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The Transformative Potential of AI: Implications for Work, Firms, and Trade

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The Transform- ative Potential of AI:

**Implications for Work,
Firms, and Trade**

Can artificial intelligence (AI) revive the long-declining productivity of European firms and boost the continent's economic growth? How well are EU economies positioned to leverage AI while mitigating risks such as job displacement and algorithmic collusion? The answers largely depend on the business ecosystem, the speed of adoption, and – ultimately – balanced regulation and policy: Upskilling workers, strengthening digital infrastructure, and deepening the EU single market are some of the priorities discussed in this Forum.

Policy Debate of the Hour

How Europe Can Capture the AI Growth Dividend

Key Messages

- The medium-term gain in productivity from AI adoption would be rather modest and about 1.1 percent over five years.
- While the average gains are modest, they vary considerably across countries
- AI could have much larger effects over the longer term by creating new industries and value chains, and accelerating R&D
- However, these gains will hinge on efforts to deepen the single market and the calibration of regulation



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Can artificial intelligence (AI) provide a much-needed boost to Europe's economic productivity? Use of AI is spreading much faster than earlier technologies, such as the personal computer and the internet. And AI promises significant productivity leaps by automating many tasks and enhancing human capabilities.

However, achieving large gains will hinge on European countries' commitment to growth-enhancing reforms and a

willingness to be flexible on regulation to help the new technology flourish. In Misch, Park, Pizzinelli and Sher (2025) we show that, in the absence of reforms, the medium-term gain in productivity from the AI adoption alone would vary considerably across countries, and, for Europe as a whole, would be rather modest: about 1.1 percent cumulatively over five years. With pro-growth reforms, though, much bigger gains are possible in the longer term.

Figure 1**Labor Productivity and GDP Per Capita Growth Have Declined in the EU**

Source: Eurostat; IMF staff calculations.

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How AI Helps Productivity Now

Three factors drive the economy-wide and one-off productivity effects of AI adoption:

1. Exposure to AI of different sectors and occupations – the degree to which AI can automate or augment tasks;
2. Companies' incentives to adopt AI, particularly potential savings in labor costs;
3. Average productivity gains across occupations: Contrary to past automation technologies, AI exposure is especially high in professional, managerial, or administrative work that is non-manual and often knowledge-based, like finance or software development.

European countries would benefit to different degrees. Higher-income countries typically gain more because they have more white-collar services, leaving them more exposed to AI. They also have higher wage levels which increase incentives to adopt labor-saving technologies. For example, Norway could gain as much as 5 percent in the most optimistic scenario.

Gains for lower-income economies will likely be more limited, which means that AI could temporarily widen productivity disparities within Europe. For instance, Romania

could only add just below 2 percent even in an optimistic scenario. Productivity gains could be larger in all countries if the cost of AI systems falls more quickly.

Strong Upsides Over Longer Term

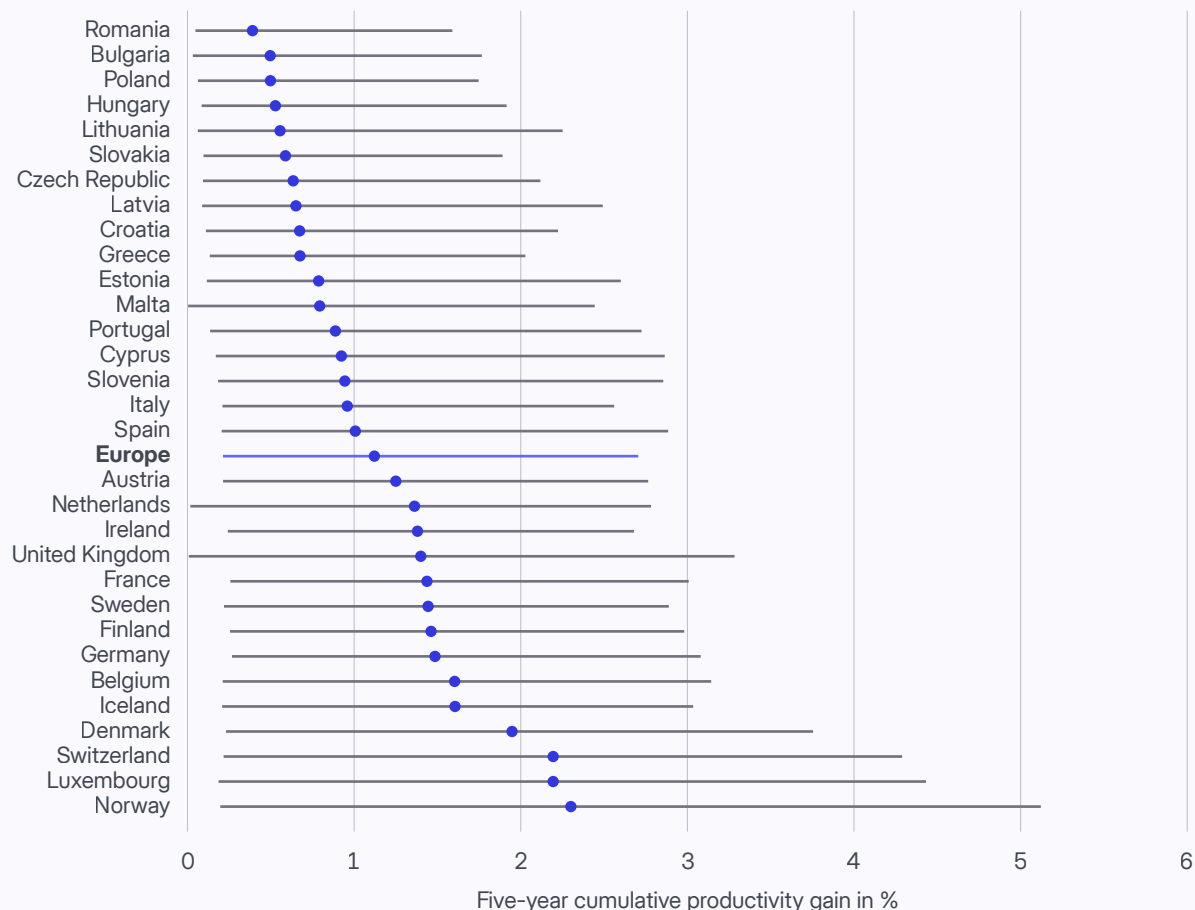
The improving capabilities of AI models (as evidenced by various tests¹) suggest that gains could be much larger over a longer time horizon. AI could have more transformational effects by creating new industries and value chains. It could also boost productivity growth more permanently by accelerating research and development (referred to in literature as "invention in the method of inventing"; see Bontadini, Haskel, Corrado and Jona-Lasinio 2025). For instance, there is already evidence that AI accelerates and enhances pharmaceutical drug development (Zhang et al. 2025).

Bontadini et al. (2025) estimate the long-run annual labor productivity growth impact when considering that AI is used not only to produce goods and services but also to create new commercial knowledge. In the United States, annual productivity growth could be boosted by 1 percent annually, while for Europe the gains could also be substantial but not as high. The analysis points to longer-lasting effects

¹ See Artificial Analysis (<https://artificialanalysis.ai/>) for intelligence, quality, performance and price benchmarking of AI models.

Figure 2**AI Impact on Productivity Is Different Among European Countries – Five-year Cumulative Gain^a**

● Most likely scenario



^a The chart reports the range of plausible cumulative medium-term productivity gains for each country across scenarios. "Europe" refers to the average of the countries in the sample.

Source: Eurostat; Misch et al. (2025).

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which imply dramatically larger gains than the short-term effects we estimated. These predicted long-term benefits could even be conservative: When estimating the impact of technology, expectations are often too optimistic about the immediate effects and too pessimistic about lasting contributions (Lin 2024).

How Europe Should Respond: Policy Implications

To take full advantage of AI's potential, Europe must focus on removing the barriers that limit diffusion of skills and technology and the growth of companies. The recent IMF Regional Economic Outlook for Europe (IMF 2025) highlights several policy priorities.

Deepening the European Union single market will be critical to counter fragmentation along national borders. The goal must be to make it easier for innovative firms in the field of AI to access a broader, EU-wide customer base. This requires removing barriers to cross-border services, opening up protected sectors, and harmonizing standards – all of which can help reduce the cost of developing and adopting AI tools.

Funding the risky investments that underpin AI development (often based on intangible assets like software and intellectual property) requires stronger and more integrated financial markets. A well-functioning capital markets union can increase the availability of venture capital by channeling

more savings to early-stage, risky technological ventures in AI. Improving the recognition and valuation of intangibles assets, such as intellectual property related to AI, in financial statements and resolution regimes would also help mobilize private financing for innovation.

Flexible labor markets and portable social protection are vital to help workers transition to sectors and firms that are expanding thanks to AI. For instance, simplifying degree recognition, enhancing housing affordability, and ensuring pension portability can facilitate movement to where opportunities from AI arise.

Creating a more efficient energy market is another key ingredient. Affordable and reliable electricity will support data centers that power AI systems. Securing competitive and low-carbon energy supplies through better market integration will support both AI infrastructure and Europe's broader green transition.

Finally, regulation needs to remain flexible. While addressing important data protection, ethical, and safety concerns related to AI, regulation will need to be dynamically calibrated to navigate the trade-offs between addressing risks and enabling growth through AI adoption. Otherwise, even some of the moderate productivity dividends from AI adoption over the next few years could be lost.

Reaping the full potential of AI depends on policy choices that Europe makes today. Even moderate AI productivity gains in the coming years would be significant relative to Europe's anemic economic growth prospects. Capturing larger, longer-term benefits – and keeping up with the United States – will hinge above all on Europe's ability to move fast in building a more dynamic and integrated single market. •

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Policy Debate of the Hour

Unlocking Export Gains

The Role of AI and AI-Related Technologies

Key Messages

- Large firms currently lead the way in AI adoption, suggesting that there is an *inclusiveness* issue in which SMEs are being left behind
- Robust digital infrastructure and specialized in-house ICT skills are the primary catalysts for AI technology adoption
- AI technologies are positively correlated with increased foreign sales per employee among firms that adopt them
- The benefits of AI-related technologies are not uniform: robotics mostly impacts manufacturing, while big data drives the services sector
- Synergies between multiple digital technologies magnify overall export performance gains



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The debate on the adoption and diffusion of digital technologies as well as on their economic impacts is flourishing, with different perspectives and topics under scrutiny. The growing digitization of economic activities offers new opportunities to reactivate, or even accelerate, the technological diffusion machine, since it makes business trialing faster and cheaper, and the possibility of replicating innovations faster and more accurate.

