Technology Gaps, Competition, and Regional Convergence*

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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. We explore the factors that constrained convergence, with a particular focus on technological differences and firm behavior. In the immediate aftermath of the reunification, per-capita output in East German regions exhibited rapid catch-up with the West with notable labor productivity gains. But the convergence quickly tapered off, with a stark difference between East and West German firms' product qualities persisting ever since. A new quantitative model of innovation, competition, and regional integration that can mimic these dynamics provides a suitable setting to evaluate alternative policies that could have altered these dynamics. We find that large initial technological differences depressed Eastern firms' incentives to compete and invest in technology improvements, perpetuating initial gaps. Delaying reunification—opening up to competition from the West—would not have helped Eastern firms build up capacity. Sustained support for R&D in the East from the West could have reduced product quality and income gaps. Yet more welfare-improving alternatives exist: subsidies to R&D by Western firms, with knowledge spillovers also lifting Eastern technology, or schemes to facilitate technology transfer to the East via licensing from Western firms.

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

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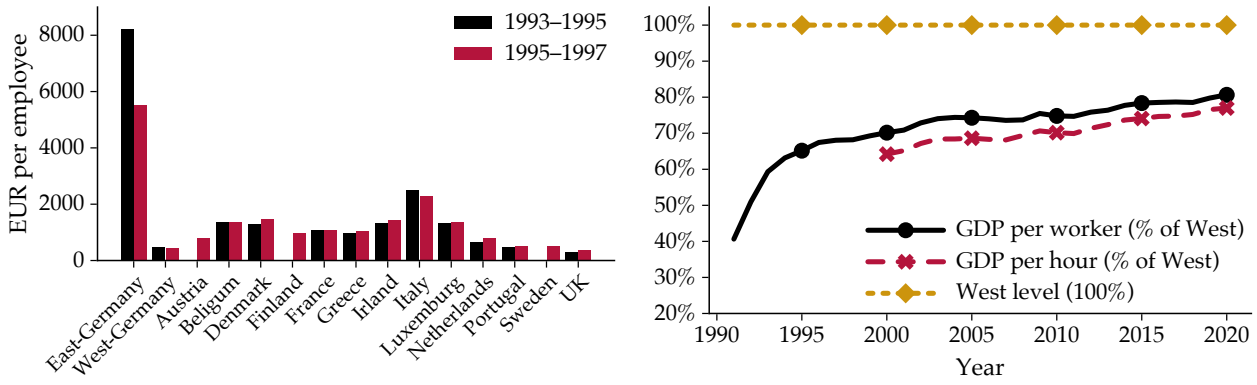
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1 Introduction

To tackle regional economic disparities, many governments across time and space have been devoting significant resources on various schemes (e.g., "Cassa per il Mezzogiorno" in Italy, "Western Development Strategy" in China, "Cohesion Policy" in the European Union).[1] Following the reunification in 1990, Germany has also provided substantial financial support for the economic development of the regions in the former East Germany (GDR) through schemes such as "Solidarpakt" (Figure 1a). Despite considerable progress, significant differences in regional economic conditions persist between East and West Germany. As of 2021, GDP per worker in the East is still about 20 percent lower than in West Germany (Figure 1b), accompanied by a comparable average wage gap. The enduring economic gap between East and West Germany—even in the absence of inhibiting barriers such as language or geographical differences—and the prospects of further convergence continue to receive perennial attention from both the general public and academia and remain a salient topic in political debate.[2] Comprehending the root causes of this persistent regional inequality would not only aid the German case but could also bear lessons for many other economies experiencing similar disparities (Breinlich et al., 2014).



A) Manufacturing subsidies per employee, by countries

B) Labor productivity and wages, East in percent of West

Figure 1: Regional Economic Performance and Subsidies in Germany

Notes: Manufacturing subsidies in Figure 1a are reported in Euro per employees using values of 1996. Sources: National accounts, data for German Länder and BMF (1999).

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

[1] To give a perspective, Italy has spent an estimated average of 0.85 percent of gross national product annually on "Cassa per il Mezzogiorno" between 1950 and 1975 (Helg et al., 2000). For "Cohesion Policy," the EU has set aside 392 billion euros—almost a third of the total EU budget—for the period 2021-2027 (`https://ec.europa.eu/regional_policy/policy/what/investment-policy_en`).

[2] See also The Economist (1999), The Economist (2014a), The Economist (2014b), Euractiv (2023), Becker et al. (2020), and Burda (2020). Research also suggests that the regional disparities contribute to political polarization in Germany and the rise of populist parties (Weisskircher, 2020; Politico, 2021; The Economist, 2023).

(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 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, while contributing to capital deepening and labor productivity, 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 effective than providing direct support to Eastern firms' R&D.



A) Trabant 1.1, 1990-1991 B) BMW M3 Cabriolet, 1986-1991

Figure 2: 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.

Our study is motivated by the established observation that the East struggled to offer competitive products and viable companies vis-à-vis the West at the time of reunification (Akerlof et al., 1991; Collier and Siebert, 1991). The automobile industry is a stark example, showcasing the profound differences in product quality and production technology between the former GDR and West Germany (Figure 2).[3] The Trabant 601 (Figure 2a), produced by Sachsenring Automobilwerke Zwickau from 1964 to 1990, had been the signature car in the former GDR for decades. Following the German reunification, however, the Trabant faced new competition form

[3]While certainly a drastic example, the automobile industry is just one of many in which 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.

major Western car manufacturers such as Mercedes, Audi, Volkswagen, and BMW, whose product range included the illustrious M3 cabriolet at the time (Figure 2b). Even after substantial price cuts, the Trabant could not retain a reasonable share of the market, and its production was discontinued swiftly.[4]

The significant technological disparity between Eastern and Western producers contributed to the massive shake-up of the industry in the East in the aftermath 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 slowed considerably therafter (Figure 1b). 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 strikingly persistent differences between the prices charged by Eastern and Western producers of similar products, as we demonstrate in Section 3. These persistent gaps at the micro level provide novel information that guides the economic theory underlying our model and allows us to determine the magnitude of the technological gaps between Eastern and Western producers through the lens of the theory.

The first goal of our study 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 (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 tradable 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 also differ in production technology due to region-specific productive efficiency, which evolves following an exogenous path calibrated to the data. This component enables the model to capture various technological differences between the regions other than product qualities. Production costs of firms vary also because of wages determined endogenously at the regional level. Consequently, firms' competitiveness in the market and their market shares reflect differences in their product qualities, production efficiencies, and labor costs.

[4]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).

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 that improve their quality at an exogenous rate. Region-specific R&D efficiency drives comparative advantage in innovation. Regional convergence dynamics in this framework are then shaped by two technological factors—endogenous evolution of product qualities and exogenous variation in relative production efficiency.

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 and frequently studied implication of this setting 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 Schumpeterian *discouragement effect*. This effect implies that firms that are too technologically 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.[5] 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 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 due to the

[5]Time-varying specifications of the size of regional labor forces matched to the data capture the variation in regional population due to factors such as migration flows.

discouragement effect, and the primary factor that drives the observed regional convergence is relative gains in the East in terms of productive efficiency, as implied by its calibrated path. While it is in the best interest of Western firms to invest in R&D and maintain their technological lead, the resulting technology gap creates a negative externality on laggard Eastern firms, depressing their hopes of catching up and therefore incentive to invest in enhancing their technology.[6]

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, effectively shielding mostly laggard Eastern firms from competing against frontier firms. 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, which also reduces spillovers from frontier firms. A simultaneous subsidy to R&D in the East, financed by the tariff revenue, could boost innovation effort in the East, 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.

Considering the calibrated lower R&D cost for Western firms, 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—even though, in relative terms, it falls behind the West faster than in the simulated baseline 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, which could help alleviate the initial technological

[6] In addition, frontier firms do not internalize the positive externality they create via technology spillovers.

disadvantage of Eastern producers more quickly.[7] 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 benefits both regions while smoothing 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 subdued 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, which were not a prominent part of the policy tools adopted at the time, 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 to speed up Eastern development 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 footing more quickly, allowing them to benefit from advances in the region with comparative advantage in R&D through knowledge diffusion.

The findings summarized above also offer broad implications for the dynamics of regional integration and technology policies. They point to (i) the perpetual nature of technological disparities as a potential impediment to sustained convergence, (ii) the need for policy to look beyond eradicating differences in physical resources and focus on alleviating initial technological differences, and (iii) the marked gains from transferring the technologies (via spillovers or licensing) from the advanced region to the laggard one to the extent possible, with the largest welfare gains in the shorter term brought about by direct technology sharing.

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 our analysis features a single country, it concerns 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,

[7] To ensure comparability across policy exercises, the amount of resources dedicated for licensing corresponds to the amount of transfers in other policy schemes we analyze. These funds are used to compensate Western firms for their losses that stem from reduced market share as Eastern firms improve their quality through mandatory licensing.

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).[8] 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).[9]

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, 2025; Atalay et al., 2023).[10] 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 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

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

[9] 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).

[10] See Juhász et al. (2024) for an expansive review.

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 early 1990s was the timing and speed of economic integration and unification. 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), first and foremost Chancellor Helmut Kohl, advocated for a more rapid integration process, and ultimately, the CDU prevailed both in 1990 and 1994 in the first federal elections of reunified Germany.

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. Within the very first years after unification, East Germany lost about one third of its GDP and two-thirds of its 3.3 million industrial jobs (Weigt, 2021), and non-employment rose from zero to 30 percent.[11] The severe economic breakdown and social

[11]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.

discontent prompted the government to respond with substantial transfers.[12] 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 percent 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.[13] Policymakers 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, production in the East quickly recovered in the first half of the 1990s from the massive 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 1b), 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 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.

[12] 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 percent.

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

3 An Empirical Account of Convergence and Firm Performance

The rich firm- and product-level micro data supplied by the German statistical offices is the main data source we use to uncover key patterns that shaped the dynamics of convergence between East and West.[14] This section first describes these micro data and then presents the stylized facts that motivate our theory. Throughout the empirical analysis, East and West Germany exclude Berlin because the German data do not allow to differentiate between its former regions.

3.1 German Firm- and Product-level Data

Our main data are the annual panel of 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.[15]

Firm-level cost structure survey. Information on firms' R&D and production workers is available via the cost structure survey (KSE)—an annual firm-level panel data. 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, total subsidies (including research, production, investment, cost/wage subsidies), 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). Appendix Table A.1 provides summary statistics on the firm-level data, highlighting that, on average, Eastern firms pay lower wages, are smaller and less productive, conduct R&D less frequently, export a much smaller share of their sales, and charge lower markups.

Firm-product-level data. Annual information on sales and quantities of firms' individual products is available via 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. Sales and quantities are reported as factory-gate values and the data cover around 80% of recorded manufacturing production values from aggregate statistics.[16] Products are categorized by an extremely fine nine-digit product classification (the German GP-classification), defining around 6,000 distinct products in our data. The first

[14] Throughout the paper, we also refer to additional data sources: such as, the national accounts, subsidy data (Appendix C.1), and the IAB data (Appendix D).

[15] 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.

[16] The remaining 20% is mostly accounted for by smaller plants and the fact that manufacturing firms in aggregate statistics also generate sales outside of manufacturing (e.g., through the provision of services).

eight digits of the product codes correspond to the PRODCOM classification. The ninth digit provides additional differentiation.[17] From the sales and quantity information, we constructed product prices. For 30 percent of products, 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 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. Over all years, we reclassify 97 percent of products and drop the three percent of products that cannot be reclassified. Moreover, to examine 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.

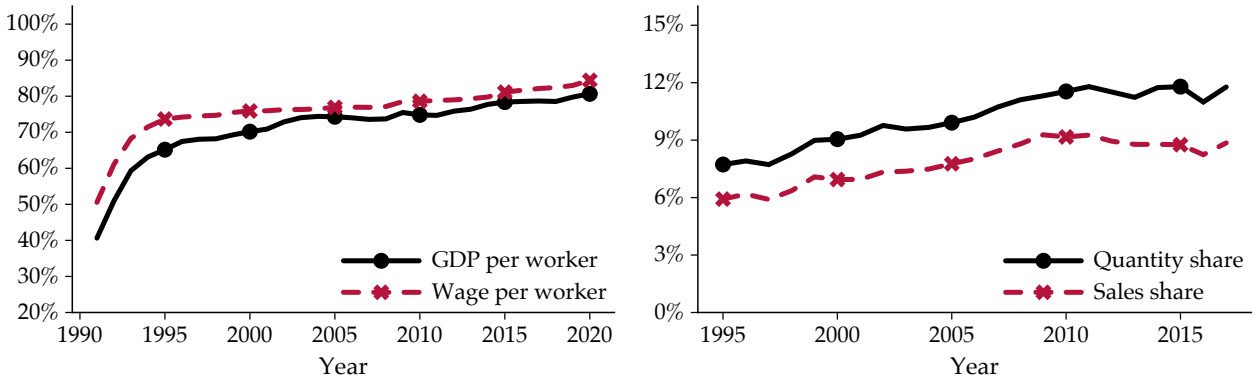
3.2 Stylized facts

Fact 1: The convergence in output per worker and wages was initially fast, but slowed markedly in subsequent years. Figure 3a shows that in 1991 East German relative GDP per worker was around 40 percent of the West German level. Rebounding from the economic collapse at the outset of integration, the East grew to two thirds of the West German productivity level by the mid-1990s, with a commensurate rise in the relative wage level. This initial recovery likely benefited from the quick returns to 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.[18] 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

[17] 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 $\leq 1,000 cm^3$".

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



A) GDP and gross wages in the East, relative to West

B) Market shares of Eastern firms

Figure 3: Regional economic performance in Germany

Notes: Panel A displays GDP and gross wages per worker in East German regions, relative to the West (source: national accounts, data for German Länder). Panel B shows 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.

of the production landscape by the Treuhand helped create economically and financially viable businesses in the East, overall, Eastern firms struggled to remain competitive. As a result, 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 3b). 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.

