describe these data sources and how we combined them.

R&D subsidies and expenditures. We define total German R&D subsidies as the sum of R&D subsidies provided by the German central government and the federal states. The German Federal Ministry of Education and Research provides two series of regional R&D subsidies for the German central government and federal states in the publicly available tables "Tabelle 1.2.1" and "Tabelle 1.2.4", which can be accessed via the website of the ministry. As the time series for the federal state subsidies dates back only to 1997, we extent the series back to 1995 based on data from the Bundesbericht Forschung 1998 and Bundesbericht Forschung 2000 (BMBF, 1998, 2000). We combine this data with state-specific R&D expenditures information that is available for three categories: private economy firms, universities, and expenditures by the state and private non-profit organizations, published by the Federal Statistical Office in their table 21821-0002 from 1995 onward. We extent the time series to 1993 using information from the Bundesbericht Forschung 1998 (BMBF, 1998). As no data is reported for 1994, 1996, and 1998, we interpolate these years using averages of the previous year and the following year.

As we are interested in recovering R&D subsidies given to private economy firms, we must invoke assumptions on the distribution of subsidies across the three expenditure categories. We define the public R&D expenditures as the sum of the R&D expenditures of universities and the state and private non-profit organizations. We assume that, every year, 85% of public R&D expenditures are paid from the government budget. Therefore, the remaining part is taken as the R&D subsidies given to private economy firms. Figure A.4 shows the calculated time series of R&D subsidies as a fraction of total German GDP. Figure shows relatively larger R&D subsidies given to West firms, however it must be noted that the total amount of subsidies is positively associated with R&D expenditures. If West firms conduct more R&D and if the government applies an R&D subsidy rate rule that compensates for a certain fraction of R&D expenditures, then the total amount of R&D subsidies given to West firms is expected to be higher than that given to East firms.

In our calibration exercise discussed in Section 5, we target total R&D subsidies given to regions as a fraction of German GDP only in two years: 1995 and 2015. These two targets help us calibrate two regional subsidy rate parameters: $\zeta^R_{r,1995}$ and ν^R_r for $r = w, e$. Note that R&D subsidies are assumed to be zero in the BGP. Therefore, we take $\zeta^R_{r,bgp} = 0$. Then, the time path of the R&D subsidy rate for region $r = w, e$ is calculated from the following exponential path:

$$\zeta^R_{r,t} = \zeta^R_{r,bgp} + \left(\zeta^R_{r,1995} - \zeta^R_{r,bgp}\right) e^{-\nu^R_r (t-1995)}, \quad t \geq 1995$$

Another set of targets that identify R&D cost scale parameters α_r are R&D expenditures by private economy firms. Figure A.5 shows the time evolution of these series for both regions. As is

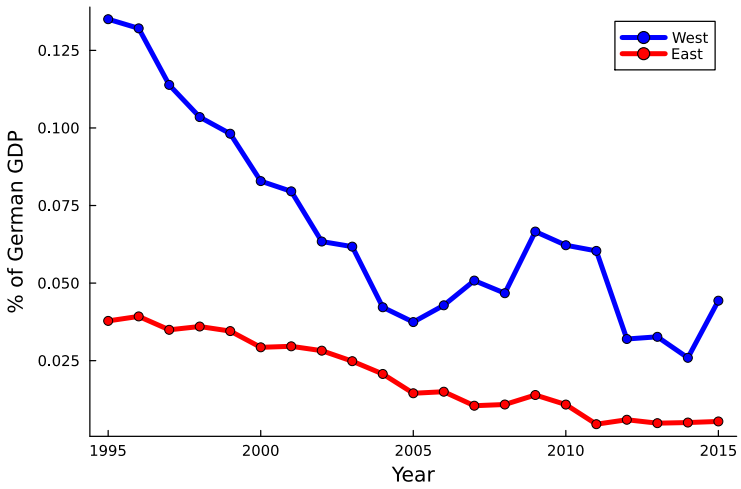


Figure A.4: Time series of R&D subsidies to private economy firms

clear from this figure, Western firms spend more resources for R&D than Eastern firms, and they increase their R&D spending over time while Eastern R&D expenditures are stationary. R&D cost parameters are calibrated by matching the time average rate of the ratio of R&D expenditures of a region to German GDP. In particular, we calculate the total R&D expenditures in a region and take its ratio to total German GDP. Then we average this ratio between the years 1995 and 2015.