Given the fundamental technological shift, there are good reasons to believe that new digital technologies – in particular artificial intelligence (AI) and AI-related technologies¹ – should yield strong positive effects on productivity and on firms' international involvement (Freund, Mulabdic and Ruta 2022). When firms embed AI in their business processes and use it to automate certain routine tasks and explore massive amounts of data with a view to improving product

¹ AI-related digital technologies enable machines to process massive datasets, learn, reason, and solve complex problems to optimize production. Here, the focus is on AI and AI-related digital technologies enabling an Industry 4.0 transformation, namely big data, robotics, 3D printing, machine learning, AI, and Internet of Things.

quality, seizing new opportunities with innovative ways to reach and better match customers' needs, and reducing the costs of interacting with suppliers and customers, productivity and export gains are likely to follow. Further, entry costs and business barriers in international markets are likely to decrease as a result of greater logistical efficiency and better alignment of supply and demand (Cassetta, Monarca, Dileo, Berardino and Pini 2020).

To better understand and assess the role of AI in firms' export gains, this article investigates the main adoption drivers of AI and AI-related digital technologies enabling Industry 4.0 for a representative sample of Portuguese firms over the period 2014–21 and their impact on the intensive (level of foreign sales) margin of exports. By focusing on AI, our analysis can provide a better understanding of heterogeneity in adoption and its interconnection with firms' international involvement. In addition, we examine whether heterogeneous effects on the intensive margin of exports exist across industries.

Digital Technologies and Export Performance

The adoption of digital technologies entails changes in firms' comparative advantages and in the geographic organization of the business, with the potential to reduce the costs of doing business across different locations and to overcome a possible lack of economies of scale due to mass customization. Despite the potential positive impact on firms' performance, adoption is not instantaneous; implementation lags may arise, and adoption may not be inclusive.

Since AI can be seen as a general-purpose technology, it is expected to take time to spread across firms and markets. The radical nature of AI and AI-related technologies usually implies a break with old routines, the write-off of capital, the availability of complementary resources (e.g., digital skills and infrastructure), and internal organizational adjustments for the successful deployment of such technologies. The availability and diffusion of complementary resources to firms, as well as the external context in which firms operate (e.g., competition and the cumulativeness of knowledge), have been identified in the technology diffusion literature as important factors driving technology adoption decisions (see, for instance, Malerba and Orsenigo 1996).

In particular, the potentially high risk and fixed costs associated with digital technology adoption may lead to selection toward larger, less financially constrained firms (Brynjolfsson, Rock and Syverson 2021). In turn, smaller firms seem to be in a worse position to adopt digital technologies, since they tend to be more financially constrained (Ferreira, Haber and Rorig 2023) and have fewer opportunities for innovation

complementarities, thereby imposing greater constraints on leveraging AI. However, Cirillo, Fanti, Mina and Ricci (2023) suggest that small firms could gain more from technology adoption, since larger firms take longer to notice the effects of their technological investments. Accordingly, firm size – a measure of a firm's ex-ante performance – seems to be a good predictor for digital technologies adoption, supported by a number of empirical studies that found a positive correlation between firm size and technology adoption (e.g., Zolas, Kroff, Brynjolfsson, McElheran, Beede, Buffington, Goldschlag, Foster and Dinlersoz 2020).

Another important issue is that a necessary prerequisite for adopting AI and AI-related technologies is computing power and access to ultra-fast broadband to handle and exploit massive quantities of digital information, enabling their application across a vast range of commercial activities and purposes. Along the same lines, the continued development and increasing sophistication of those technologies mean that their adoption requires complementary assets, such as skill-specific labor or organizational adjustments.

From a firm-level perspective, AI and AI-related digital technologies are likely to enable flexible manufacturing processes and to ease real-time data analysis, leading to reduced operational costs and decision-making uncertainty. By improving business processes, reducing operational and search costs, reducing informational frictions, and enabling faster adaptation to market and consumer preference changes, those technologies may affect export performance by generating additional foreign sales and making it easier to enter international markets.

These effects, and consequently the impact on trade, are product-specific. They depend on two product characteristics: complexity and weight. The dimension of weight is an indicator for general trade costs, while product complexity constrains the international transfer of technology, since the high capital intensity and localized tacit knowledge required for production limit technological mobility. Since complex, lightweight goods are more suited for global trade expansion during any technological shift, the positive effects of AI and AI-related technologies on a firm's international involvement increase with product complexity and decrease with product weight. On the other hand, openness to Industry 4.0 has the potential to create new opportunities for production flexibility and improved product quality. The variety and complementarity of digital technologies seem to be key drivers of firms' adoption and of the subsequent performance gains. Overall, adoption of the new generation of digital technologies may lead to improvements in product quality, allowing firms to create and virtually examine the feasibility and value of more sophisticated products, enabling greater accuracy and precision in production. None-

Data and Empirical Strategy

To empirically assess the relationship between AI and export gains, two datasets provided by the Portuguese National Institute of Statistics (INE) – Information and Communication Technology Usage and e-Commerce in Enterprises (*Inquérito à utilização de tecnologias de informação e comunicação nas empresas* – IUTICE) for digital adoption and Integrated Business Accounts System (Sistema de Contas Integradas das Empresas – SCIE) for firm-level sales in international markets and other firm-specific characteristics – form the basis for computing empirical variables. IUTICE is part of the Community Survey on ICT Usage and e-Commerce, an annual survey conducted since 2004. In Portugal, this survey is a census of large firms (with more than 250 employees or revenue of more than EUR 25 million) and a stratified random sample of other firms based on size and industry affiliation. The survey is compulsory by law for selected firms, making it a reliable, rich, and valuable dataset. The survey comprises several questions on e-commerce and the use of digital technologies in enterprises, allowing us to assess their adoption in transforming businesses, firms, and economic performance. The final sample consists of 42,940 firm-year observations, of which only 7,799 firms (25.68 percent) were observed in at least two years.

Regarding export performance regressions, the extended linear performance regressions – one for each digital technology – are defined as

$$\ln(\text{Exports})_{i,t} = a + b_1 \text{Adopter}_{i,t} + b_2 \text{SizeClass}_{i,t} + b_3 \text{NumberDTs}_{i,t} + D_t + D_s + e_{i,t}$$

where the dependent variable is a measure of performance in international markets defined as firms' foreign sales per employee, the main variable of interest is an indicator of adoption of AI and AI-related digital technologies, and as control variables the regression includes binary variables based on firms' size and a variable counting the overall number of digital technologies used at firm level (excluding the digital technology under scrutiny) as a proxy of firm digitalization and complementarities in the use of digital technologies. The need to develop a series of complementary assets and capabilities, either related to digital capabilities or organizational resources, to further exploit the new generation of digital technologies may help firms upgrade intangible resources that facilitate the realization of performance gains from international engagement. Each regression also controls for 2-digit sector and year fixed effects.

theless, product quality gains will depend on the radicalness of digital technologies relative to the prior technology used and on the availability of digital skills to leverage adoption gains.

AI as a Catalyst for Firm-Level Exporting

Firms' Capabilities, Size, Age, and Adoption Profile

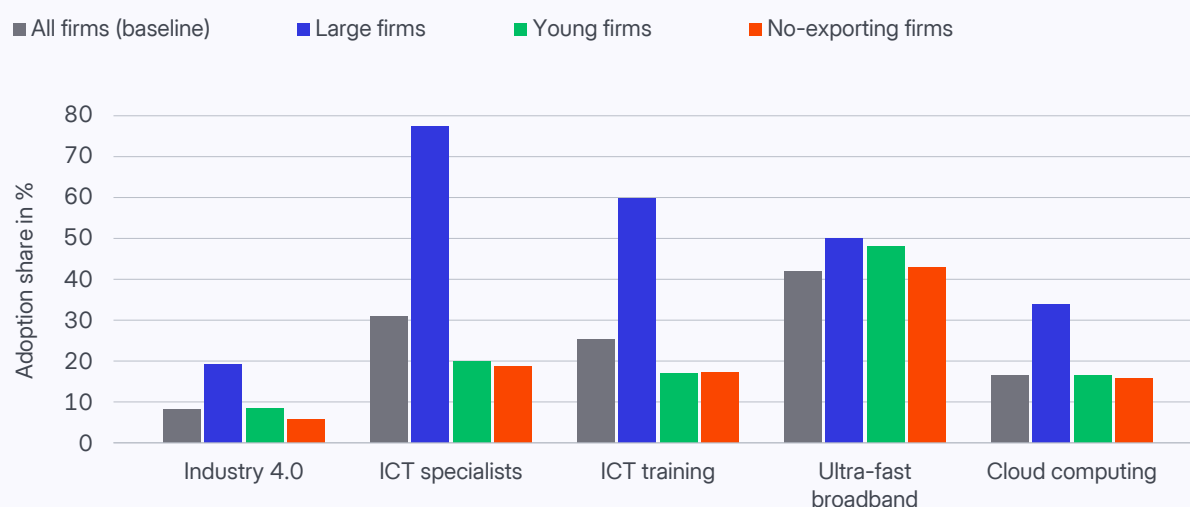
Overall, Portuguese firms report a modest rate of AI and AI-related technology adoption, with a slight increase among large and exporting firms. Figure 1 shows the adoption share of digital technologies and infrastructure by firm type.

Young firms do not seem to be responding to the AI-driven technological shift any differently than older firms to promote competitive advantage. While this modest rate of adoption seems to suggest that the performance and efficiency of Portuguese firms could be strongly compromised, it also points to significant potential: non-exporting and young firms in particular appear not be taking full advantage of this digital infrastructure yet, since they report lower

adoption rates of these technologies. Consistently, those firms report lower ICT skills, suggesting that the process of digitalization is still at an early stage, with potentially low levels of sophistication and limited combinations of digital technologies. Conversely, large firms report, on average, higher ICT skills and higher cloud computing adoption, disclosing high potential in taking benefits from the adoption of AI and AI-related technologies.