Further evidence from the micro-level data highlights the competitive and technological disadvantage of East German firms, as we discuss next. Importantly, the competitive and technological state of Eastern firms vis-à-vis their Western counterparts and persistent technological gaps between them emphasize the key mechanisms that the theoretical framework needs to address. Our model considers explicitly Eastern firms' relative performance and examines its influence on their incentives to invest and enhance their competitiveness.

Fact 3: Eastern firms produce with lower prices, reflecting, in part, lower product quality. Long-standing differences in productivity and wages are accompanied by persistent price differences across varieties produced in both regions within granular product categories, and these product-level price gaps naturally map to the theoretical framework we adopt. Figure 4 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.[19] It highlights that in

[19]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 aggregate and then divide firm-product-level

1995 the prices of Eastern goods were lower than their Western rivals in most narrowly defined product categories (74%, sales-weighted). Moreover, notwithstanding some widening, the distribution in these regional price differences across products exhibited remarkable stationarity 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.

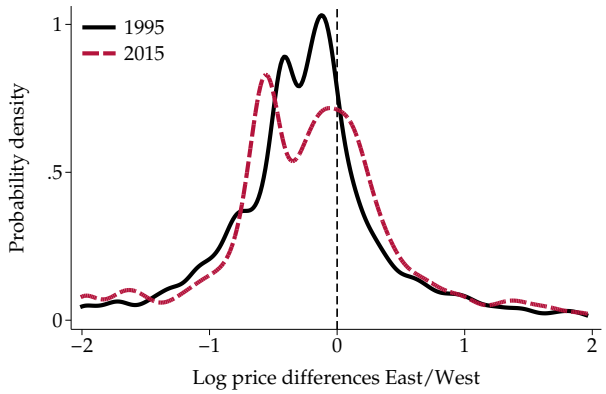


Figure 4: Relative price differences, East/West

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 derived at nine-digit product level as a quantity-weighted average of firm-product-level prices (this is equivalent to dividing the sum of sales by the sum of quantities per product category). The density plots weight each product by its sales share within our data (as quantity shares cannot be constructed across products). 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 5 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. In the figure, 74% (65%) of the mass lies in the negative area in 1995 (2015).

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 (Figure 3a). 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 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 distinct margins and generate an overall price patterns that is consistent with the data.

Fact 4: R&D expenditures have been much lower in the East. Consistent with persistently lower quality in the East, R&D investment (as a fraction of the regional output) has been much

sales and quantities in each region and year. From these regional product-level prices, we finally construct log price differences between products produced in both regions (i.e., manufactured by at least three firms in both West and East German regions).

lower than in the West, as shown in Figure 5. 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. The theory will provide an explanation for the deficient R&D incentives of Eastern firms based on their initial technological disadvantages.

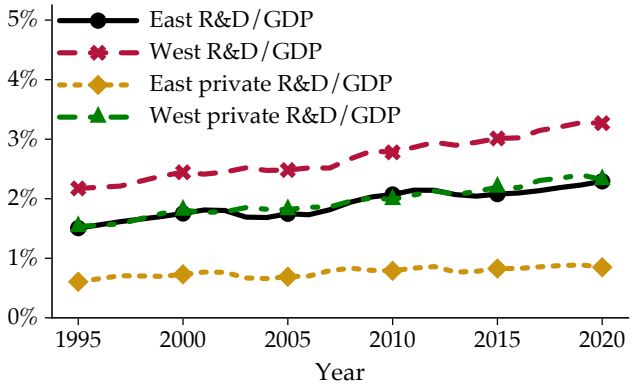


Figure 5: R&D expenditures in East and West Germany

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: German Federal Statistical Office (Destatis).

Fact 5: Firms' R&D 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 described in the next section, the variety with the highest price is defined as the industry leader for each nine-digit product industry j and year t. The (inverse) price gap between the leader variety in j at time t (P_{jt}^{Max}) and all other varieties within the same industry produced by different firms denoted by i (P_{ijt}) is then the ratio $Proximity_{ijt} = P_{ijt}/P_{jt}^{Max} \in (0,1)$. This measure increases when the price distance diminishes. For firms that produce multiple products (78% of firms), we aggregate the product-level measures to the firm level using sales shares as weights, because information on R&D activity is available at the firm level. As such, the firm-level gap $Proximity_{it} = \sum_j s_{ijt} Proximity_{ijt}$ 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.

The measure of firms' R&D effort is the share of R&D workers in the firm's total workforce: $RDI_{it} = \ln(L_{it}^{R\&D}/L_{it})$. The exercise focuses 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. The following firm-level regression is estimated to recover 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:

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

where ν_i and ν_t denote firm and year fixed effects, and lagged values ($Proximity_{it-1}$) account for adjustment lags in firms' R&D decisions. The following discussion examines the results for the East German sample given the focus of the analysis, and the results for the whole sample are reported in the Appendix (Table A.2).

Table 1: R&D intensity and price gaps

	RDI_{it}	
	All East firms	Single-product East firms
	(1)	(2)
$Proximity_{it-1}$	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. $Proximity_{it}$ 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 hampered 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. Section 4 presents 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 $r \in \{w, e\}$, respectively. 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 (e.g., due to 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. Firms also differ in terms of production efficiency—a region-specific variable moving exogenously—and production costs (wages), which 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 respond to the technology (quality) difference between the two firms in a product line. Knowledge spillovers that occur at an exogenous rate comple-

ment this process, helping technologically laggard firms learn from the frontier. As such, product market outcomes reflect product quality, production efficiency, and production cost differences across firms, and 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 between regions and product qualities, with the latter being determined by endogenous firm investments and knowledge spillovers.

4.1 Preferences

Time is continuous and denoted by $t \in [t_0, \infty)$. Each region $r \in \{w, e\}$ is populated by a measure of representative households, denoted by $L_r(t)$. They derive utility from consuming tradable and nontradable goods and supply labor inelastically. The demand system is characterized by the following nested constant elasticity of substitution (CES) preferences:

$$\int_{t_0}^{\infty} e^{-\rho(t-t_0)} \log C_r(t) dt \tag{2}$$

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

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

$$Q_r^T(t) \equiv \exp \left\{ \int_0^1 \log q_{rj}(t) dj \right\}. \tag{3}$$

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., $Q_r^{NT}(t) = Q_r^T(t)$.

The budget constraint of the consumer is specified as

$$\dot{\mathcal{Z}}_r(t) = R_r(t)\mathcal{Z}_r(t) + w_r(t)L_r(t) + \Pi_r(t) + T_r(t) - E_r(t) \tag{4}$$
$$with\ E_r(t) \equiv \int_0^1 \left(p_{rj\leftarrow w}(t)c_{rj\leftarrow w}(t) + p_{rj\leftarrow e}(t)c_{rj\leftarrow e}(t)\right) dj + P_r^{NT}(t)C_r^{NT}(t).$$

In these expressions, $L_r(t)$ denotes labor, $E_r(t)$ denotes the total expenditure of the representative household in r on goods, $\Pi_r(t)$ denotes dividends from regional firms (operational profits net of R&D spending), $\mathcal{Z}_r(t)$ denotes assets that households own (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.[20] Households finance their total consumption expenditure with labor income, profits rebated from the regional firms they own, returns on assets, and government transfers (if any). Markets are incomplete in the sense that households from different regions cannot trade assets; however, households in the same region can. This assumption implies regional financial autarky, with local firms being owned solely by local households. Therefore, $\Pi_r(t)$ is the sum of dividends distributed by firms producing in region r, and $\mathcal{Z}_r(t)$ equals their total market value. The rate of return, $R(t)$, is therefore region-specific. Another implication of financial autarky is that goods trade between the regions is balanced at all times when government transfers and subsidies are absent.[21]

Regional population sizes $L_r(t)$ are time-varying to account for changes in the size of the regional labor force observed in the data due to factors such as migration.[22] We postulate that the following functional form governs this variable:

$$L_r(t) = L_{r,bgp} + (L_{r,t_0} - L_{r,bgp})e^{-\nu^L(t-t_0)}. \tag{5}$$

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.[23] Section 5 details the calibration of the process, which produces a near perfect fit to the data (see Appendix C).

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

[21] 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.

[22] 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 unification predating the period of our analysis.

[23] Given the restriction $\nu^L > 0$, the labor share process $L_r(t)$ converges to $L_{r,bgp} \in (0,1)$ as $t \to \infty$, starting from the initial condition $L_r(t_0) = L_{r,t_0} \in (0,1)$.

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 product line $j \in [0,1]$, West and East firms produce differentiated varieties under a linear production function:

$$y_{rj}(t) = A_r(t) l_{rj}^T(t),$$

where $l_{rj}^T(t)$ denotes labor used by the firm from region r in product line j, and $A_r(t)$ denotes the region-specific efficiency level. As discussed below, 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. The 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 technological dynamics other than the product quality margin with the following exogenous, parametric process, whose parameters we discipline in the model calibration:

$$A_r(t) = A_{r,bgp} + \left(A_{r,t_0} - A_{r,bgp}\right) e^{-\nu_r^A (t - t_0)}, \tag{6}$$

where region-specific parameters 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 $A_r(t)$ to its BGP level. Given our specific focus

on convergence, we normalize the Western aggregate efficiency 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 $A_e(t)$, which is to be determined in the calibration of the model, was initially lower than its Western counterpart (as implied by the calibration results) and allow it to vary over time according to the exogenous path defined in equation (6). Notice that $A_e(t)$ also corresponds to the relative level of production efficiencies 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., 2025). 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 $q_{rj} = q_{-rj}$. 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, $q(t + dt) = \lambda q(t)$ upon successful innovation, with dt denoting an infinitesimal change in time. We normalize the initial quality levels of Western producers to unity such that $q_{wj}(t_0) = 1$ for all $j \in [0, 1]$.

Product qualities evolve also with knowledge spillovers within product lines that flow from the technologically superior firm (leader firm) to the inferior one (follower firm). Follower firms, independent of their region, receive spillovers from technology leaders with Poisson rate $\delta > 0$. Technology spillovers occur in heterogeneous sizes; the number of steps with which it improves the follower quality follows a probability mass function that is derived from a Pareto distribution

with scale parameter one and shape parameter θ (the exact structure is outlined in Section 4.4). 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 $m_{rj}(t)$:

$$\frac{q_{rj}(t)}{q_{-rj}(t)} = \lambda^{N_{rj}(t)-N_{-rj}(t)} = \lambda^{m_{rj}(t)}. \tag{7}$$

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 that 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 them "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. From the households' life-time utility maximization follows the Euler equation:

$$\frac{\dot{E}_r(t)}{E_r(t)} = R_r(t) - \rho. \tag{8}$$

The representative household in region r allocates expenditures E_r to tradable and nontradable goods based on static maximization in each period generating the following demand functions:

$$P_r^{NT}(t)C_r^{NT}(t) = (1-\beta)\, E_r(t), \tag{9}$$

$$p_{kj}(t)c_{rj\leftarrow k}(t) = \frac{\left(\frac{q_{kj}(t)}{p_{kj}(t)}\right)^{\sigma-1}}{\left(\frac{q_{wj}(t)}{p_{wj}(t)}\right)^{\sigma-1} + \left(\frac{q_{ej}(t)}{p_{ej}(t)}\right)^{\sigma-1}}\beta E_r(t), \qquad \text{for } k = w, e. \tag{10}$$

Nontradable sector. The nontradable-good firms solve a static problem at each instant:

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

taking prices $P_r^{NT}(t)$ and wages $w_r(t)$ as given. Given the demand for the nontradable good in Equation (9), the labor allocated for nontradable good production is given by $l_r^{NT}(t) = (1-\beta)\, E_r(t)/w_r(t)$, and the equilibrium price of the nontradable good is $P_r^{NT}(t) = w_r(t)/A_r(t)$.

Tradable sector. A tradable-good producer in region r maximizes its profits according to

$$\pi_{rj}(t) = \max_{p_{rj}(t)} \left[p_{rj}(t) - \frac{w_r(t)}{A_r(t)}\right] y_{rj}(p_{rj}(t)),$$

subject to feasibility $y_{rj}(t) = c_{wj\leftarrow r}(t) + c_{ej\leftarrow r}(t)$ and demand equation (10). With Bertrand competition, firms choose the optimal price given the price of their competitor, $p_{-rj}(t)$. 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:

$$p_{rj}(t) = \frac{\varepsilon(s_{rj}(t))}{\varepsilon(s_{rj}(t)) - 1}\frac{w_r(t)}{A_r(t)} = \mu\left(s_{rj}(t)\right)\frac{w_r(t)}{A_r(t)}, \tag{11}$$

where the markup $\mu(s_{rj}(t))$ can be written as a function of the residual demand elasticity, $\varepsilon(s) = s + (1-s)\,\sigma$, which declines in firm size as measured by the firm's market share. The equilibrium price elasticity 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 the size of the firm increases, the firm faces more inelastic demand, which allows it to charge higher markups. Lastly,

the equilibrium market share of the firm is given by

$$s_{rj}(t) = \frac{p_{rj}(t)y_{rj}(t)}{\beta E(t)} = \frac{\left(\frac{q_{rj}(t)}{p_{rj}(t)}\right)^{\sigma-1}}{\left(\frac{q_{wj}(t)}{p_{wj}(t)}\right)^{\sigma-1} + \left(\frac{q_{ej}(t)}{p_{ej}(t)}\right)^{\sigma-1}}, \tag{12}$$

where $E(t) = E_w(t) + E_e(t)$ measures the total expenditure of both regions.