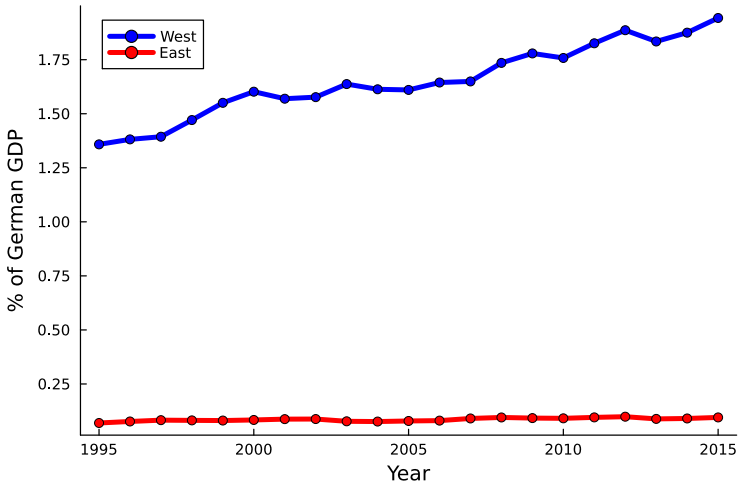


Figure A.5: Time series of R&D expenditures of private economy firms

Lump-sum transfers to East. We compute a time series for lump-sum consumption transfers based on information provided by Paqué (2009), who uses back-of-the-envelope calculations to calculate the total transfers from the West to the East over the period from 1991 to 2009. As explained in Section 2, according to Paqué (2009), the West transferred a sum of 1,400 billion Euro (nominal values) to the to East over the period of 1991-2009 including infrastructure investments

and repayment of GDR debt. 900 billion of these transfers consist of social transfers mostly captured by pensions, unemployment benefits, and active labor market policies. We assume that 2/3 of these transfers constitute lump-sum transfers to East consumers, and replicate a total amount of 600 billion Euros of transfers in our model as explained below. Firstly, similar to equation (3), we assume that T_{et} follows an exponential process governed by parameters $T_{e,bgp}$, $T_{e,1995}$ and ν_e^T:

$$T_{et} = T_{e,bgp} + \left(T_{e,1995} - T_{e,bgp}\right) e^{-\nu_e^T (t-1995)}.$$

We have a single data point as the total amount of transfers between 1991 and 2009. Therefore, we have to externally calibrate two of the three variables. Firstly, we assume that lump-sum transfers to East end completely in the BGP. Therefore, we take $T_{e,bgp} = 0$. Secondly, we assume a half-life of 10 years of the series T_{et}, which gives $\nu_e^T = \frac{\log 2}{10} \approx 0.06931$. The last parameter $T_{e,1995}$ is then calculated by replicating the total amount of the transfers in the model and equating it to the same quantity calculated from the data. As total German GDP flow is normalized to one at every point in time, we solve the following equation

$$\frac{\int_{1991}^{2009} T_{et} \times 1dt}{\int_{1991}^{2009} 1dt} = \frac{600}{\sum_{y=1991}^{2008} Y_y}$$

where 1 stands for the nominal GDP of German economy in the model, and Y_y is annual Germany GDP in billion Euros in the data. Left hand side of this equation equals to the fraction of accumulated transfers to East to total German GDP, whereas the right hand side of the equation represents the same quantity calculated from the data. Replacing $T_{et} = T_{e,1995} e^{-\nu_e^T (t-1995)}$, taking $\nu_e^T = \frac{\log 2}{10}$ in the expression above, and solving for $T_{e,1995}$ yields

$$T_{e,1995} = \frac{\frac{600}{\frac{1}{18}\sum_{y=1991}^{2008} Y_y}}{\frac{1}{\nu_e^T}\left[e^{-\nu_e^T(1991-1995)} - e^{-\nu_e^T(2009-1995)}\right]} \approx 0.0222$$

We interpret this finding as follows: In year 1995, the German government lump-sum transferred to East households equals approximately 2.2% of total German GDP. However, this transfer scheme decreases and converges to zero over time. The calibrated T_{et} schedule that we take to the model is depicted in Figure A.6.[31]

[31] We take the full path of T_{et} to the model until its convergence to zero in the BGP. In Figure A.6, only a part of this series until recent years is shown.

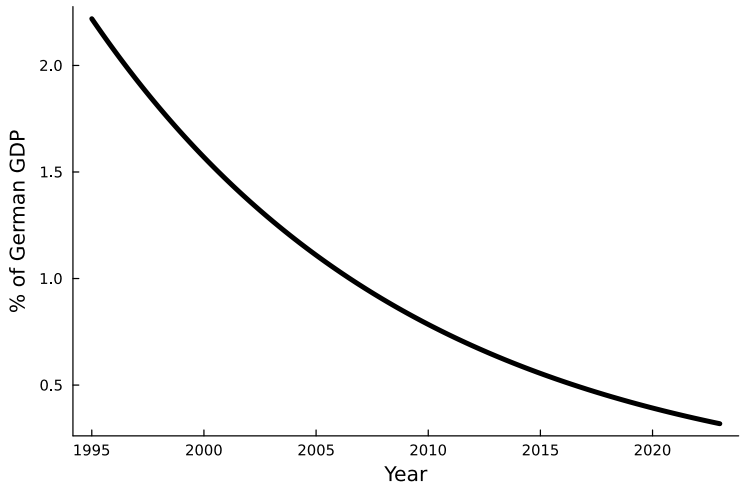


Figure A.6: Calibrated time path of lump-sum transfers to East households, T_{et}.