On the other hand, Portuguese firms show limited engagement in international markets and, consequently, reduced exposure to more competitive markets. Only 37.5 percent of the firms are exporters and, for them, the average export performance does not exceed 40 percent of their average revenue, indicating considerable scope to expand their activity in international markets. More importantly, young firms have less exposure to international markets, with only 25.3 percent of them being exporters, suggesting greater difficulty in overcoming potential entry barriers.

This heterogeneity in a firm's resources, competences, and incentives appears to lead to a positive selection of ex-ante large firms (i.e., ex-ante better-performing firms),

Figure 1**Digital Technology and Infrastructure Adoption by Firm Type^a**

^a Digital technologies, ICT skills, and digital infrastructures, averaged over all firm-year observations and over several different partitions of the data. The variable "Industry 4.0" takes a value of 1 if a firm adopts any of the six digital technologies (robots, big data, 3D printing, machine learning, artificial intelligence, Internet of Things) related to the Industry 4.0 transformation.

Source: Barbosa (2023).

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as large firms are better suited to efficiently adopt digital technologies. This skew toward large firms discloses a lack of inclusiveness in the adoption process. Yet another interesting finding is that only large firms are significantly more likely to adopt AI and 3D printing technologies than smaller firms, suggesting that these digital technologies are at a very early stage of adoption among Portuguese firms, and only large firms can deal with the high risk and fixed costs involved.

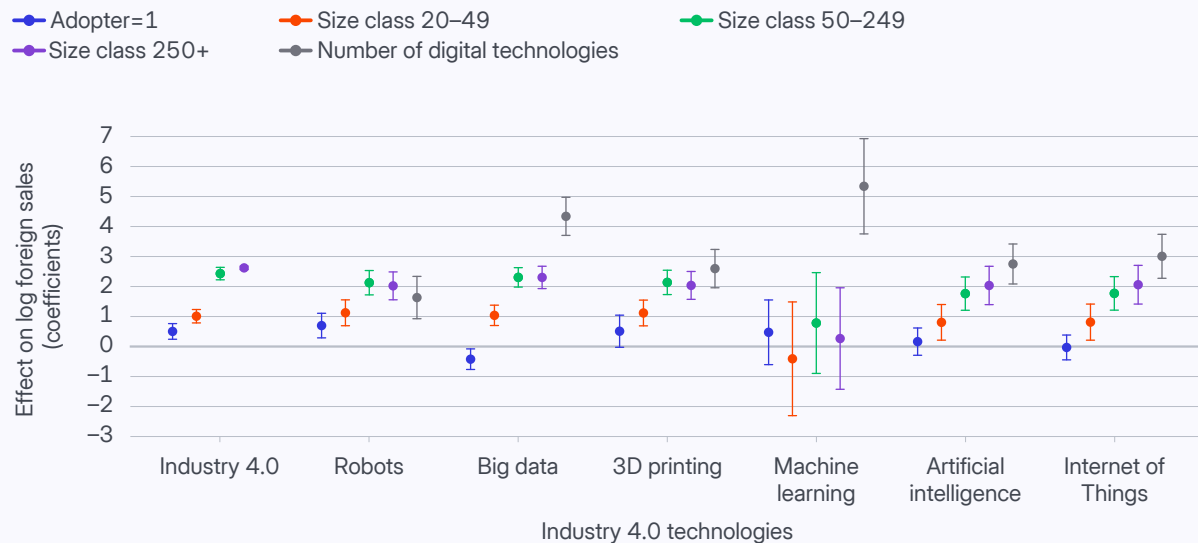
On the other hand, the availability of in-house ICT skills suggests that adopters of AI and AI-related technologies are firms pursuing an upgrade in the degree of sophistication and complementarities among digital technologies. Since the degree of openness toward digital technologies creates opportunities for production and product quality, it appears to be a relevant incentive toward digitalization, particularly the adoption of AI and AI-related digital technologies.

The Impact of Digitalization Profiles on Export Performance

Looking at export performance, the findings suggest scale effects, regardless of digital technologies, with large firms reporting higher levels of foreign sales per employee. More importantly, there is relevant evidence that AI and AI-related digital technology adopters can leverage these technological investments in international markets. By en-

abling massive amounts of customer and competitor data in international markets to be analyzed and by promoting greater flexibility and precision in manufacturing processes, AI and AI-related technologies have the potential to impact cross-border business operations. The export premium, nonetheless, seems to depend on a firm's digitalization profile, echoing the heterogeneous productivity effects of different digital technologies. Figure 2 shows coefficient estimates and 95 percent confidence intervals across digital technologies.

Increasing openness and sophistication toward AI and AI-related digital technologies – as measured by the number of digital technologies adopted – enhances firm-level export performance and may strengthen a firm's position vis-à-vis competitors. On the other hand, firms at the initial stage of the adoption process, adopting only one digital technology, benefit differently in terms of foreign sales per employee. Adopters of robots or 3D printing technologies seem to attain higher export performance than non-adopters. But similar results cannot be found among adopters of other AI and AI-related digital technologies, reinforcing the argument that the digitalization profile matters and that some complementarity in adoption is required to extract economic benefits. More recent digital technologies, such as artificial intelligence (AI) or the Internet of Things (IoT), may require a longer time horizon to generate export gains when adopted separately from other digital technologies. It is interesting to note that robot- and 3D-printing-adopt-

Figure 2**Effect of Technology Adoption and Firm Size on Exporting Performance^a**

^a The coefficients are from OLS regressions with (log) of sales in international markets per employee as the dependent variable and Industry 4.0 technology adoption, size, and other firm-specific characteristics as explanatory factors. The dummy variable "Industry 4.0" equals 1 if a firm adopts any of the six digital technologies related to Industry 4.0 technologies under scrutiny. Each regression includes 2-digit sector and year fixed effects. Whiskers represent 95% confidence intervals.

Source: Barbosa (2023).

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ing firms seem to increase their presence in international markets, serving larger markets than non-adopters. These technologies emerge as a specific source of export performance, which would impact future productivity gains.

Impact of AI and AI-Related Technologies Across Industries

As firms across industries differ in their adoption and exposure to international markets, Table 1 presents the estimated effects of different digital technologies across heterogeneous industries to explore potential heterogeneity in digitalization paths and their impact on firms' export performance.

Technologies that involve greater integration of data across firms, suppliers, and customers, such as IoT and AI, seem to generate export gains for firms in the professional & scientific, accommodation & storage, and wholesale & retail industries. Robot and 3D printing technologies, which are more closely related to manufacturing processes and offer the potential to reduce operating costs, seem to be the main drivers of export performance for firms operating in the manufacturing and utilities industries. It is also interesting to note the positive effect on export performance of robot adopters in the wholesale & retail and transport & storage industries, suggesting that in these industries, the impact

of digital technology adoption on operating costs, flexibility, and production time could be the main driving factors behind export gains, as compared to non-adopters. This also reveals that the use of robots is gaining ground in the service industry, with a positive impact on export performance.

Yet, on the services industry side, the results suggest that firms that base their business on exploiting massive quantities of digital information improve their export performance mostly through big data technologies, confirming that heterogeneous digitalization profiles are likely to generate export gains. This heterogeneity across AI and AI-related digital technologies, and across industries, also reinforces the argument that there is scope for positive effects on firm-level export performance, regardless of the non-inclusive nature of the adoption process. The lack of inclusiveness is likely to exacerbate firm and industry heterogeneity, strengthening existing trends in industry concentration and weakening any potential catch-up process.

Finally, we should acknowledge that we need to be cautious in interpreting empirical results as causal. The estimated results show a significant correlation between measures proxying AI and AI-related technologies and export performance, but firms operating in international markets may be more likely to adopt these technologies during periods of faster expansion. In this case, we cannot rule out reverse

Table 1**Export Performance and Digital Technology Adoption Across Industries**

Industry	I4.0	Robots	Big data	3D printing	Machine learning	Artificial intelligence	Internet of Things
Manufacturing & utilities	0.455*** (0.214)	1.943*** (0.250)	-0.870*** (0.267)	1.954*** (0.288)	0.558 (1.009)	0.508 (0.372)	-0.315 (0.339)
Construction	-0.018 (0.763)	-0.296 (1.397)	0.070 (0.810)	2.287 (2.129)	2.451 (3.084)	-0.196 (1.379)	0.712 (1.078)
Wholesale & retail	1.111*** (0.341)	2.147*** (0.711)	0.992*** (0.353)	1.983 (1.276)	-1.159 (1.175)	0.994* (0.563)	-0.561 (0.487)
Transport & storage	1.371* (0.768)	2.630*** (1.297)	1.292 (0.800)	-2.452 (2.838)	4.891* (2.466)	-0.167 (1.367)	1.101 (1.130)
Accommodation & food	0.161 (0.393)	-0.682*** (0.208)	0.222 (0.324)	1.586 (1.603)	3.957 (2.525)	0.401 (0.730)	1.713*** (0.586)
Information & communication	0.748 (0.458)	0.174 (1.740)	0.878* (0.461)	-2.191 (3.547)	-0.044 (1.436)	1.050 (0.747)	-0.211 (1.782)
Professional & scientific	-0.319 (0.953)	-5.649* (3.120)	-0.992 (0.976)	0.829 (1.799)	1.003 (3.691)	1.839* (1.079)	2.254** (1.051)
Administrative & real estate	-0.347 (0.550)	-1.45s4 (1.246)	-0.302 (0.568)	2.023 (2.085)	2.503 (2.329)	0.729 (0.879)	0.225 (0.808)

Notes: The export performance regressions are OLS models for each industry and include a (log) of sales in international markets per employee as the dependent variable and Industry 4.0 technology adoption, size, and other firm-specific characteristics as the main explanatory factors. The dummy variable "I4.0" equals 1 if a firm adopts any of the six Industry 4.0 technologies under scrutiny. Each regression includes year-fixed effects. Robust standard errors in parentheses. Significance levels: *, 10%; **, 5%; ***, 1%.