Equations (10)-(12), with the fact that the market shares of two rivals sum to one (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. Remark 1 describes the factors that shape the equilibrium market share of a firm.

Remark 1 *The equilibrium market share of a firm is determined by three factors: (i) the relative product quality of the firm, i.e., the quality gap by equation* (7)*, (ii) the relative region-specific production efficiency, and (iii) the relative region-specific wage:*

$$\Gamma\left(s_{rj}(t)\right) = \left[\frac{q_{rj}(t)}{q_{-rj}(t)}\frac{A_r(t)}{A_{-r}(t)}\left(\frac{w_r(t)}{w_{-r}(t)}\right)^{-1}\right]^{\sigma-1}, \tag{13}$$

where $\Gamma(s) = \left(\frac{s}{1-s}\right)^{\sigma}\left(\frac{s}{1-s} + \sigma\right)^{\sigma-1}\left(1 + \sigma\frac{s}{1-s}\right)^{1-\sigma}$ *defines an implicit function of* s *that follows from combining equations* (11) *and* (12) *and is increasing in* s *for* $\sigma > 1$.

Equation (13) reveals that 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, the market share of a firm also depends on its technology in terms of product quality relative to its competitor—a higher relative quality level implies higher market share.

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

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

The pay-off relevant variable for the firm is its market share, which determines the level of profits the firm can earn. As implied by equation (13), the firm-level variable that influences the firm's market share is its (relative) product quality. Therefore, the quality gap as defined in equation (7) is the relevant state variable in the firm's dynamic optimization problem. Forward-looking firms invest in R&D to improve their product quality and attain a larger share of the market.

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

$$\begin{aligned} R_r(t)V_r(m,t) = &\left[1 - \mu\left(s_r(m,t)\right)^{-1}\right] s_r(m,t)\beta E(t) \\ &+ \max_{x_r}\left\{-\left(1-\zeta_r^R(t)\right) w_r(t)\alpha_r \frac{x_r^\gamma}{\gamma} + x_r\left[V_r(m+1,t) - V_r(m,t)\right]\right\} \\ &+ x_{-r}(-m,t)\left[V_r(m-1,t) - V_r(m,t)\right] \\ &+ \mathbf{1}_{\{m\neq 0\}}\delta \sum_{n=1}^{|m|} f\left(|m|,n\right)\left[V_r(m+\kappa(m)n,t) - V_r(m,t)\right] + \frac{\partial V_r(m,t)}{\partial t}, \end{aligned} \tag{14}$$

where $\kappa(m)$ is a step function that takes the value -1 (1) if $m > 0$ ($m < 0$).[24]

The left-hand side of equation (14) 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, x_r, 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 $m+1$.[25] The 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, $f\left(|m|,n\right)$ gives the probability of jumping by n steps if the absolute gap between the firms is $|m|$.[26] If the firm is laggard, then the spillover increases its value ($\kappa(m) = 1$). If the firm is the leader in the market, then the spillover decreases its value ($\kappa(m) = -1$). 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

[24] The function $s_r(m,t)$ denotes the market share of a firm from region r at time t, when the quality gap of the firm is m. Formally, $s_{rj}(t) = s_r(m,t)$ when $m_{rj}(t) = m$.

[25] When $m = \bar{m}$, the rate of return to innovation is zero, as $\bar{m}$ is the maximum gap allowed. We modify the HJB equation (14) accordingly for this limit value of the state variable.

[26] The probability mass function $f\left(|m|,n\right)$ is derived from an underlying Pareto distribution inheriting its shape. The scale parameter of the underlying Pareto distribution, i.e. the lower bound of its support, is one, while its shape parameter, $\theta > 0$, is a positive real number. The density of such a Pareto distribution is given by $\theta x^{-(\theta+1)}$ for $x \geq 1$. Using this expression, we define the probability mass function $f\left(|m|,n\right)$ on the finite support $\{1,2,\ldots,|m|\}$ as follows:

$$f\left(|m|,n\right) = \frac{\theta n^{-\theta+1}}{\sum_{k=1}^{|m|}\theta k^{-(\theta+1)}}.$$

optimal innovation rate:

$$x_r(m,t) = \left[\frac{V_r(m+1,t) - V_r(m,t)}{(1-\zeta_r^R(t))\,\alpha_r w_r(t)}\right]^{\frac{1}{\gamma-1}}. \tag{15}$$

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 that are 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 evolves endogenously over time, with its law of motion being determined by firms' innovation rates and quality spillovers. Let $\psi_w(m,t)$ denote the share of sectors in which Western firms are at position $m \in \{-\bar{m},\ldots,\bar{m}\}$, with the total mass being $\sum_{n=-\bar{m}}^{\bar{m}} \psi_w(n,t) = 1,\ \forall t$. Correspondingly, the mass of sectors in which East firms command a gap of m equals $\psi_e(m,t) = \psi_w(-m,t)$. 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:

$$\begin{aligned}\dot{\psi}_w(m,t) = {} & \psi_w(m-1,t)x_w(m-1,t) + \psi_w(m+1,t)x_e\left(-(m+1),t\right) \\ & + \delta\left[\sum_{n=1}^{\bar{m}-|m|} \mathbf{1}_{\{m\geq 0\}} f(m+n,n)\psi_w(m+n,t) + \mathbf{1}_{\{m\leq 0\}} f\left(|m-n|,n\right)\psi_w(m-n,t)\right] \\ & - \psi_w(m,t)\left[x_w(m,t) + x_e(-m,t) + \mathbf{1}_{\{m\neq 0\}}\delta\right].\end{aligned} \tag{16}$$

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.[27]

Closing the model. Labor and asset markets clear in each region every period. The market clearing condition for labor, which is used in goods production and R&D is

$$L_r(t) = \left(\sum_{m=-\bar{m}}^{\bar{m}} \psi_r(m,t) \frac{s_r(m,t)}{\mu\left(s_r(m,t)\right)} \right) \frac{\beta E(t)}{w_r(t)} + (1-\beta)\frac{E_r(t)}{w_r(t)} + \sum_{m=-\bar{m}}^{\bar{m}} \psi_r(m,t)\alpha_r \frac{x_r(m,t)^\gamma}{\gamma}, \quad (17)$$

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 the total expenditure of a region on consumption goods equals the total income:

$$E_r(t) = w_r(t)L_r(t) + \Pi_r(t) + T_r(t). \quad (18)$$

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

Using equation (18), the (nominal) GDP of a region, which will define the model counterpart of key moments in the calibration exercise, is given by the following expression:

$$Y_r(t) \equiv (1-\beta)\, E_r(t) + \left(\sum_{m=-\bar{m}}^{\bar{m}} s_r(m,t)\psi_r(m,t) \right) \beta E(t), \quad (19)$$

Regional GDP is equal to the sum of total value added generated by both the nontradable and tradable firms in the region (first and second summands, respectively) with $E(t)$ denoting the total expenditure across both regions and $S_r(t) \equiv \sum_{m=-\bar{m}}^{\bar{m}} s_r(m,t)\psi_r(m,t)$ denoting the average market share of the region's tradable firms (consequently, $S_w(t) + S_e(t) = 1$). From equation (19), it follows that the total GDP of Germany equals $\sum_{r\in\{w,e\}} Y_r(t) = E(t)$. We normalize $E(t) = 1$ for all $t \geq t_0$.

Finally, regional governments can send (receive) funds to (from) the other region. Let $\mathcal{T}_r(t)$ denote the net inter-regional flow of funds to or from region r. Defining $G_r(t)$ as the expenditure

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

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

of the regional government in r on local industrial policy, the following accounting identity holds:

$$\mathcal{T}_r(t) \equiv G_r(t) + T_r(t) = -(Y_r(t) - E_r(t)).$$

A negative (positive) $\mathcal{T}_r(t)$ implies outflows from (inflows to) region r equal to the net savings in the regional economy, which reflects the difference between the regional GDP and the regional expenditures.[28] The federal German government is not allowed to borrow to finance its expenditures. Accordingly, the sum of inter-regional transfers is zero at all times, $\mathcal{T}_w(t) + \mathcal{T}_e(t) = 0$.

4.5 Convergence

In this framework, convergence between two regions stems mainly from two technological forces: changes in the exogenous region-specific efficiency and product qualities, with the latter evolving as a result of firms' endogenous innovations and knowledge spillovers. Remark 2 illustrates this relationship characterizing the expression for consumption per capita, the welfare-relevant metric for the representative household.

Remark 2 *Consumption per capita in region r can be derived as*

$$C_r(t)/L_r(t) = \tilde{\beta} \cdot A_r(t) \cdot Q_r^T(t) \cdot \mathcal{L}_r^T(t)^{\beta}\, \tilde{l}_r^{NT}(t)^{1-\beta},$$

where $\tilde{\beta} = \beta^{-\beta}(1-\beta)^{-(1-\beta)}$ *is a constant,* $\mathcal{L}_r^T(t)$ *represents a weighted aggregate of labor allocated to the production of tradable goods, and* $\tilde{l}_r^{NT}(t)$ *denotes the share of labor used in nontradable production in region r.*[29] *Consequently, the relative level of consumption per capita across regions follows as*

$$\frac{C_r(t)/L_r(t)}{C_{-r}(t)/L_{-r}(t)} = \frac{A_r(t)}{A_{-r}(t)} \cdot \frac{Q_r^T(t)}{Q_{-r}^T(t)} \cdot \left(\frac{\mathcal{L}_r^T(t)}{\mathcal{L}_{-r}^T(t)}\right)^{\beta} \cdot \left(\frac{\tilde{l}_r^{NT}(t)}{\tilde{l}_{-r}^{NT}(t)}\right)^{1-\beta}. \tag{20}$$

The two components that can generate sustained changes in consumption per capita are regional quality and efficiency dynamics $Q_r^T(t)$ and $A_r(t)$ (as defined in equations 3 and 6, respectively). Consequently, equation (20) reveals their role in shaping the convergence pattern of regional consumption per capita levels. The relative regional efficiency level, $A_r(t)/A_{-r}(t)$, follows the path defined by equation (6) and is is disciplined by the data. The ratio of aggregate (locally produced) tradable qualities, $Q_r^T(t)/Q_{-r}^T(t)$, evolves as a result of firms' R&D

[28] 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.

[29] The expressions for $\mathcal{L}_r^T(t)$ and $\tilde{l}_r^{NT}(t)$ are derived in Appendix B.4.

investments and knowledge spillovers.[30] Firms' incentive to invest in quality improvements is, in turn, influenced by their competitiveness in the market. Neck-and-neck rivals, which are close in competition, are motivated to improve their product quality and overtake their rival (the escape-competition effect in this class of models). By contrast, firms that are technologically laggard and farther behind their rival in the market suffer from the Schumpeterian discouragement effect: their hope of capturing a large share of the market, which requires much effort, is slim, depressing their incentive to invest. This effect is particularly relevant to Eastern firms given their technological disadvantage observed empirically. Laggard firms benefit from occasional spillovers that help them remain in competition, but spillovers do not ensure sustained convergence. We demonstrate these forces quantitatively in Section 5.2 in the discussion of the equilibrium properties of the calibrated model (see Figure 7).

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 shape the 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.[31] We assume that the subsidy rate in the model follows a smooth, declining curve, shaped by the starting level and a parameter governing its curvature, such that the total amount of consumption subsidy

[30] We can derive the following time path:

$$\frac{d \ln \left(Q_r^T(t) / Q_{-r}^T(t) \right)}{dt} = \ln \lambda \sum_{m=-\bar{m}}^{\bar{m}} m \, \dot{\psi}_r(m,t).$$

From equation (16), which defines $\dot{\psi}_w(m,t)$, it follows that the dynamics of the relative aggregate qualities are governed by relative innovation rates as well as technology spillovers.

[31] We detail the steps of constructing the series of consumption transfers and R&D subsidies in Appendix C.1.

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,t_0}	East labor in 1995	0.168
$L_{e,bgp}$	East labor in BGP	0.133
$\nu^L(\times 10^2)$	Half-life of labor	6.583
T_{e,t_0}	East lump-sum transfer in 1995	0.022
$\nu_e^T(\times 10^2)$	Half-life of East lump-sum transfer	6.931

over the same period matches the corresponding value in the data.[32] 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 (5) via nonlinear least squares to the empirical aggregate employment series for East Germany, we obtain the parameters L_{e,t_0}, $L_{e,bgp}$ 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.4 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 $t_0 = 1995$. The procedure centers on the transition path of the economy to pin down the parameters that enable the model to replicate the observed time variation in the relevant empirical moments once the initial state of the economy is determined in line with the data. The key insight underlying this procedure is the observation that, while both quality and efficiency gains raise aggregate income of a region via higher market shares of firms (recall equation 19), they affect the relative prices in the opposite direction. Consider the following:

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

which follow from equations (11) and (12) with $\hat{x}_{rj}(t) \equiv \log(x_{rj}(t)/x_{-rj}(t))$ for $r = \{e, w\}$ and $r \neq -r$. Once the relative average wage rate is controlled, as observed from the national accounts, higher regional efficiency decreases the relative price of good j in region r, which, in turn, increases the market share. By contrast, higher relative quality of a product in r raises both

[32] The specific path of the annual level of consumption subsidies flowing to the East is assumed to take the form $T_e(t) = T_{e,t_0} e^{-\nu_e^T(t-1995)}$, which also corresponds to the subsidy rate, as the nominal GDP is normalized to one, allowing us to determine it externally.

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.[33] 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,t_0}	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
ζ_{w,t_0}^R	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
ζ_{e,t_0}^R	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 $\{\lambda, \sigma, \delta, \nu_e^A, A_{e,t_0}\}$, 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,t_0}) and the elasticity of substitution between goods (σ).[34] 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.

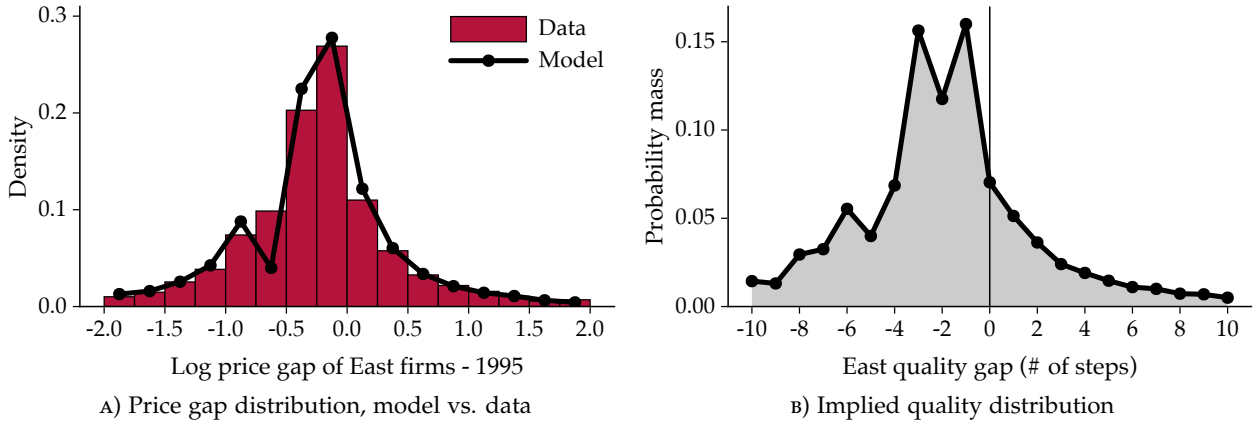
Turning to the R&D process, regional R&D-to-GDP ratios help discipline the R&D cost scale parameters, together with the regional R&D subsidy rates, which are calibrated to match the

[33] 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.

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

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.

The model closely matches the empirical targets. In particular, the model-implied initial price distribution mimics the empirical counterpart well (Figure 6a), with the implied quality gap distribution $\psi_e(m,t)$ shown in Figure 6b. 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).



A) Price gap distribution, model vs. data

B) Implied quality distribution

Figure 6: Price and quality gap distributions in 1995

Notes: Panel A shows the log price gap $(\log(p_e/p_w))$ distribution in 1995. Red bars plot the histogram of price gaps across products in the data. The black line plots the corresponding distribution implied by the model. For any given bin on the x-axis, it is equal to the total mass of Eastern firms with a log price gap within the bin. Panel B shows the calibrated Eastern quality gap distribution in $t_0 = 1995$ denoted by $\psi_e(m,t_0)$ for $m \in \{-10,\ldots,10\}$.

5.2 Equilibrium Properties

Model validation. 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 7, 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 model to replicate the negative relationship between a diminishing price gap and higher R&D effort.

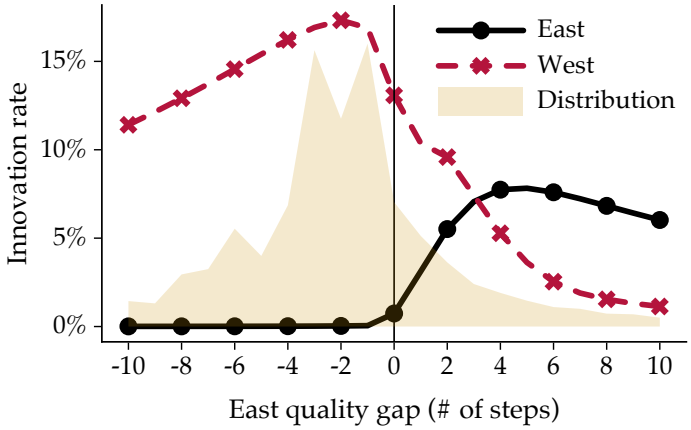


Figure 7: Innovation effort in the model

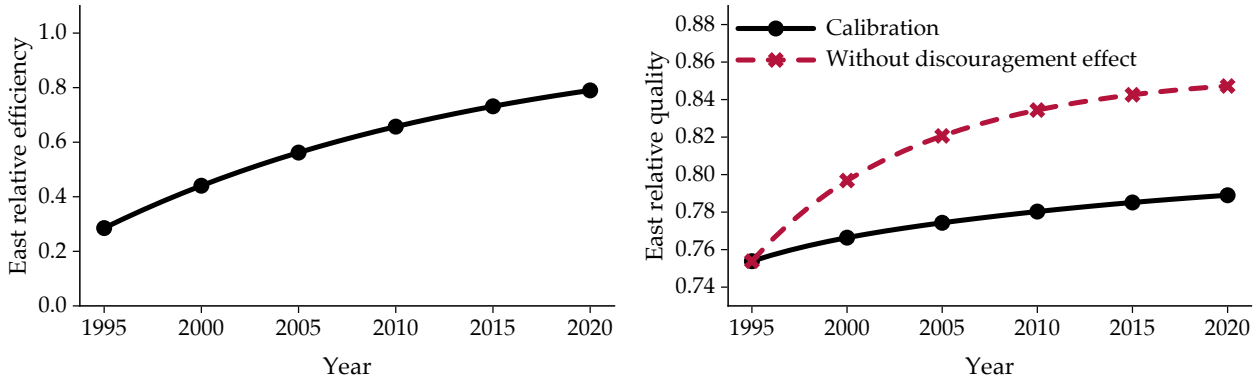
Notes: Figure plots the average innovation rates of East and West firms between 1995 and 2015 as a function of East quality gaps. Quality gaps are restricted between -10 and 10 for clarity. The shaded area shows the Eastern quality gap distribution in $t_0 = 1995$, i.e. $\psi_e(m, t_0)$ for $m \in \{-10, \ldots, 10\}$.

This key mechanism of the step-by-step framework also helps the calibrated model generate dynamics that are consistent with salient empirical indicators. One such variable is the average market shares of the regions, which result from technology and competition dynamics in the model, and their variation over time. Figure A.7a in the Appendix highlights that the model closely tracks the time path of the average market share of Western manufacturing firms. This finding is an indication that the model successfully captures the position of Eastern firms' in the market with respect to their Western competitors, an important aspect of the analysis. Another indicator that lends credibility to the dynamics admitted by the calibrated economy is the aggregate job reallocation rate. Figure A.7b shows that the model is broadly consistent with the data, somewhat overshooting the level in the first half of the period that we use to calibrate the model. Overall, these observations suggest that the calibrated model generates a reasonable degree of dynamism at the firm level and provides a credible laboratory for the analysis of convergence dynamics and relevant policies.

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 $(\log Q_e^T(t))$, 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 $(A_e(t))$. 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 8a 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 8b 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.[35]



A) Efficiency channel

B) Quality channel and discouragement

Figure 8: Convergence and discouragement effect

Notes: Panel A shows the East efficiency relative to the West $(A_e(t)/A_w(t))$. Panel B shows the discouragement effect on the aggregate quality of East relative to West $\left(Q_e^T(t)/Q_w^T(t)\right)$. Black solid line plots the relative quality in the benchmark calibration. Red dashed line plots the relative quality under the counterfactual where laggard Eastern firms innovate at a rate equal to the maximum innovation rate in the East in that year under the calibration.

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 7). As a result, 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

[35]This result does not imply that the average quality in the East did not improve at all. In fact, as Figure A.6a in the Appendix shows, quality improvements contributed to Eastern income growth and in growing proportion over time, mostly benefiting from spillovers. That said, the average rate of innovation was only modest and not enough to close the technology gap with the West meaningfully (Figure A.6b).

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.[36] Figure 8b 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 (see equation 20). 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.

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 while improving overall welfare.

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 $t_0 = 1995$. Let $U_r(T)$ denote the total discounted utility the representative household in region r

[36] 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.

derives from consumption over a period of length T starting from t_0:

$$U_r(T) \equiv \int_{t_0}^{t_0+T} e^{-\rho(t-t_0)} \log c_r(t) dt,$$

where $c_r(t) = C_r(t)/L_r(t)$ denotes per capita consumption. 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:

$$\int_{t_0}^{t_0+T} e^{-\rho(t-t_0)} \log \left[c_r^{\text{cal}}(t) \left[1 + \gamma_r(T)\right] \right] dt = U_r^{\text{policy}}(T),$$

where $c_r^{\text{cal}}(t)$ refers to the consumption path that would arise in the calibrated economy in the absence of policy changes. This implies

$$\gamma_r(T) = \exp\left[\rho \, \frac{U_r^{\text{policy}}(T) - U_r^{\text{cal}}(T)}{1 - e^{-\rho(T-t_0)}} \right] - 1.$$

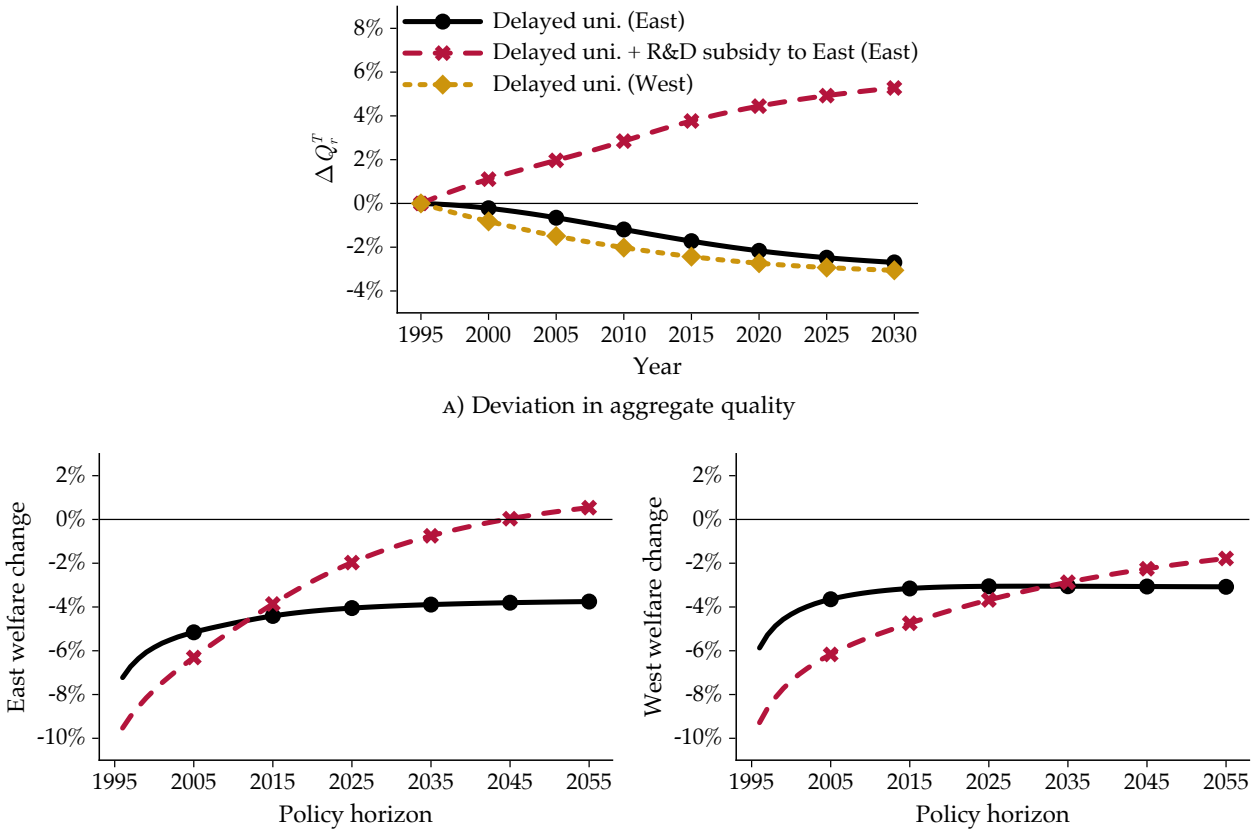
A positive $\gamma_r(T)$ means that the consumer is better off under the new policy, with a $\gamma_r(T)$ percent increase in CEQW over a horizon of T years. Conversely, a negative $\gamma_r(T)$ implies a $|\gamma_r(T)|$ percent decline in CEQW.

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 purchases from the West effectively prohibit access of Western goods to the East. Initially, they protect Eastern firms to the full extent and gradually decline thereafter, easing the tariff burden on Western producers.[37]

Figure 9 shows the path of regional average qualities and changes in consumption-equivalent welfare over different horizons. Figure 9a 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

[37] Figure A.8 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.



A) Deviation in aggregate quality

B) Consumption equivalent welfare change — East

C) Consumption equivalent welfare change — West

Figure 9: Effects of delaying unification

Notes: Panel A plots the percent deviation in aggregate quality, $Q_r^T(t)$ for $r = e, w$, from the calibrated benchmark, and panels B and C plot the consumption equivalent welfare changes, for East (bottom left) and West (bottom right). The solid line represents the policy where unification is delayed via tariffs imposed on Western firms when selling to East. Yellow-dashed line represents the policy where, in addition to delayed unification with tariffs as before, East R&D expenditures are subsidized with tariff revenue. See Section 6.1 for details.

seemingly improved Eastern technological position relative to the West clearly occurs at the expense of overall technological deterioration. As shown in Figures 9b and 9c, 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

development, weighing on incomes and consumer welfare.[38]

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 9 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.