Source: Barbosa (2023).

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causality and, hence, the results could be overestimated. But we should also recognize that it is hard to find appropriate exogenous instruments for the adoption of both Industry 4.0 technologies overall and for each specific technology, varying across firms, sectors, and years. Nonetheless, aside from that limitation, our findings reveal important relationships that warrant further academic and public debate.

Concluding Remarks and Policy Implications

The findings reveal fresh evidence on the main factors prompting firms to adopt AI and AI-related technologies, enabling Industry 4.0, and on the size of the impact on export performance of adopting firms relative to non-adopting firms. While correlation does not imply causality, the strong associations offer important insights to the ongoing debate about the effects of digitalization on business performance and, in particular, international engagement, and highlight key areas for policy intervention.

Bridging the Digital Divide

There is clear evidence of positive selection toward large (ex-ante better-performing) firms in AI adoption, suggesting

a lack of inclusiveness in the adoption process. This concentration of adoption in large firms could exacerbate firm and industry heterogeneity, strengthening existing trends in industry concentration and weakening any potential catch-up process.

Policymakers need to design and implement a broad policy mix that more intensively affects incentives and digital capabilities across a wider range of firms, specifically small and medium-sized enterprises (SMEs). Measures that facilitate easier access to and greater awareness of these advanced technologies, improving cooperation in the adoption and diffusion process, are crucial to reducing the perceived risk and fixed costs that currently constrain smaller firms.

Fostering a Robust Digital Ecosystem

The availability of complementary resources, such as ultra-fast broadband and in-house ICT skills, is a significant driver of adoption and performance gains, strengthening a firm's position in international markets vis-à-vis competitors. Moreover, it is often necessary to adopt a combination of complementary and diverse digital technologies, rather than a single solution in isolation, to leverage significant eco-

nomic and export gains. Public investment and incentives should target the development of both digital infrastructure and specific skill-training programs to ensure firms can effectively deploy new technologies and to encourage integrated approaches to digitalization through support programs that promote the complementarities between different digital technologies.

Sector-Specific Support

The findings also highlight that firms across industries benefit differently from AI and AI-related digital technologies. Given this heterogeneity, policy interventions should be tailored to industry-specific needs to maximize effectiveness and ensure a meaningful impact across the diverse industrial landscapes of both Portugal and other European economies. The Portuguese context provides scalable insights that can enhance policy effectiveness across the European economies. •

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Policy Debate of the Hour

AI and Trade

Why Europe Cannot Afford to Lag on Adoption^{*}

Key Messages

- AI boosts productivity, but gains depend on how fast countries adopt it into their core activities
- Most EU economies are trailing behind AI adoption leaders, with the risk of compounding growth divergence over time
- AI is a global trade shock: foreign productivity gains lower import prices but sharpen competition for EU producers
- Foreign AI gains bring cheaper imports but erode competitiveness; Europe cannot free-ride its way to growth
- Openness and domestic adoption are complements; Europe needs both to fully capture AI's growth potential



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Artificial intelligence (AI), and generative AI in particular, is poised to transform productivity across a broad range of activities, with the strongest effects concentrated in knowledge-intensive services such as finance, professional services, and ICT. Its economic impact will nevertheless depend on how quickly countries adopt and integrate it into their economies. Evidence points to substantial cross-country differences in adoption, particularly within Europe. Yet AI is not only a domestic transformation; it is also a productivity shock transmitted through international trade. Productivity gains abroad lower import prices and reshape competitiveness across countries and sectors. Our analysis shows that these forces interact: countries can benefit from foreign AI progress through cheaper imports, but without sufficient domestic adoption, they risk losing competitiveness in AI-exposed sectors. The global diffusion of AI therefore makes domestic adoption capacity and openness to trade complementary determinants of future growth.

^{*} This article builds on the methodology and results presented in Filippucci, Gal, Laengle, Schief and Yildirim (2026) and introduces a Europe-focused analysis through additional model simulations. I am indebted to Francesco Filippucci, Peter Gal, Katharina Laengle, and Matthias Schief for their valuable comments.

Artificial Intelligence in an Interconnected World

AI is projected to transform economic growth by raising productivity across a broad range of activities, from professional services and finance to retail and public administration (Aghion and Bunel 2024; Acemoğlu 2025; Filippucci, Gal and Schief 2024). Much of the current policy debate focuses on how countries can foster AI innovation, invest in computing infrastructure, or accelerate domestic adoption. Yet this perspective overlooks a central feature of modern economies: production and consumption are deeply embedded in global trade networks (Baqaee and Farhi 2024; Çakmaklı, Demiralp, Kalemli-Özcan, Yeşiltaş and Yıldırım, in press).

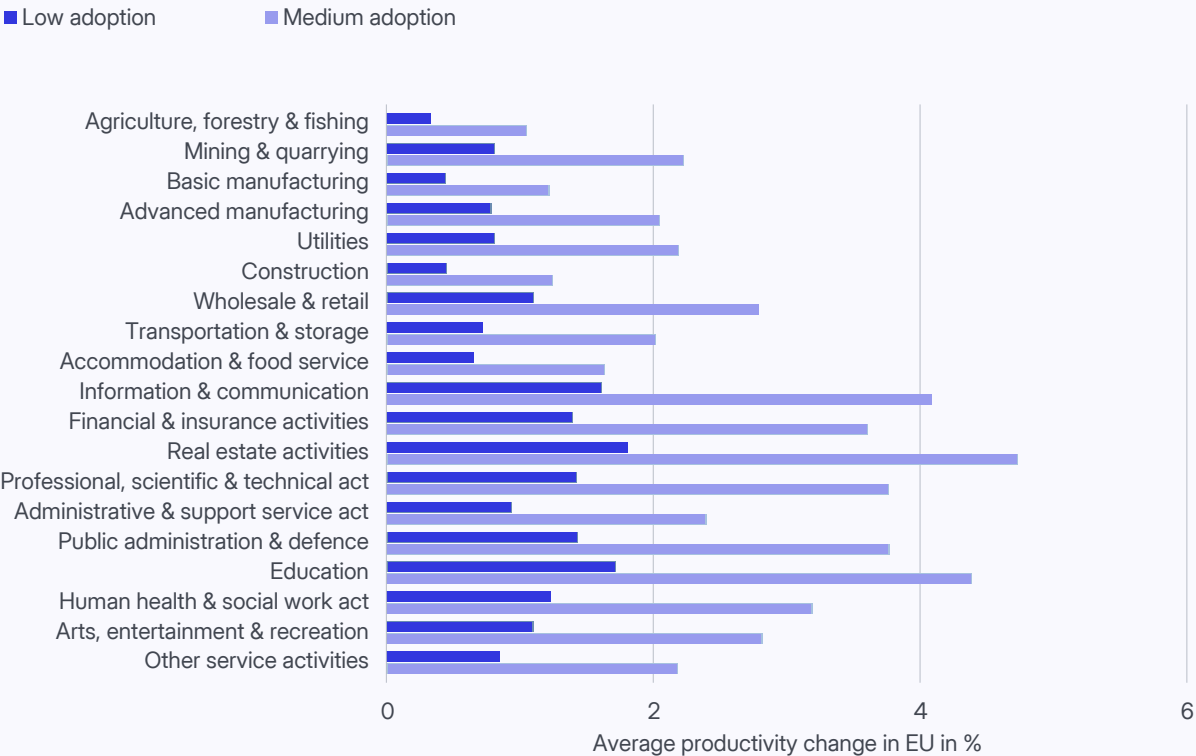
In an integrated world economy, productivity gains generated by AI in one country alter relative prices, reshape patterns of specialization, and affect competitiveness across global markets. Consumers and producers benefit from cheaper imported goods and services made possible by AI-driven productivity gains abroad. But countries may also face stronger competition from trading partners that adopt the technology more rapidly.

These international linkages are particularly relevant for Europe. While European economies are highly open and deeply integrated into global value chains, Filippucci et al. (2026) document that progress in adopting AI across firms and sectors remains uneven compared with leading adopters. Building on their theoretical framework and empirical results, this article focuses on how these gains are distributed across European economies.

Adoption, Sectoral Exposure, and Uneven Gains from AI

The economic effects of AI depend on how micro-level productivity improvements translate into economy-wide outcomes. Generative AI primarily enhances tasks involving prediction, information processing, and routine cognitive work, allowing firms to automate certain functions while augmenting others. Drawing on experimental evidence that finds productivity gains for AI-exposed tasks of between 14 percent and 55 percent (Brynjolfsson, Li and Raymond 2025; Gambacorta, Qiu, Shan and Rees 2024), we estimate country-sector productivity gains by combining these micro-level estimates with sector-level measures of task

Figure 1
Aggregate AI-Driven Productivity Gains Across Industries in EU Countries over the Next Ten Years^a



^a The low adoption scenario assumes an S-curve following the diffusion of electricity, whereas the medium adoption scenario follows the diffusion of the internet and PCs. See source for scenario details.
Source: Filippucci et al. (2026). © ifo Institute

exposure and country-level adoption rates. These gains vary widely across occupations and industries depending on task composition (Filippucci et al. 2024), producing sector-specific efficiency gains rather than a uniform productivity shock. We then feed these country-sector productivity gains into a general equilibrium trade model to assess their distribution across economies, as described in Filippucci et al. (2026).

Experience with earlier general-purpose technologies shows that productivity gains emerge gradually and unevenly, reflecting differences in adoption and industrial structure (Brynjolfsson, Rock and Syverson 2021). Adoption levels differ substantially across economies due to variations in digital infrastructure, skills, and firms' ability to reorganize production. Because diffusion typically follows an S-shaped pattern, even modest initial differences can turn into wide gaps in adoption at later stages of the adoption process (Comin and Mestieri 2018). To capture this uncertainty, we consider three adoption scenarios calibrated to the historical diffusion of electricity (slow), computers and the internet (medium), and mobile phones (fast), with the slow and medium scenarios forming the basis of the results presented here.