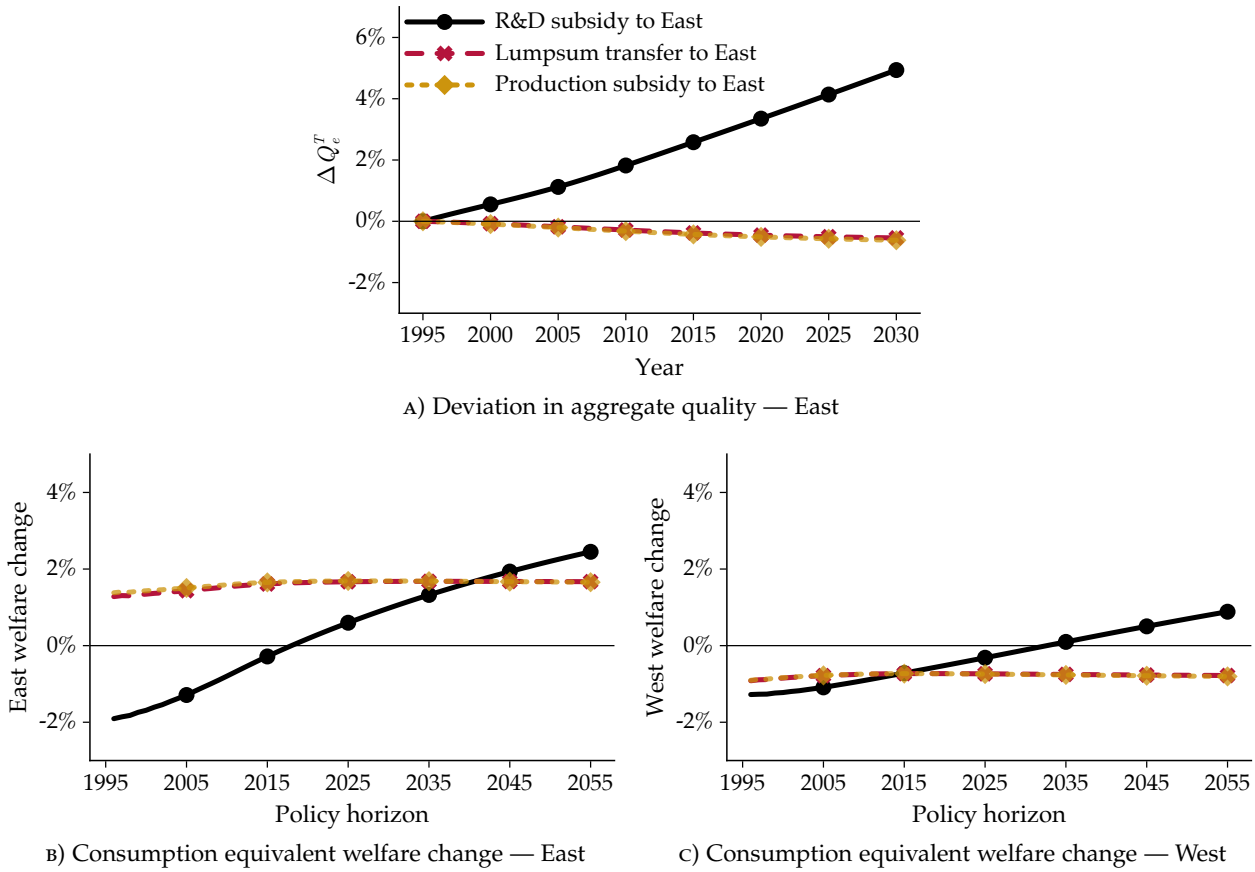
6.2 Subsidy Policies

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 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) production subsidies to Eastern firms, (ii) lump-sum transfers to Eastern consumers, and (iii) R&D subsidies to Eastern firms. 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 10a, 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 10b. 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.[39]

[38]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.

[39]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, in-



A) Deviation in aggregate quality — East

B) Consumption equivalent welfare change — East

C) Consumption equivalent welfare change — West

Figure 10: Effects of East subsidy policies

Notes: Panel A plots the percent deviation in East aggregate quality $Q_e^T(t)$ from the calibrated benchmark, and panels B and C plot the consumption equivalent welfare changes, for East (top-right) and West (bottom). Black-solid and red-dotted lines represent policies where R&D and production expenditures of East firms are subsidized, respectively. Yellow-dashed line represents the policy where East households are subsidized in lumpsum. All three policies are permanent and each amounts to 0.3% of total Germany GDP.

A plausible question then is 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 10 confirms this conjecture, though with some important nuances.[40] 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 10a). 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,

creasing 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 10a) are slightly worse than in the baseline.

[40] Figure A.9 in the Appendix shows the implied R&D subsidy rate to Eastern firms (solid line).

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.

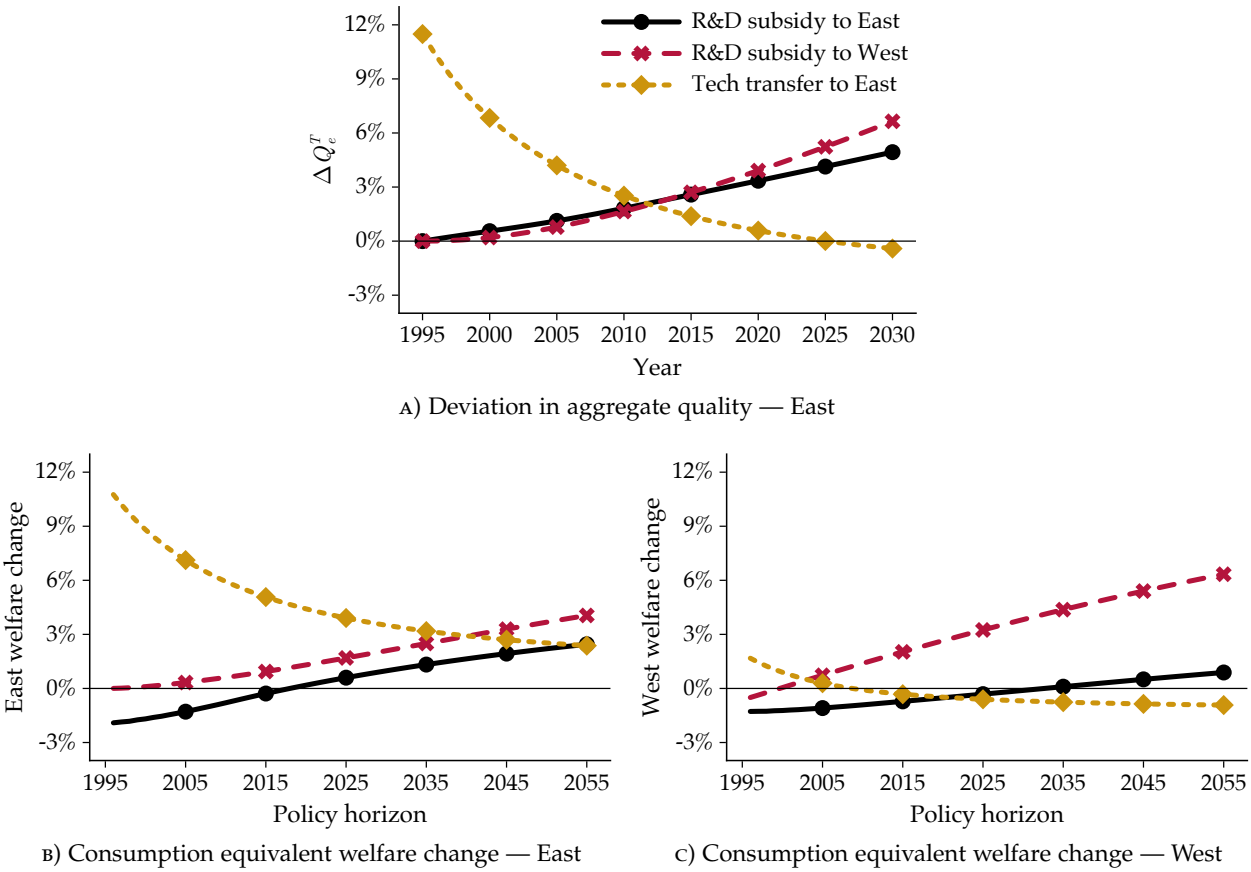
Turning to the implications of these alternative policies for Western consumers, Figure 10c shows that all these schemes to provide additional support to the East reduce welfare in the West, except in the very long run in the case of R&D subsidies. The benefits from improved product quality eventually dominate the welfare gains for the Western consumer, making them better off, but only when a horizon of at least four decades is considered.

R&D subsidy in the West. The previous investigation revealed that among the analyzed subsidy schemes, only R&D subsidies boost 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 11a, 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.[41] In addition, welfare in both regions improves (except for the immediate horizons in the West) owing to improved quality of products sourced from both regions (Figures 11b and 11c). As such, spending resources on supporting R&D activity in the more productive region helps technological development and incomes in both regions as long as Eastern agents are able to rely on technology spillovers from the West to a reasonable degree.

The relative gains in the East from subsidizing R&D in the West instead of the East crucially hinge on the Western comparative advantage in R&D and the magnitude of spillovers. In fact, as illustrated in Figure A.10 in the Appendix, R&D subsidies to the East could dominate R&D subsidies to the West in terms of Eastern welfare under alternative settings. If innovative capabilities in the East were similar to those in the West ($\alpha_e = \alpha_w$) or if the rate of spillovers was drastically lower, R&D subsidies to the East could make Eastern households better off than subsidies to the West when the policy horizon is long enough. In the former case, Eastern firms could use the funds as efficiently as Western ones in conducting R&D, and in the latter, technological improvements would not flow quickly enough to the East, limiting potential gains from increased R&D in the West.[42] In both cases, R&D to the East becomes a relatively more viable policy alternative

[41] Figure A.9 in the Appendix shows the implied R&D subsidy rate to Eastern firms (dashed line).

[42] This discussion focuses on the gains of the East. In both cases, funding R&D subsidies to the East creates losses for Western households relative to subsidies to Western firms.



A) Deviation in aggregate quality — East

B) Consumption equivalent welfare change — East

C) Consumption equivalent welfare change — West

Figure 11: Effects of R&D subsidy and technology transfer policies

Notes: Panels A and B plot the consumption equivalent welfare changes, for East (top-left) and West (top-right), and panel A plots the percent deviation in East aggregate quality $Q_e^T(t)$ from the calibrated benchmark. Black-solid and yellow-dashed lines represent policies where R&D expenditures of East and West firms are subsidized, respectively. Subsidy policies are permanent and each amounts to 0.3% of total Germany GDP. Red-dotted line represents the one-time technology licensing policy where West firms transfer technology to East firms in 1995. The total value of the transfer equals to the discounted value of 0.3% of total Germany GDP every year. See Section 6.3 for details.

when compared with the baseline economy, highlighting the importance of these aspects.

6.3 Licensing Western Technologies

An alternative policy that could facilitate the flow of technology to the laggard region would be incentivizing West German firms to share their frontier technologies with laggard Eastern firms in their sectors via licensing schemes. 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.[43] Accordingly, we set the size of the step gain via licensing to be two.[44]

Licensing has an immediate large impact on the relative technology level of Eastern firms, as shown in Figure 11a. 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 remaining at levels materially higher than the path arising in the calibrated economy for an extended period. Second, the technologically improved position of Eastern firms translate into higher market shares, incomes, and considerable permanent welfare gains, especially over shorter horizons (Figure 11b). 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 11c). 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, compared with the scenario of increased R&D subsidies to Western firms, this policy appears to shuffle welfare gains across time and space: toward earlier periods and Eastern consumers.

Additional empirical findings lend support to the potential benefits technology sharing bring about. Appendix D presents robust evidence that plants from Western (or foreign) firms located in the East exhibit similar levels of value added per employee to the benchmark sample of Western plants operating in the West (Table A.3), demonstrating that, having access to superior technology, they can avoid the productivity shortfall that ails Eastern plants in the sample.[45]

[43] 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.

[44] 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 lead over its competitor in 1995. Figure A.11 in the Appendix shows the shift in the initial quality gap distribution as a result of technology transfer.

[45] One caveat is that, due to the lack of better data, the exercise cannot differentiate between the product quality and

This finding is consistent with our proposed idea that inferior technology is a key factor behind Eastern firms' low competitiveness, and enabling them to have access to superior technology can indeed improve their productivity and position in the market.[46]

6.4 Combining Best Policies

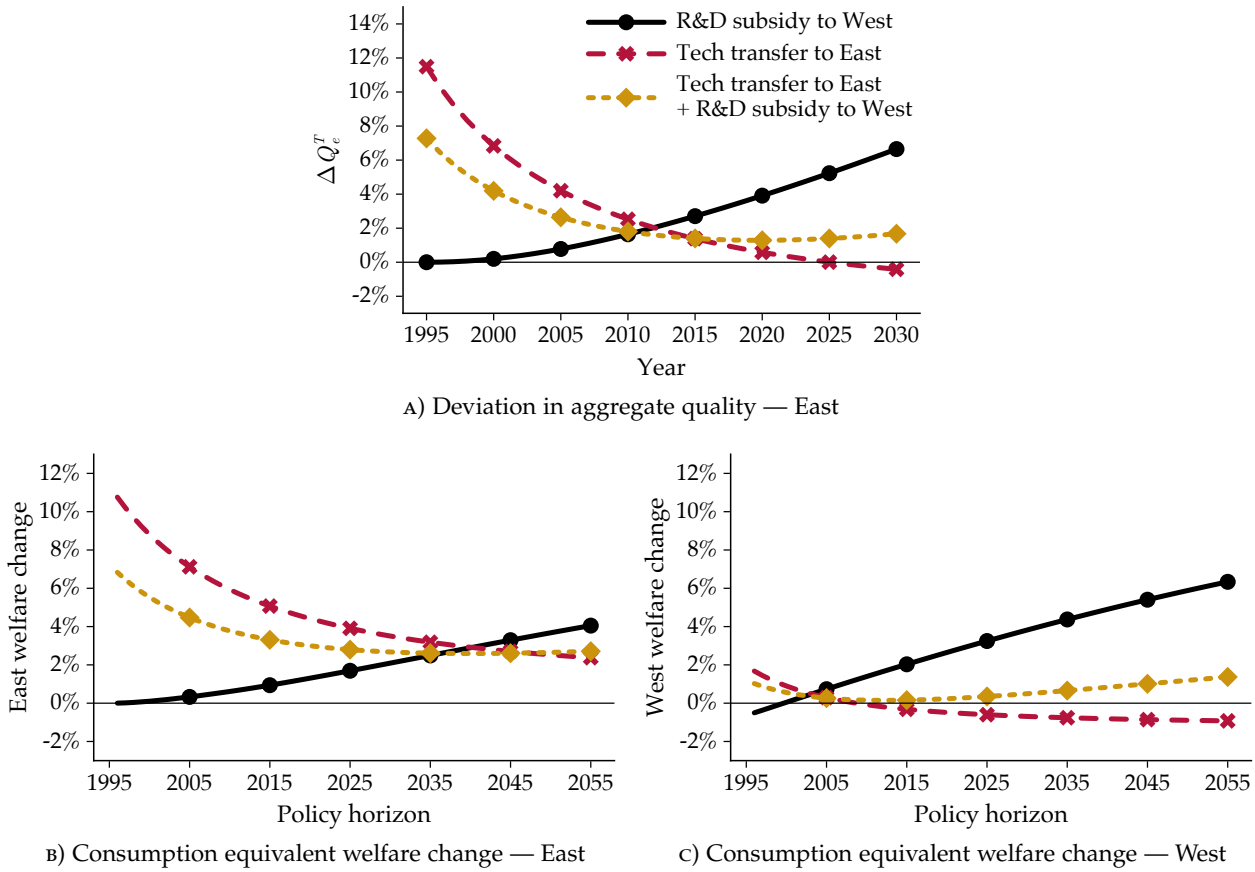
The previous analysis suggests that relying on the Western frontier technology and creating schemes to make the Eastern producers benefit from it produce the best welfare outcomes, albeit with some nuances as to who happens to benefit more and when. We then ask, is there a way to achieve a more balanced 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 12a displays average quality under this scenario. As could be expected, the resulting path (solid line) lies in between the ones obtained separately in each scenario, still implying 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 (Figure 12c).

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 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 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.

production efficiency channels as value added per employee combines both factors. The data suitable for this analysis do not include price information. Appendix D provides the details and also additional background information on technology transfers and ownership changes between West and East Germany and the relevant Treuhand policies.

[46] Certainly, the benefits for the Eastern firms may be smaller than what the Western plants operating in the East enjoy, considering that plants of Western firms may have near perfect access to the original technology at home.



A) Deviation in aggregate quality — East

B) Consumption equivalent welfare change — East

C) Consumption equivalent welfare change — West

Figure 12: Effects of combining technology transfer with R&D subsidies

Notes: Panels A and B plot the consumption equivalent welfare changes, for East (top-left) and West (top-right), and the panel A plots the percent deviation in East aggregate quality $Q_e^T(t)$ from the calibrated benchmark. Black-solid line represents R&D subsidy policy for Western firms. The subsidy is permanent, and amounts to 0.3% of total Germany GDP every year. Red-dotted line represents the one-time technology licensing policy where West firms transfer technology to East firms in 1995. The total value of the transfer equals to the discounted value of 0.3% of total Germany GDP every year (see Section 6.3 for details). Yellow-dashed line represents the policy mix where West firms transfer technology to East firms in 1995 whose total value equals to the discounted value of 0.15% of total Germany GDP every year and R&D expenditures of Western firms are subsidized permanently with an amount of 0.15% of total Germany GDP every year.

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 subdued 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 upfront technology transfers from Western firms via licensing while supporting their innovative activity, respecting their comparative advantage and ensuring the flow of knowledge spillovers.

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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Appendix

A Additional Empirical Results

Table A.1: Summary statistics for the German manufacturing firm-level data.

	East-German firms			West-German firms		
	Mean (1)	St.Dev. (2)	Median (3)	Mean (4)	St.Dev. (5)	Median (6)
Number of employees	133	260	71	291	2103	91
Number of researchers	3.54	24	0	20.70	291.88	0
Real wage (1995 values)	24,587	8,103	23,576	35,142	11,316	34,793
Dummy variable: R&D activity	0.29	0.45	0	0.34	0.47	0
Dummy variable: Export activity	0.61	0.49	1	0.79	0.41	1
Exports over revenue	14.74	22.32	2.61	24.49	26.40	16.33
Number of products	3.28	3.59	2	3.45	4.95	2
Log of value-added per employee	10.26	0.97	10.27	10.60	0.92	10.66

Notes: This table presents summary statistics for selected variables from the German manufacturing sector firm-level data.

Table A.2: 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)
$Proximity_{it-1}$	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. $Proximity_{it}$ 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.

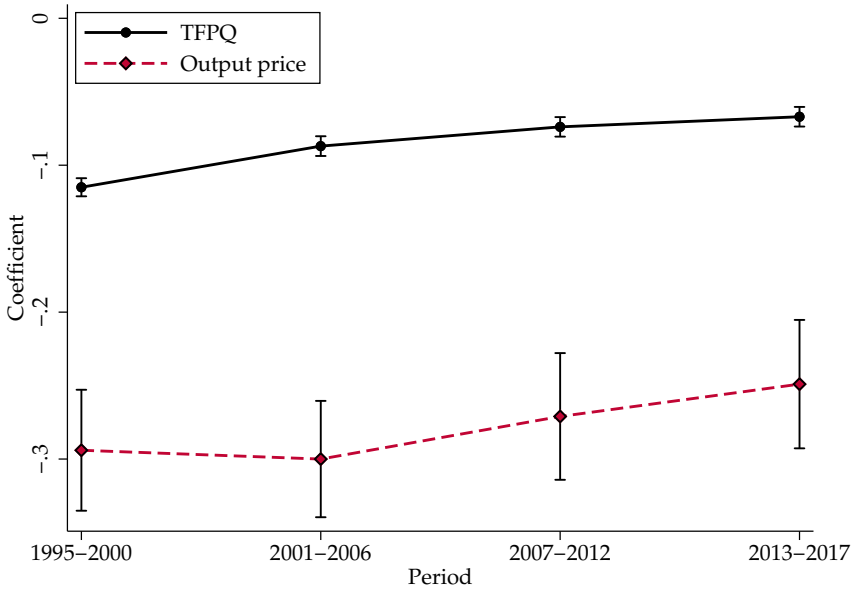


Figure A.1: Firm-level productivity and output prices.

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 Theory Appendix

In this section, we provide the derivations of the equilibrium conditions outlined in Section 4.4.

B.1 Household Problem

Households maximize (2) subject to the intertemporal budget constraint (4). The Hamiltonian for region r reads as

$$\mathcal{H}_r\left(\mathcal{V}_r, E_r, \Lambda_r, t\right) = e^{-\rho(t-t_0)} \log\left(\frac{E_r}{P_r}\right) + \Lambda_r\left(R_r\mathcal{V}_r + w_r L_r + \Pi_r + T_r - E_r\right),$$

where P_r denotes the ideal price index so that $P_r(t)C_r(t) = E_r(t)$. The necessary first order conditions for a maximum are given by

$$\begin{aligned}
\frac{\partial \mathcal{H}_r\left(\mathcal{V}_r, E_r, \Lambda_r, t\right)}{\partial E_r} &= e^{-\rho(t-t_0)} E_r^{-1} = \Lambda_r, \\
\frac{\partial \mathcal{H}_r\left(\mathcal{V}_r, E_r, \Lambda_r, t\right)}{\partial \Lambda_r} &= R_r\mathcal{V}_r + w_r L_r + \Pi_r + T_r - E_r, \\
\frac{\partial \mathcal{H}_r\left(\mathcal{V}_r, E_r, \Lambda_r, t\right)}{\partial \mathcal{V}_r} &= \Lambda_r R_r = -\dot{\Lambda}_r.
\end{aligned}$$

Taking time derivative of Λ_r from the first condition and substituting it in the third condition delivers the Euler equation (8):

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

At each instant of time, households maximize the consumption index given the expenditure $E_r(t)$. Dropping time argument, we state the static maximization problem as follows:

$$\begin{aligned}
&\max_{\left\{c_{wj}^r\right\}_{j=0}^1, \left\{c_{ej}^r\right\}_{j=0}^1, C_r^{NT}} \left(\frac{1}{\beta}\exp\left[\int_0^1 \log\left(\sum_{k\in\{e,w\}}\left(q_{kj}c_{kj}^r\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} dj\right]\right)^{\beta}\left(\frac{Q_r^{NT}C_r^{NT}}{1-\beta}\right)^{1-\beta}, \\
&\text{s.t.} \int_0^1 \left(p_{wj}^r c_{wj}^r + p_{ej}^r c_{ej}^r\right) dj + P_r^{NT} C_r^{NT} = E_r.
\end{aligned}$$

Setting up the Lagrangian and taking first order conditions deliver the demand equations (9) and (10) as in the main text.

B.2 Tradable Sector

The profit maximization problem of the tradable-good firm producing variety j in region r is given by

$$\begin{aligned}\pi_{rj}(t) = &\max_{p_{rj}(t)} \left[p_{rj}(t) - \frac{w_r(t)}{A_r(t)}\right] y_{rj}(t), \\ &\text{s.t. } y_{rj}(t) = c^w_{rj}(t) + c^e_{rj}(t), \\ &\quad p_{-rj}(t) \text{ is taken as given,}\end{aligned}$$

where $c^k_{rj}(t)$ denotes the demand from region $k = w, e$ and is defined by equation (10), and the subscript $-r$ denotes the other competing region. Dropping time arguments, define the demand function $y_{rj}(p_{rj}) = c^w_{rj} + c^e_{rj}$. Using equation (10), we show

$$y_{rj}(p) = \frac{1}{p_{rj}} \frac{\left(\frac{q_{rj}}{p_{rj}}\right)^{\sigma-1}}{\left(\frac{q_{rj}}{p_{rj}}\right)^{\sigma-1} + \left(\frac{q_{-rj}}{p_{-rj}}\right)^{\sigma-1}} \beta E.$$

Taking the first order condition with respect to price, p_{rj}, gives the optimal markup decision:

$$p_{rj} = \underbrace{\frac{\varepsilon_{rj}(p_{rj})}{\varepsilon_{rj}(p_{rj}) - 1}}_{\mu_{rj}} \frac{w_r}{A_r},$$

where $\varepsilon_{rj}(p_{rj})$ is defined as the price elasticity of demand and equals to

$$\varepsilon_{rj}(p_{rj}) \equiv -\frac{y'_{rj}(p_{rj}) p_{rj}}{y_{rj}(p_{rj})} = s_{rj} + (1 - s_{rj})\, \sigma,$$

where $s_{rj} = \frac{\left(q_{rj}/p_{rj}\right)^{\sigma-1}}{\left(q_{rj}/p_{rj}\right)^{\sigma-1} + \left(q_{-rj}/p_{-rj}\right)^{\sigma-1}}$ denotes the market share. The price elasticity of demand, ε_{rj}, is a weighted average of elasticity of substitution across varieties j, which is equal to one, and elasticity of substitution across regions, which is equal to σ, weights being the market share of the firm, s_{rj}. Higher market share reduces this average towards one as $\sigma > 1$, and the firm obtains a higher product market power with lower demand elasticity. This allows the firm to charge higher markups. We finally solve for the equilibrium market shares from the constraint

that $s_{rj} + s_{-rj} = 1$. Dividing s_{rj} to $s_{-rj} = 1 - s_{rj}$, we can show

$$\begin{aligned}\frac{s_{rj}}{1-s_{rj}} &= \frac{\left(\frac{q_{rj}}{p_{rj}}\right)^{\sigma-1}}{\left(\frac{q_{-rj}}{p_{-rj}}\right)^{\sigma-1}} \\ &= \left(\frac{q_{rj}}{q_{-rj}}\right)^{\sigma-1}\left(\frac{\mu_{rj}}{\mu_{-rj}}\right)^{1-\sigma}\left(\frac{w_r}{w_{-r}}\right)^{1-\sigma}\left(\frac{A_r}{A_{-r}}\right)^{1-\sigma},\end{aligned}$$

with $\mu_{rj} = \frac{s_{rj}+(1-s_{rj})\sigma}{s_{rj}+(1-s_{rj})\sigma-1}$. Further reorganizing the terms delivers the market share equation (13) in the main text. For any given quality, wage, and efficiency ratios, we calculate the implied equilibrium market share using equation (13).