Sectoral composition further shapes exposure to generative AI. Productivity gains are concentrated in activities relying heavily on cognitive and information-processing tasks (Filippucci et al. 2024). As Figure 1 shows, information and communication, financial and insurance activities, and professional and scientific services are projected to see the largest gains, while agriculture, construction, and accommodation and food services experience more modest improvements. Countries where high-exposure sectors represent a larger share of value added are therefore more strongly affected by AI-driven productivity improvements. Using a first-order approximation, projected increases in annual productivity growth range from modest gains in some economies to close to one percentage point in others (Filippucci, Gal, Laengle and Schief 2025), depending on industrial composition and the pace of adoption.

These sectoral differences feed into country level adoption differences as well. Economies such as Luxembourg, Sweden, Belgium, and Ireland combine strong exposure to knowledge-intensive activities with advanced digital ecosystems, positioning them to benefit disproportionately from faster adoption. These economies are projected to see productivity gains approaching or exceeding the world average across all adoption scenarios. By contrast, economies such as Cyprus, Bulgaria, Romania, and Croatia are projected to fall below the world average. The gap between low and medium adoption scenarios is itself un-

even: countries already well-positioned to adopt AI stand to gain most from faster diffusion, while laggards see smaller differences between scenarios, suggesting that adoption dynamics risk compounding existing differences rather than narrowing them.

Differences in adoption capacity, industrial composition, and firm-level readiness suggest that AI will generate uneven growth paths across countries. Understanding this mechanism is essential before considering how international trade propagates these sectoral productivity shocks globally.

AI as a Trade Shock: How Global Linkages Shape the Distribution of Gains

Because countries are linked through trade in goods, services, and intermediate inputs, productivity improvements generated by AI in one economy alter prices and competitiveness far beyond its borders (Baqae and Farhi 2024). Two distinct channels shape how these effects are distributed.

A first transmission channel operates through imports. Productivity gains lower production costs and reduce the price of traded goods and services, allowing importing countries to benefit from cheaper intermediate inputs and consumption goods. For many European economies that are deeply embedded in global value chains, this channel provides gains even when domestic adoption progresses more slowly.

A second channel works through global competitiveness. As adoption accelerates in leading economies, firms that adopt AI gain cost advantages in international markets. Countries specialized in knowledge-intensive services and advanced manufacturing therefore face shifting market shares depending on their relative pace of adoption. Moreover, countries whose dominant sectors are more easily substitutable, such as base metal or fossil fuel industries, may need to adjust prices downward to remain competitive.

Crucially, these channels operate differently. The import channel is largely passive: countries benefit automatically from cheaper goods and inputs as trading partners adopt AI, regardless of their own adoption pace. The competitiveness channel is conditional: gains accrue only to countries that match or exceed their trading partners' or competitors' adoption pace in AI-exposed sectors. This asymmetry means that the net effect of trade on any given country depends critically on where it sits in the global adoption distribution, and underscores why domestic adoption cannot be treated as optional.

Europe’s Economic Position in the AI-Transforming Global Economy

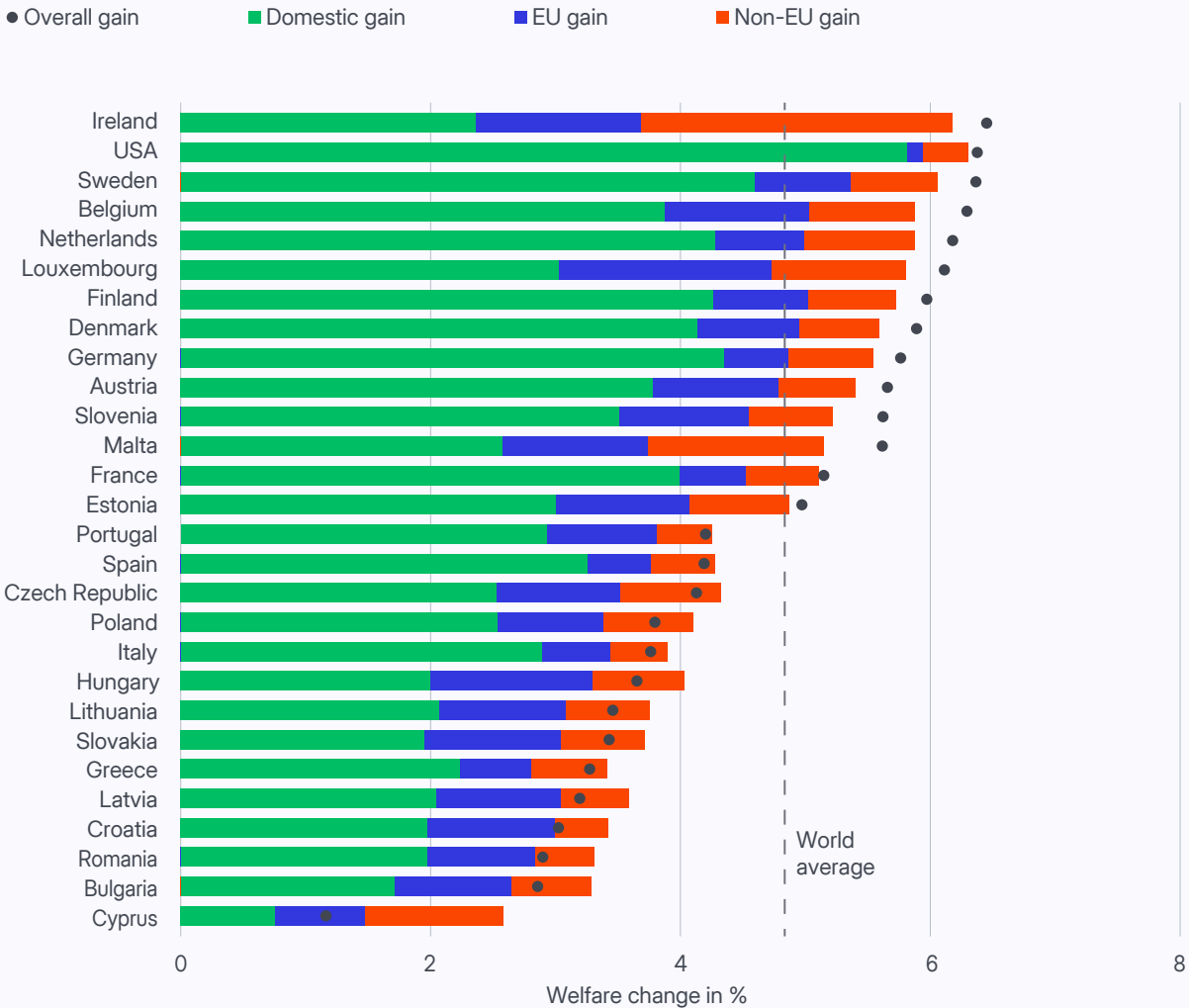
Europe’s position in the emerging AI economy reflects the interaction between adoption capacity, sectoral specialization, and trade integration; the risks and opportunities these create are not evenly shared.

Several European economies combine advanced digital ecosystems with large knowledge-intensive service sectors highly exposed to AI. Where adoption progresses successfully, these characteristics can support significant

productivity gains and reinforce competitive advantages in globally traded services. However, the same exposure increases sensitivity to technological leadership elsewhere. If adoption proceeds more slowly than in frontier economies, productivity improvements abroad may erode competitiveness in precisely the knowledge-intensive sectors that have driven European growth in recent decades, namely finance, professional services, and advanced manufacturing.

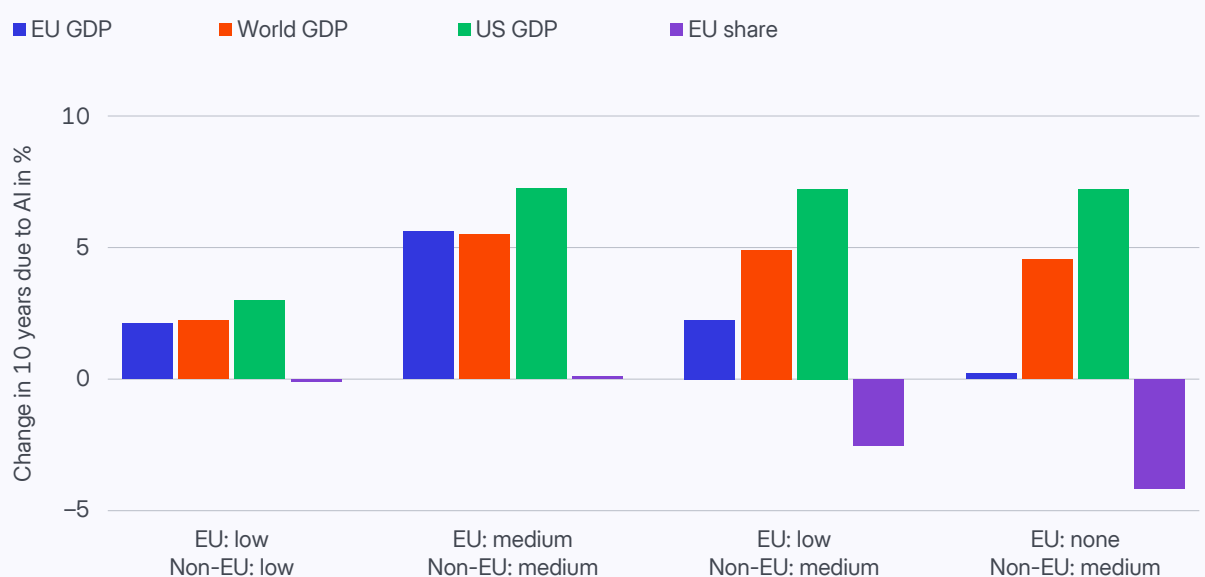
To understand how AI-driven productivity gains propagate across borders, we rely on a general equilibrium model of world trade (Baqae and Farhi 2024; Çakmaklı et al., in press).

Figure 2
Expected Welfare Gains in Ten Years for EU Countries and the US in the Medium Adoption Scenario^a



^a Welfare gains for the medium adoption scenario are computed as equivalent variation in a general equilibrium trade model that incorporates AI-driven productivity gains at the country-sector level, following Filippucci et al. (2026). Values for the USA are included for comparison. Overall gains are decomposed into domestic gains, gains from other EU countries, gains from the rest of the world, and a competition (allocation) effect. The overall gain is the sum of these four components; the competition effect can be positive or negative depending on whether a country’s adoption pace exceeds or falls short of the world average and is not shown separately in the figure. The details of the decomposition can be found in Filippucci et al. (2026).
Source: Filippucci et al. (2026) and own calculations.