B.3 Consumption

We derive consumption per capita, C_r/L_r, using equilibrium labor allocations and production decisions. Let l_{kj}^r denote the labor used in region k for the production shipped to region r. Then $c_{kj}^r = A_k l_{kj}^r$. Also $C_r^{NT} = A_r l_r^{NT}$. For labor allocations, we have

$$l_r^{NT} = \frac{(1-\beta)E_r}{w_r} \quad \text{and} \quad l_{kj}^r = \frac{\frac{s_{kj}}{\mu_{kj}}\beta E_r}{w_k}.$$

The second equation follows from the demand equation, $p_{kj}A_k l_{kj}^r = s_{kj}\beta E_r$, and the optimal pricing relationship, $p_{kj} = \mu_{kj} w_k / A_k$. In the absence of trade costs and tariffs, the market shares of a firm in both regions equal to each other, i.e. $s_{kj}^r = s_{kj}^{-r} = s_{kj}$, where the superscripts r and $-r$ denote markets. Therefore, firms charge equal markups in both regions, i.e. $\mu_{kj}^r = \mu_{kj}^{-r} = \mu_{kj}$. Replacing the consumption of tradable and nontradable products in equation (2) and factoring out Q_r^T and A_r delivers

$$\begin{aligned}\frac{C_r}{L_r} &= A_r Q_r^T \left(\frac{1}{\beta}\exp\left[\int_0^1 \log\left(\left(\frac{q_{rj}}{Q_r^T}\frac{A_r}{A_r}\frac{l_{rj}^r}{L_r}\right)^{\frac{\sigma-1}{\sigma}} + \left(\frac{q_{-rj}}{Q_r^T}\frac{A_{-r}}{A_r}\frac{l_{-rj}^r}{L_r}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} dj\right]\right)^{\beta}\left(\frac{1}{1-\beta}\frac{l_r^{NT}}{L_r}\right)^{1-\beta}, \\ &= A_r Q_r^T \left(\frac{1}{\beta}\exp\left[\int_0^1 \log\left(\left(\frac{l_{rj}^r}{L_r}\right)^{\frac{\sigma-1}{\sigma}} + \left(\lambda^{m_{-rj}}\frac{A_{-r}L_{-r}}{A_r L_r}\frac{l_{-rj}^r}{L_{-r}}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} dj\right]\right)^{\beta}\left(\frac{1}{1-\beta}\frac{l_r^{NT}}{L_r}\right)^{1-\beta},\end{aligned}$$

where the second equality follows from the definition $Q_r^T = \exp\left[\int_0^1 \log q_{rj} dj\right]$. Denoting $\tilde{l}_k^r(m_{kj}) = \frac{l_{kj}^r}{L_k}$ and $\tilde{l}_r^{NT} = \frac{l_r^{NT}}{L_r}$, and aggregating across j with the relationship $m_{-rj} = -m_{rj}$ yields

$$\frac{C_r}{L_r} = \tilde{\beta} A_r Q_r^T \left(\underbrace{\exp\left[\sum_{m=-\bar{m}}^{\bar{m}} \log\left(\tilde{l}_r^r(m)^{\frac{\sigma-1}{\sigma}} + \left(\lambda^{-m} \frac{A_{-r} L_{-r}}{A_r L_r} \tilde{l}_{-r}^r(-m) \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \psi_r(m) \right]}_{=\mathcal{L}_r^T} \right)^{\beta} \left(\tilde{l}_r^{NT} \right)^{1-\beta},$$

where $\tilde{\beta} = \beta^{-\beta}(1-\beta)^{-(1-\beta)}$. Let $\tilde{l}_r^P$ denote the share of labor allocated to production in region r. Then

$$\tilde{l}_r^P = \frac{L_r - \sum_{m=-\bar{m}}^{\bar{m}} \alpha_r \frac{x_r(m)^\gamma}{\gamma} \psi_r(m)}{L_r}.$$

We use the labor market clearing condition (17) to derive an expression for regional wage rate in terms of the share of labor allocated to production:

$$w_r L_r = \left[\left(\sum_{m=-\bar{m}}^{\bar{m}} \psi_r(m) \frac{s_r(m)}{\mu(s_r(m))} \right) \beta E + (1-\beta) E_r \right] \frac{1}{\tilde{l}_r^P}.$$

This wage expression implies

$$\tilde{l}_r^{NT} = \frac{(1-\beta) E_r}{\left(\sum_{m=-\bar{m}}^{\bar{m}} \psi_r(m) \frac{s_r(m)}{\mu(s_r(m))} \right) \beta E + (1-\beta) E_r} \tilde{l}_r^P,$$

$$\tilde{l}_k^r(m) = \frac{\frac{s_k(m)}{\mu(s_k(m))} \beta E_r}{\left(\sum_{m=-\bar{m}}^{\bar{m}} \psi_k(m) \frac{s_k(m)}{\mu(s_k(m))} \right) \beta E + (1-\beta) E_k} \tilde{l}_k^P.$$

Finally, we derive an expression for the total expenditure of region r, E_r, in terms of average market share of firms in the region and transfers to the region. As discussed in Section 4.4, asset market clearing condition yields the following relationship between regional GDP and expenditures:

$$E_r = Y_r + \mathcal{T}_r.$$

Using the definition of GDP, $Y_r = (1-\beta) E_r + S_r \beta E$, and the normalization $E = 1$, we can show

$$E_r = S_r + \frac{1}{\beta} \mathcal{T}_r.$$

Intuitively, transferring one dollar to region r raises expenditure in the region by one dollar. A share $1-\beta$ of this additional spending falls on nontradables, generating $1-\beta$ dollars of extra income in that sector. Of that income, the fraction $1-\beta$ is again spent on nontradables, and the

process repeats. Hence total expenditure rises by

$$1 + (1-\beta) + (1-\beta)^2 + \cdots = \frac{1}{\beta},$$

while GDP rises by

$$(1-\beta) + (1-\beta)^2 + \cdots = \frac{1-\beta}{\beta}.$$

To confirm this, substituting E_r into Y_r yields

$$Y_r = S_r + \frac{1-\beta}{\beta}\mathcal{T}_r.$$

B.4 Convergence

The region-specific index $\mathcal{L}_r^T(t)$ equals

$$\mathcal{L}_r^T(t) \equiv \exp\left[\sum_{m=-\bar{m}}^{\bar{m}} \log\left[\left(\frac{A_{-r}(t)L_{-r}(t)}{A_r(t)L_r(t)}\lambda^{-m}\tilde{l}_{-r}^r(-m,t)\right)^{\frac{\sigma-1}{\sigma}} + \tilde{l}_r^r(m,t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \psi_r(m,t)\right],$$

where $\tilde{l}_k^r(m,t)$ denotes the share of labor allocated in region k when shipping to region r of the production of tradable varieties with a quality gap of m. Defining the share of labor allocated to overall production as $\tilde{l}_r^P(t) \equiv \left(L_r(t) - \sum_{m=-\bar{m}}^{\bar{m}} \alpha_r \frac{x_r(m,t)^\gamma}{\gamma}\psi_r(m,t)\right)/L_r(t)$, we can show that

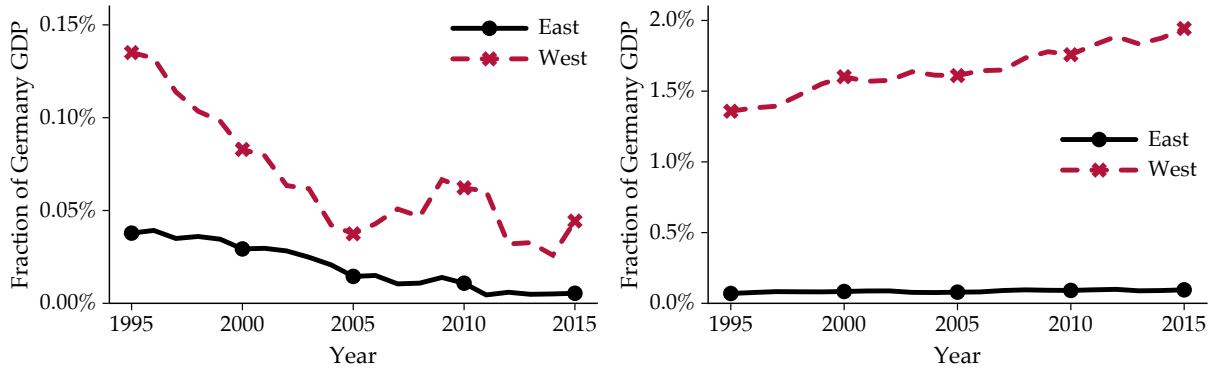
$$\tilde{l}_k^r(m,t) = \frac{\frac{s_k(m,t)}{\mu(s_k(m,t))}\beta E_r(t)}{\beta\left(\sum_{m=-\bar{m}}^{\bar{m}} \frac{s_k(m,t)}{\mu(s_k(m,t))}\psi_k(m,t)\right) + (1-\beta)\left(S_k(t) + \frac{1}{\beta}\mathcal{T}_k(t)\right)}\tilde{l}_k^P(t) \quad \text{and} \quad \tilde{l}_r^{NT}(t) = \frac{1-\beta}{\frac{s_r(m,t)}{\mu(s_r(m,t))}\beta}\tilde{l}_r^r(m,t).$$

C Additional Quantitative Results

C.1 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



A) R&D subsidies

B) R&D expenditure

Figure A.2: R&D expenditure by and R&D subsidies to private sector firms

categories: private sector 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 sector 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 sector firms. Figure A.2a 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 sector firms. Figure A.2b shows the time evolution of these series for both regions. As is 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 Germany GDP. In particular, we calculate the total R&D expenditures in a region and take its ratio to total Germany GDP. Then we average this ratio between the years 1995 and 2015.

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 (5), we assume that $T_e(t)$ follows an exponential process governed by parameters $T_{e,bgp}$, $T_{e,1995}$ and ν_e^T:

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

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 $T_e(t)$, 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

$$\frac{\int_{1991}^{2009} T_e(t) \times 1 dt}{\int_{1991}^{2009} 1 dt} = \frac{600}{\sum_{y=1991}^{2008} Y_y}$$

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 $T_e(t) = T_{e,1995} e^{-\nu_e^T (t-1995)}$, 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 trans-

fer scheme decreases and converges to zero over time. The calibrated T_{et} schedule that we take to the model is depicted in Figure A.3.[47]

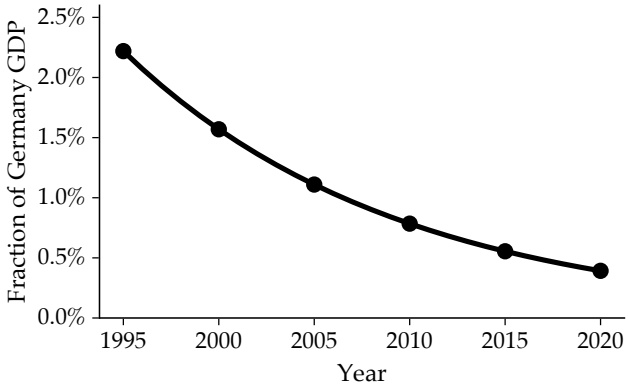
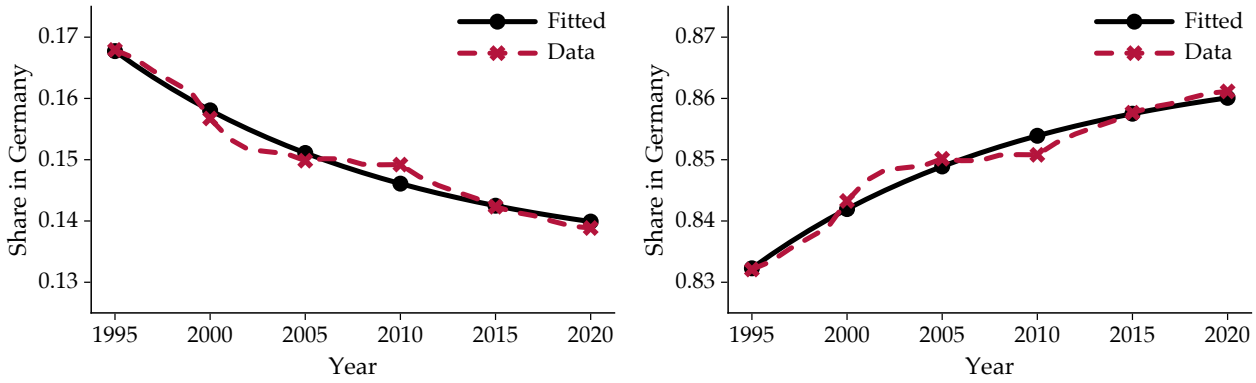


Figure A.3: Calibrated time path of lump-sum transfers to East households, $T_e(t)$

C.2 Additional Figures



A) East share in labor force

B) West share in labor force

Figure A.4: 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 (5) to East normalized labor force with nonlinear least squares. West parameters are recovered from the relationship $L_{w,1995} = 1 - L_{e,1995}$ and $L_{w,bgp} = 1 - L_{e,bgp}$. Panel A and B show the fits for the East and the West, respectively.

[47] We take the full path of $T_e(t)$ to the model until its convergence to zero in the BGP. In Figure A.3, only a part of this series until recent years is shown.

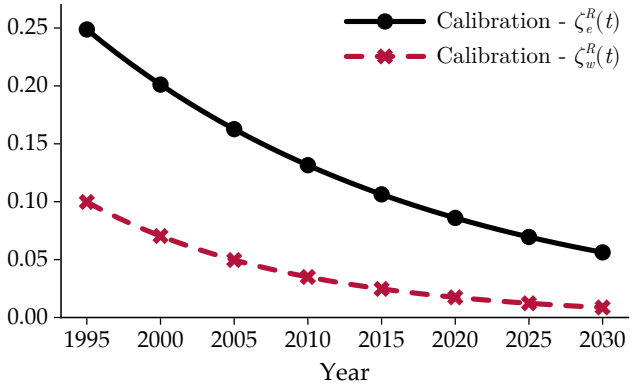
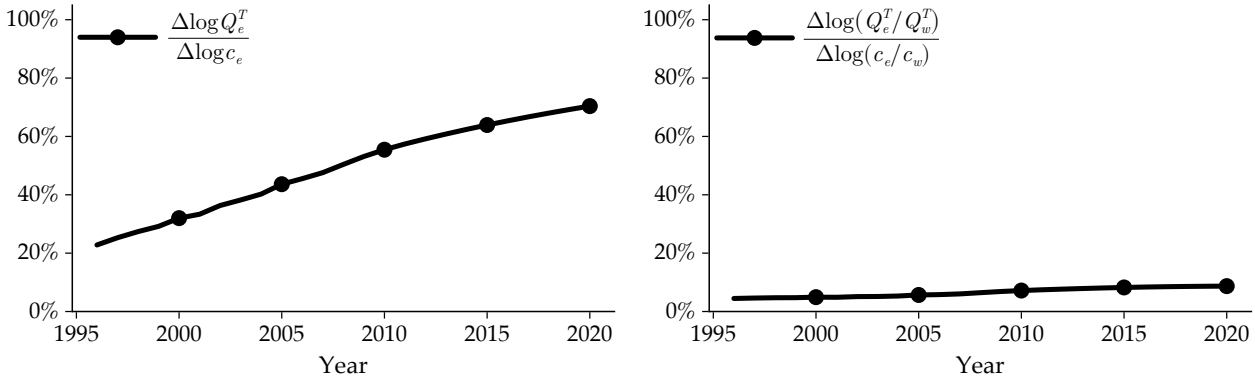


Figure A.5: R&D subsidy rates in calibration

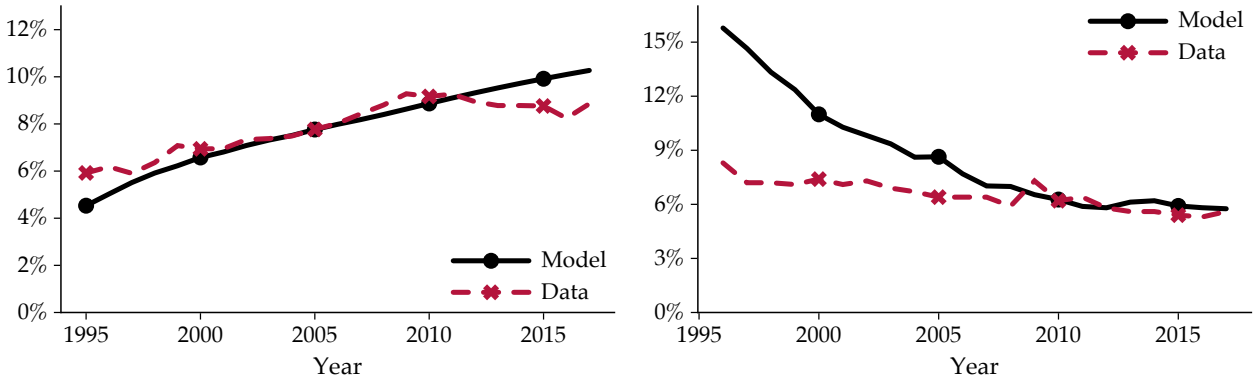


A) East efficiency and quality growth

B) East relative efficiency and quality growth

Figure A.6: Efficiency and quality channels

Notes: Panel A plots the annual growth rate of East efficiency $A_e(t)$ and quality $Q_e(t)$. Panel B plots the annual growth rate of East relative efficiency $A_e(t)/A_w(t)$ and quality $Q_e(t)/Q_w(t)$.



A) East average market share

B) Germany job reallocation rate

Figure A.7: Untargeted moments

Notes: Gross job reallocation is calculated from a simulated panel of 10000 firms in the model.

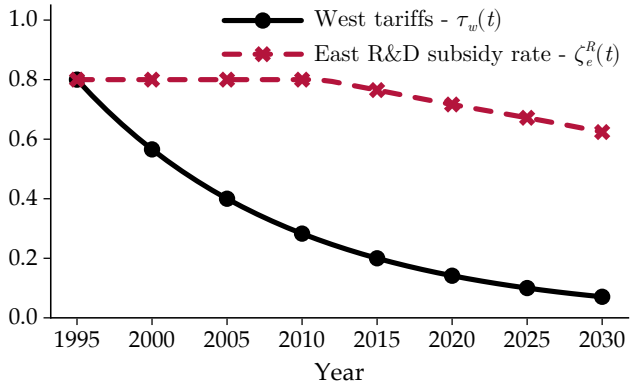


Figure A.8: Tariffs and R&D subsidy rates under delayed unification policy

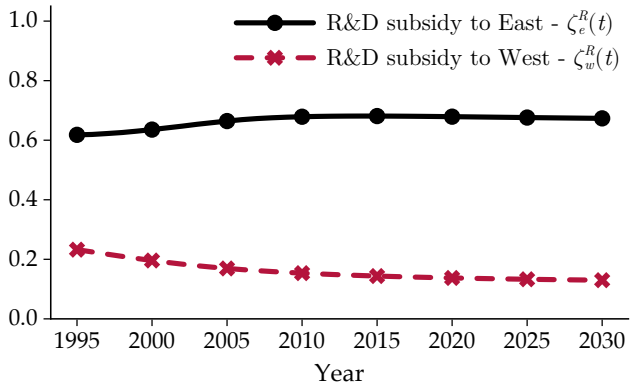


Figure A.9: R&D subsidy rates under R&D subsidy policies

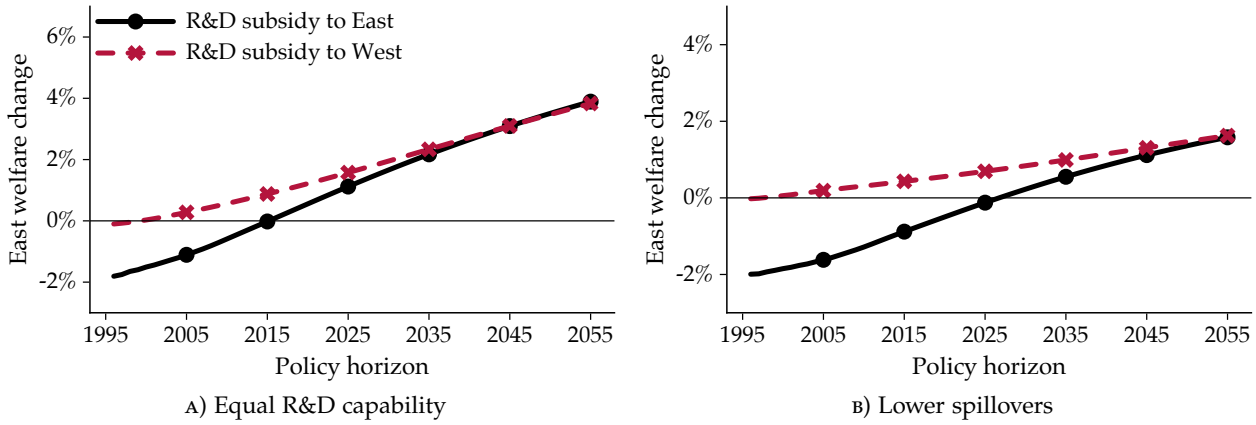


Figure A.10: R&D policies under different counterfactuals

Notes: Panel A considers $\alpha_e = \alpha_w^{calibration}$. Panel B considers $\delta = 0.6 * \delta^{calibration}$.

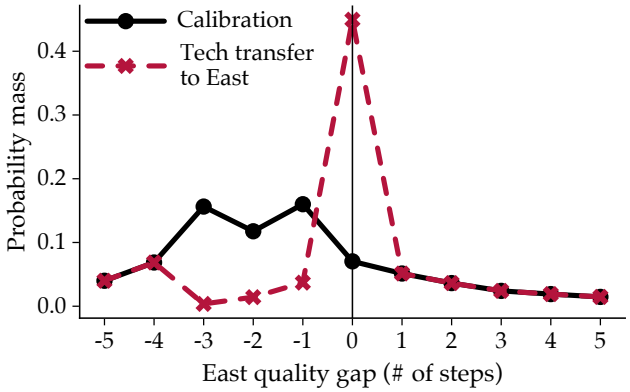


Figure A.11: Initial quality gap distribution under technology licensing policy

D Technology Transfer

Our core argument is that technology transfer, most effectively through broad licensing, would have offered East Germany a chance for rapid post-unification convergence. Licensing could have moved East German firms technologicallycloser to their Western competitors while preserving local ownership and control, which, through the lens of our model, strenghtens Eastern firms' incentives to innovate.

Historical background. Broad technology licensing did not occur. Alternatively, joint ventures (JVs) could, in principle, serve as a partial substitute for broad licensing, since they allow host economies to exchange market access for foreign technology while retaining domestic participa-

tion in governance and learning. China offers a well-known example of how such arrangements can build local technological capabilities under certain conditions and over long time horizons. While the GDR government tried to foster the formation of JVs in early 1990, a Chinese-type JV strategy turned out to be infeasible after unification.[48] JVs require domestic firms as partners, but on the eve of unification virtually all East German enterprises were owned by the Treuhandanstalt, which was a temporary agency with a narrow, legally defined mandate to privatize rapidly rather than to cultivate long-term co-ownership structures. The Treuhand was neither designed nor incentivized to function as a JV partner, and its planned four-year lifespan made such strategies institutionally impossible. The Treuhand used JVs mainly as transitional steps toward full sales. As a result, the potential JV-based channel of technology transfer that played a prominent role in other late-industrializing contexts played no important role in East Germany.

Privatization thus overwhelmingly took the form of full takeovers by West German and foreign firms. While East German subsidiaries of West German or foreign firms may have benefited from direct technology transfer, a major difference compared to the JV or licensing scenarios is that subsidiaries are dependent and typically have no influence over strategic or R&D decisions. Indeed, R&D capabilities in the East have often been closed by the Treuhand or the new owners and therefore remained concentrated in West Germany. This hindered the emergence of self-sustaining R&D activity in the East and jeopardized the possibility of leapfrogging or genuine technological competition. Among the 8,444 firms that survived until the end of Treuhand activity in 1994, 42 percent were sold to West German (32 percent) or foreign owners (10 percent) (cf. Grunert et al., 1998). Another 35 percent were management buy-outs or buy-ins and are therefore mostly privatized under East German ownership. The remainder went either to public owners or was restituted to its former expropriated owners. According to Mergele et al. (2025), West German and foreign owners cherry-picked the most promising Treuhand firms. In parallel to Treuhand privatization, many new firms emerged, most of them under East German ownership.

Data and ownership analysis. In the following, we use the IAB Establishment Panel (Bellmann et al., 2024), which contains plant-level ownership information.[49] The data for the years 2000–2018 show that, within the East, only 10.3 percent of all private-sector establishments and 28 percent of all private-sector employment belong to West German or foreign owners.

[48] As a step toward a market-based economy, the GDR Council of Ministers adopted the "Regulation on the Establishment and Operation of Enterprises with Foreign Ownership" (*Verordnung über die Gründung und Tätigkeit von Unternehmen mit ausländischer Beteiligung*) on January 25, 1990 - called the 'Joint Venture Regulation'. According to Schwalbach and Schwerk (1992), 2,741 joint ventures had been registered with the GDR authorities by July 1, 1990, after which many restrictions on foreign ownership were lifted. Almost all JV's (96.5 percent) were formed between East- and West German owners. Their economic significance was, however, likely minimal, as these ventures involved very small firms, mainly in the retail sector (only 9 percent were in manufacturing). According to the numbers reported in Schwalbach and Schwerk (1992), we compute that the employment covered by these 2,741 joint ventures was below 1.5 percent of GDR employment.

[49] This high-quality survey is representative of all German establishments with at least one employee subject to social security contributions. Reliable ownership information is available beginning in the year 2000. Berlin is excluded because the city historically comprised both socialist East and capitalist West, and the data do not distinguish between these two parts.

Table A.3 runs several regressions of log value added per employee on dummies indicating East plant location and ownership status, conditional on 3-digit industry, logged establishment size, establishment age, and year. Column reports results for the full sample. The results are clear: West German and foreign-owned establishments located in the East exhibit productivity levels comparable to the West German benchmark throughout 2000–2018.[50] By contrast, East-owned establishments' productivity is, on average, 19 log points below West German plants.

As discussed above, the evidence suggests that West German and foreign owners cherry-picked the most promising Treuhand-managed East German firms, which could confound our results. Accordingly, Column (1) should be interpreted as capturing the combined effects of cherry-picking and technology differences. To better isolate the technology channel, Columns (2)–(4) progressively restrict the sample to establishments that are less likely to be affected by cherry-picking. Column (2) excludes all establishments that were part of the Treuhand portfolio. Column (3) further removes all establishments founded before the dissolution of Treuhand in January 1995. Finally, Column (4) excludes East German establishments founded after Treuhand that ever switched from East to West or foreign ownership, thereby ruling out post-Treuhand cherry-picking. None of these sample restrictions materially alters our results.

[50]The result is similar when we omit controls for size and age. Labor productivity is winsorized at the 2nd and 98th percentiles.

Table A.3: Performance by Ownership Type

	Dependent variable: log value added per employee			
	Full sample	*No cherry-picking samples*		
	(1)	(2)	(3)	(4)
East location & East owned	-0.194***	-0.196***	-0.186***	-0.189***
	(0.018)	(0.018)	(0.027)	(0.027)
East location & West or foreign owned	0.036	0.040	0.000	-0.002
	(0.030)	(0.031)	(0.054)	(0.061)
West location (reference category)	—	—	—	—
3-digit sector FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Log employment	yes	yes	yes	yes
Establishment age	yes	yes	yes	yes
Exclud. Treuhand establishm.	no	yes	yes	yes
Exclud. founded before 1995	no	no	yes	yes
Exclud. East-West/Foreign Ownership changes	no	no	no	yes
Observations	90,019	87,588	64,767	64,250
R^2	0.203	0.204	0.203	0.203

Notes: IAB Establishment Panel, years 2000–2018, weighted using survey weights. Berlin is excluded. The dependent variable is log value added per employee. A dummy variable indicating the very small group of East-based establishments with split ownership is always included. Column (1) covers the full sample. Columns (2)–(4) impose increasingly strict sample restrictions to reduce the influence of cherry-picking as discussed in the text: Column (2) excludes Treuhand establishments, Column (3) additionally excludes all establishments founded before January 1995, Column (4) additionally excludes establishments with East-to-West/Foreign ownership changes. Standard errors are clustered at the establishment level. Significance: *p*<0.10, **p*<0.05, ***p*<0.01.

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