Figure 3

Quantifying the Effects of Differential Adoption of AI in the EU After Ten Years^a

Source: Authors' calculations.

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Figure 2 shows that once international trade exposure is taken into account, welfare gains differ markedly across EU economies. Countries more strongly integrated into global production networks benefit more from foreign productivity improvements, even when domestic adoption progresses more gradually, but this channel cannot fully offset differences in adoption and sectoral exposure. Ireland leads the EU, surpassing even the United States, reflecting its highly open economy and concentration in knowledge-intensive services. Sweden, Belgium, the Netherlands, and Luxembourg also capture above-average gains. By contrast, several Eastern European economies, including Cyprus, Bulgaria, Romania, and Croatia, remain below the world average even under medium adoption, suggesting that trade integration alone cannot offset weaker sectoral exposure and lower adoption readiness.

We decompose welfare gains into three components: gains from domestic adoption, gains from foreign adoption, and an allocation (competitiveness) effect. The gains from foreign adoption can be further divided into gains from other EU countries and gains from the rest of the world. This decomposition is exact for certain global value chain structures and accounts for network effects. For example, a productivity improvement in the German steel industry lowers input costs for the Slovak car industry, whose output can in turn be purchased by German consumers – in this case, the downstream benefits are attributed to Germany's

domestic adoption. The allocation effect arises from the more realistic economic structure of the model and reflects competitiveness: for countries adopting below the world average, this effect is negative. Foreign adoption gains vary markedly across countries, reflecting differences in trade openness and the extent to which trading partners are themselves adopting AI. For Ireland, foreign adoption gains are almost as large as domestic gains, reflecting its highly open economy, and Ireland has more exposure to non-EU gains. For France, by contrast, the foreign component is small, consistent with its larger and more self-sufficient economic structure.

Can Europe rely on foreign AI gains? It is worth noting that Europe's relatively slower adoption partly reflects deliberate policy choices around safety, privacy, and regulatory frameworks rather than passive inaction. The EU AI Act represents a significant investment in AI governance from which other economies may themselves benefit, and there are legitimate reasons to prioritize getting the regulatory environment right before scaling adoption rapidly. However, our analysis raises the question of whether these regulatory benefits offset the economic costs of slower diffusion. Figure 3 compares outcomes across four scenarios, ranging from symmetric adoption, where the EU and its trading partners adopt at the same pace, to a counterfactual in which AI diffusion accelerates abroad while European adoption remains limited. When the EU maintains an adoption

pace comparable to its trading partners, its global income share remains broadly stable. However, when the EU lags, its global income share falls by an estimated 2.5 percent to 4.1 percent – a striking result that underscores the stakes involved. The cost of slower adoption therefore rises not only in absolute terms but relative to a global economy that continues to grow with or without European participation.

These results confirm that foreign productivity gains generate positive spillovers through trade, but these benefits are insufficient to offset competitiveness losses from slow domestic diffusion. Europe's future competitiveness will depend less on frontier innovation abroad than on its ability to translate AI into widespread adoption within an open economic system.

Policy Implications: Supporting Adoption in an Open Economy

Our analysis suggests that the economic impact of AI will depend less on frontier innovation alone than on how effectively countries integrate it into existing economic structures while remaining open to global markets. For Europe, this creates a genuine trade-off. The EU's emphasis on safety, privacy, and regulatory governance reflects legitimate priorities, and the AI Act may generate benefits for trading partners that adopt Europe's standards. But slower adoption carries measurable costs: a lag in diffusion relative to trading partners could reduce Europe's global income share by 2.5 percent to 4.1 percent. The policy challenge is therefore not whether to regulate AI, but how to pursue robust governance without sacrificing the pace of adoption needed to remain competitive.

Three Priorities Follow

First, EU-level coordination is essential. The heterogeneity documented in Figures 1 and 2 is striking: slower-adopting economies face structural constraints in infrastructure, skills, and firm readiness that national policy alone cannot address in time. Common EU investments in digital infrastructure, coordinated skills frameworks, and knowledge-sharing mechanisms across member states could help narrow the gap before differences compound. Given that AI benefits diffuse through trade networks spanning the entire single market, the returns from coordinated action are likely to exceed those of national strategies alone.

Second, maintaining open trade and digital integration remains critical. Openness provides meaningful gains even for slower adopters, but these are maximized when combined with domestic capability building. Openness and adoption are complements, not substitutes.

Third, policies should account for sectoral exposure. Economies specializing in knowledge-intensive services face both faster potential gains and stronger competitive pressures. Supporting diffusion across sectors and regions can ensure productivity improvements translate into broad-based growth. Better measurement of AI adoption at the firm and sector level would help governments track diffusion and evaluate policy effectiveness – an area where current data remains limited.

Artificial intelligence is reshaping the global economy through technological innovation, international trade, and sectoral specialization simultaneously. Openness ensures access to global progress, but sustained competitiveness requires domestic diffusion. Europe's challenge is to pursue both – building the adoption capacity needed to participate fully in AI's productivity gains while maintaining the open economic system that amplifies them. •

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Policy Debate of the Hour

Firms' AI Productivity Beliefs and Adoption Decisions

Key Messages

- On average, German firms expect about 7 percent productivity gains from AI for their own business by 2029
- Expected gains are especially high in industries dominated by tasks like programming, writing, and customer service
- Firms are more optimistic about macroeconomic productivity effects than their own gains, which may hint at “bubble-like” expectations
- There is high uncertainty about these productivity gains and about the extent to which competitors are using AI
- New information about AI's productivity potential and competitors' use of AI makes firms more optimistic and more likely to adopt AI



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European economies have been marked by sluggish growth and weak productivity in recent years. Artificial intelligence (AI) is widely seen as a key driver of future productivity gains, yet predictions about its economic impact remain highly uncertain. Moreover, whether AI delivers on its promise depends crucially on whether firms actually adopt the technology.

This article analyzes firms' productivity beliefs about AI by directly eliciting the expectations of top decision-makers in a large, representative firm survey. On average, firms in Germany expect 7 percent productivity growth from AI for their own business over the next five years. However, firms are highly uncertain about these gains, and their expectations are significantly influenced by new information about AI's productivity potential and about competitors' adoption behavior. These findings imply that managers are imperfectly informed about the benefits of AI, and that targeted

information provision could help leverage AI's productivity potential. For a detailed analysis, see Menkhoff (2026).

Data: The ifo Business Survey

To answer how many firms use AI and what managers expect from it, this analysis draws on the ifo Business Survey, a long-running monthly panel of more than 4,000 German firms. The survey is well-established and widely known to the public through the ifo Business Climate Index, one of the most closely watched economic indicators in Europe. The survey covers manufacturing, services, and retail/wholesale, spans a wide range of firm sizes, and is designed to be representative of the German economy.

A key feature of the survey is that it is typically answered by actual decision-makers within the firm, such as CEOs, managing directors, or firm owners. The median firm in the sample has 36 employees and annual revenues of EUR 7 million.

Since 2023, the ifo Business Survey has regularly polled firms about their status of new technology adoption, including AI and cloud computing. In the June 2024 wave, an additional module elicited firms' beliefs about the productivity potential of AI – both for their own business and for the macroeconomy – over a five-year horizon. Firms reported expected productivity gains as a range ("increase in productivity between X % and Y %"), which allows both the level of productivity expectations (the midpoint) and the associated uncertainty (the width of the range) to be measured.

AI Adoption Is Accelerating

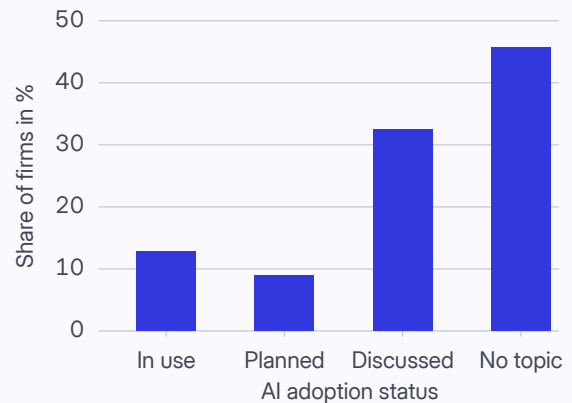
AI adoption among German firms has been remarkably dynamic, as visible in Figure 1. In June 2023, only 13 percent of firms reported using AI, while 46 percent had not even considered it. By June 2024, the adoption rate had nearly doubled to 24 percent, while the share of firms not considering AI at all had fallen to 27 percent. By May 2025, more than one-third of firms reported using AI. This rapid trajectory suggests that AI is transitioning from an emerging technology to a general-purpose technology (see Licht and Wohlrabe 2024 for more detailed summary statistics on firms' adoption of AI).

Notably, cloud computing appears to serve as an enabling technology for AI: firms that already use cloud computing are 25 percentage points more likely to also adopt AI. This pattern is consistent with the idea that existing digital infrastructure lowers the barriers to integrating AI into business processes (see McElheran, Li, Brynjolfsson, Kroff, Dinlersoz, Foster and Zolas 2024).

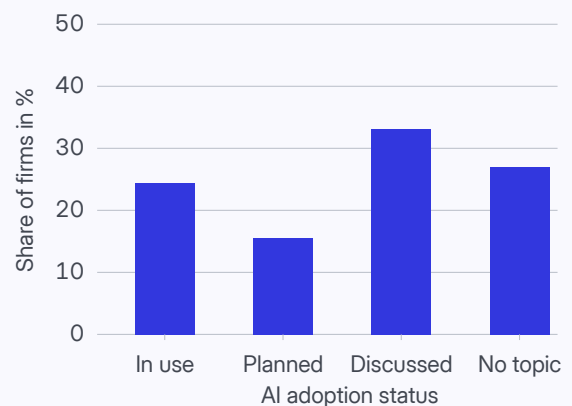
Figure 1

Firms' AI Adoption Status

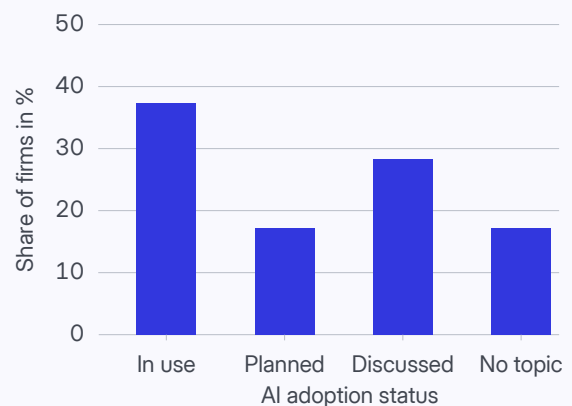
A. AI Adoption in June 2023



B. AI Adoption in June 2024



C. AI Adoption in May 2025



Source: ifo Business Survey.

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What Do Firms Expect from AI? Productivity Beliefs for the Own Business

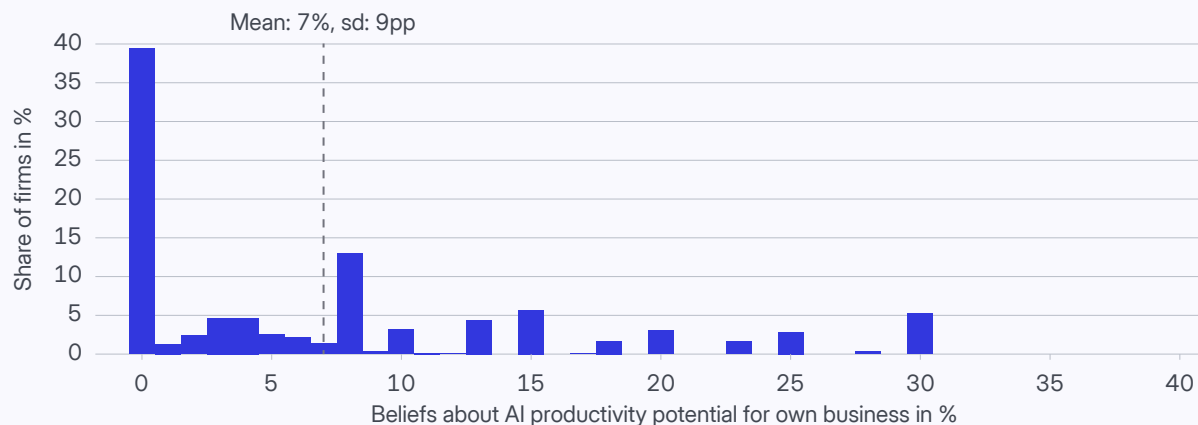
On average, firms in the survey expect about 7 percent productivity gains for their own business from AI over the next five years (see Figure 2, Panel A). However, this average masks large heterogeneity. The standard deviation of productivity expectations is 9 percentage points, and close to 40 percent of firms expect no productivity benefits from AI at all. At the other end of the distribution, some firms anticipate gains of 20 percent or more.

These expectations are not random: they are systematically related to how relevant AI is for the firm's industry. Firms in industries where AI-exposed occupations – such as software developers (ISCO 251), authors and journalists (ISCO 264), and customer service clerks (ISCO 422) – are particularly overrepresented expect productivity gains of 10 percent or more. Firms in industries with low exposure to these tasks expect only around 5 percent. This pattern holds even after accounting for whether a firm has already adopted AI, which suggests that managers' productivity beliefs reflect meaningful, task-based assessments of AI's relevance.

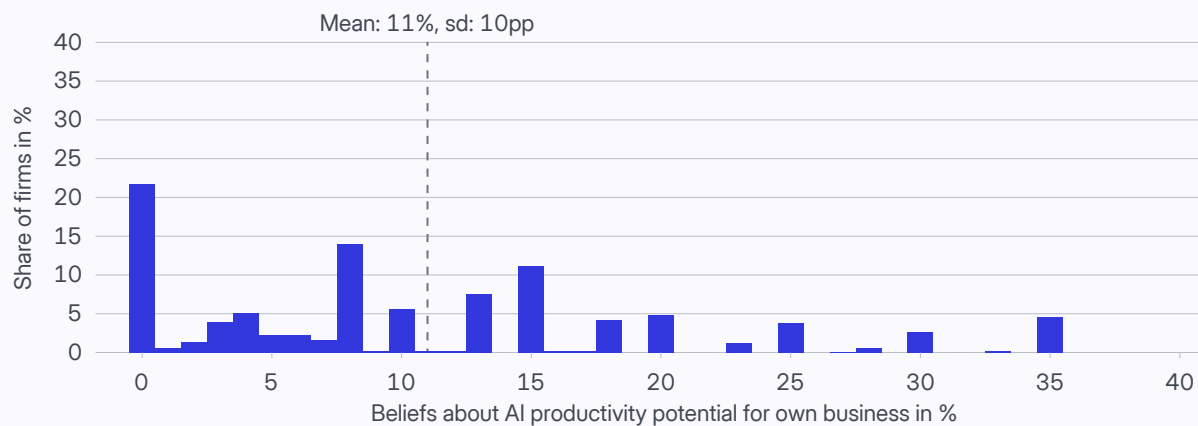
Figure 2

Firms' AI Productivity Beliefs, June 2024

A. Own business



B. Macroeconomy



Macroeconomic Productivity Beliefs

Interestingly, firms' expectations for the macroeconomy are systematically higher than for their own business: the average expected macroeconomic productivity gain from AI is 11 percent (Figure 2, Panel B), compared to 7 percent for the own firm. This gap is consistent with firms following broad macro narratives about AI while being more conservative when assessing their own ability to realize productivity gains.

The finding that macroeconomic expectations significantly exceed own-firm expectations could be a sign of "bubble-like" optimism: firms believe AI will transform the economy at large, even if many are unsure it will transform their own business. This gap warrants monitoring, since unmet expectations for aggregate productivity could eventually lead firms to revise sentiment downward.

High Uncertainty About AI's Impact

Firms report a high degree of uncertainty about AI's productivity effects. When reporting their expected productivity gains, firms provide a range with a lower and an upper bound. The average width of this range is 8.4 percentage points for the own business and 10.4 percentage points for the macroeconomy. These are economically large spans: a firm reporting expected gains of, say, between 1 percent and 10 percent, is effectively acknowledging that AI could be a minor or a major productivity driver for its business.

This uncertainty is not limited to productivity. Firms also express high uncertainty about competitors' adoption of AI. When asked about the share of firms in their industry that already use or plan to use AI, the interquartile range of responses spans from 10 percent to 35 percent, and the most commonly reported uncertainty ranges are 10 to 20 percentage points wide.

Information Matters: What Shifts Firms' Beliefs and Behavior?

Another finding of Menkhoff (2026) is that firms' beliefs about AI, and ultimately their adoption decisions, respond significantly to new, credible information. When presented with evidence on documented AI productivity gains from well-known scientific studies, such as time savings of 56 percent in programming (Peng, Kalliamvakou, Cihon and Demirer 2023), 40 percent in writing (Noy and Zhang 2023), 14 percent in customer service (Brynjolfsson, Li and Raymond 2025), or on the share of firms in their industry that already use or plan to use AI, firms revise their AI productivity expectations upward. The effects are strongest among firms that have not yet adopted AI.

Crucially, these belief shifts translate into actual behavior. Among firms where the survey respondent has high decision-making authority, exposure to such information is linked to an 8 percentage point higher probability of AI adoption one year later – roughly a 40 percent increase relative to the baseline rate. The effect is concentrated in industries with high AI exposure and among firms that finance investment with internal funds.

Policy Implications

AI adoption is accelerating, yet it remains highly uneven across firms, and firms report wide uncertainty about both productivity effects and competitors' use. Policy should therefore focus on strengthening basic digital readiness, especially among SMEs, so diffusion and potential gains do not concentrate in already advanced firms.

Firms expect substantially larger productivity gains for the overall economy than for their own business, and many anticipate no firm-level gains at all. Policymakers should regularly track this gap between aggregate optimism and firm-level expectations, since a persistent divergence could increase the risk of a later setback in confidence if broad productivity gains do not materialize.

Beliefs about AI's productivity potential vary widely, consistent with incomplete knowledge of the areas in which AI pays off in practice. Policymakers can support efficient adoption by providing neutral, evidence-based summaries and sector benchmarks via trusted intermediaries (e.g., chambers, industry associations, official statistics), framed as practical decision support for firms. •

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Policy Debate of the Hour

The Effects of AI on Economic Growth and Employment

Results from the Economic Experts Survey

Key Messages

- AI is expected to significantly accelerate economic growth over the next decade
- Expert expectations exceed most current estimates in the academic literature
- A majority of experts support tighter AI regulation – Germany is the notable exception
- AI will likely intensify labor market polarization, with medium-skilled workers most at risk
- Policy must balance innovation, regulation, and workforce adaptation to fully realize AI's benefits



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Artificial intelligence (AI) is a general-purpose technology with the potential to fundamentally transform economic growth and labor markets over the coming decade. However, uncertainty remains regarding the magnitude, timing, and distribution of its effects. Empirical evidence remains

limited and highly context-specific. Expert assessments therefore provide critical guidance for policymakers and business leaders. To collect the views of economic experts on the potential economic effects of AI, we asked economists in Europe and the United States about their

expectations regarding the effects of AI in the fourth wave of the Economic Experts Survey (EES) in 2025.¹

Does AI Serve as a Driver of Economic Growth?

AI influences economic growth and employment in several ways. In principle, AI holds the potential to substantially raise productivity, with productivity effects of AI potentially being either labor-augmenting or labor-saving.

Several microeconomic studies have examined the productivity effects of AI in very specific settings, including call centers (Brynjolfsson, Li and Raymond 2025a), taxi services (Kanazawa, Kawaguchi, Shigeoka and Watanabe 2025), professional writing (Noy and Zhang 2023), consulting (Haslberger, Gingrich and Bhatia 2023; Dell'Acqua, McFowland III, Mollick, Lifshitz-Assaf, Kellogg, Rajendran, Krayer, Candelon and Lakhani 2023), and software programming/development (Peng, Kalliamvakou, Cihon and Demirel 2023; Cui, Demirel, Jaffe, Musolff, Peng and Salz 2024; Gambacorta, Qiu, Shan and Rees 2024). These studies generally report large productivity gains for workers. For instance, Brynjolfsson et al. (2025a) find that access to generative AI assistance increases worker productivity – measured by issues resolved per hour – by 15 percent on average, with substantial heterogeneity across workers. Less experienced and lower-skilled workers improve both the speed and quality of their output, while the most experienced and highest-skilled workers see small gains in speed and small declines in quality. Despite these findings, the overall evidence remains limited and highly context-specific.

However, it remains unclear to what extent these micro-level productivity gains and potential employment effects translate into aggregate macroeconomic outcomes such as economic growth and employment.² Acemoğlu (2025) was among the first to address this question, finding a relatively moderate aggregate effect for the United States, with an increase in total factor productivity (TFP) of around 0.71 percent over ten years – or a 0.07 percent increase in TFP growth annually – in his “optimistic” specification. Aghion and Bunel (2024) employ two approaches to measure how AI influences productivity. In the first, they

find that the AI revolution is likely to increase aggregate productivity growth by 0.8 to 1.3 percentage points per year over the next ten years. Using Acemoğlu's activity-based approach, but incorporating their own interpretation of the current empirical literature on the various components of the task-based formula, they arrive at a median estimate of 0.68 pp (0.07–1.24 pp) of additional annual total factor productivity (TFP) growth.

Subsequent studies have extended the Acemoğlu analysis to European countries (Misch, Park, Pizzinelli and Sher 2026) and broadened the methodological framework (Filippucci, Gal and Schief 2024; Filippucci, Gal, Laengle, Schief and Yildirim 2026). In their preferred scenario, based on what they think are the most plausible assumptions on AI occupational exposure and adoption rates in European countries, Misch et al. (2026) estimate that the Europe-wide effects are modest, at around 1.1 percent cumulatively over the medium term of five years. Nonetheless, this figure exceeds Acemoğlu's estimates for the United States by almost 60 percent. Their estimates of average productivity gains in 31 European countries range from 0.4 percent in Romania – followed by Bulgaria, Poland, Hungary, Lithuania, and Slovakia – to close to 1.5 percent in France, Sweden, and Germany, and nearly 2.3 percent in Norway. Broadly, higher-income countries tend to have larger gains due to higher aggregate AI exposure.

Filippucci et al. (2025) study the expected macroeconomic productivity gains from AI over a ten-year horizon. They develop a novel micro-to-macro framework that integrates existing estimates of micro-level performance gains with evidence on the exposure of activities to AI and projected future adoption rates, and, as the key novel feature of the model, explicitly incorporates cross-country input-output linkages, through which AI adoption in one country generates positive spillover effects on productivity in other countries. Their results suggest that annual aggregate total-factor productivity growth in the United States due to AI ranges between 0.25 pp under a low-adoption scenario and 0.6 pp under a high-adoption and expanded capabilities scenario.

Similar-sized annual total-factor productivity gains are found for Germany (0.25 and 0.6 pp), while in France and Italy, the gains would be about half of that (0.1 and 0.3 pp). For Germany, Zika, Hassemer, Hummel, Krebs, Maier, Mönnig, Schneemann, Weber and Zenk (2025) find that the adoption of AI could increase annual GDP growth by 0.8 pp. Survey-based evidence from Germany provides a complementary firm-level perspective. Kerkhof, Licht, Menkhoff and Wohlrabe (2024) draw on the Ifo Business Survey to elicit firms' own assessments of AI's

¹ This article examines economic experts' expectations about the effects of AI on economic growth and employment based on the fourth wave of the Economic Experts Survey (EES) in 2025. The EES is a global survey of economic experts (see Heil and Potrafke 2025 and Gründler, Heil, Potrafke and Wochner 2023 for a detailed description of the survey). The survey collected responses from around 600 economists across EU member states and around 100 economists based in the United States, providing a comprehensive overview of current expert assessments of AI-driven structural change in the global economy.

² A comprehensive overview of the literature on AI-driven productivity effects can be found, for example, in Filippucci, Gal and Schief (2024), who synthesize various estimates and methods in the field.

productivity potential. A large majority of German firms anticipate positive productivity effects: 70 and 84 percent of the sample expect a positive impact at the firm level and on the economy as a whole, respectively. Among those expecting positive effects, the estimated annual productivity increases on average around 1.6 percent at the firm level and 2.4 percent for the overall economy, considerably exceeding the model-based estimates discussed above, with considerable heterogeneity across sectors.

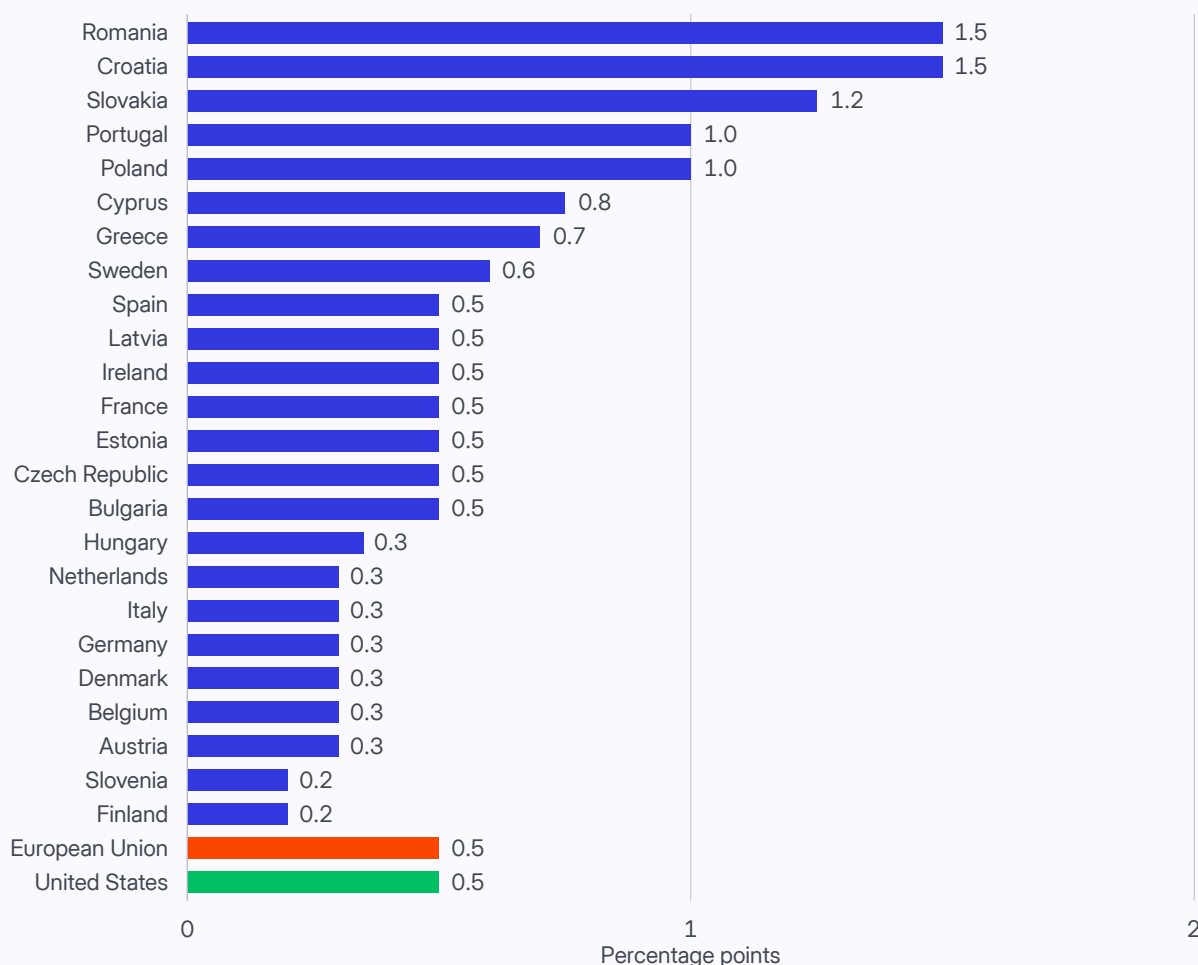
Yotzov et al. (2026) extend this firm-level perspective to an international comparison, surveying nearly 6,000 senior executives across the United States, United Kingdom, Germany, and Australia. While over 90 percent of firms across all four countries report no impact of AI on productivity over the past three years, forward-looking expectations are more

optimistic. German firms anticipate an annual productivity gain of around 0.29 percent over the next three years, markedly more modest than US (0.75 percent) and UK firms (0.62 percent) – a pattern the authors attribute in part to differences in labor market institutions.

So far, the literature has found limited growth effects from AI, but we may be approaching a turning point. As Brynjolfsson (2026), for example, noted in the *Financial Times* in February 2026, “the AI productivity take-off is finally visible.” Based on updated 2025 US data, the US economy appears to be transitioning out of the investment phase and into a harvest phase, where earlier efforts start to translate into measurable output. He projects that US productivity could increase by roughly 2.7 percent in 2025, nearly double the modest 1.4 percent annual average of the past decade.

Figure 1

Expected Effect of AI on the Annual Median GDP Growth Rate over the Next Ten Years – EU and US^a



^a The figure reports the expected effect of AI on annual economic growth over the next ten years, according to experts. The effect of AI on growth is calculated as the median responses in the respective countries. The sample consists of countries in the European Union and the United States.
Source: Economic Experts Survey Q4 2025.

How Is AI Transforming the Labor Market?

In principle, the macroeconomic impact of AI on employment could be labor-augmenting or labor-saving: AI can either complement human labor by enhancing productivity and expanding task capabilities, or substitute for it by automating tasks and, in some cases, entire occupations. For overall employment, the evidence in the literature is not yet entirely conclusive: while AI can increase workers' productivity – task-based studies document sizeable performance gains in specific activities with the largest gains observed among lower-skilled workers (see the above literature) – it also replaces workers, particularly entry-level ones (Brynjolfsson 2025b).

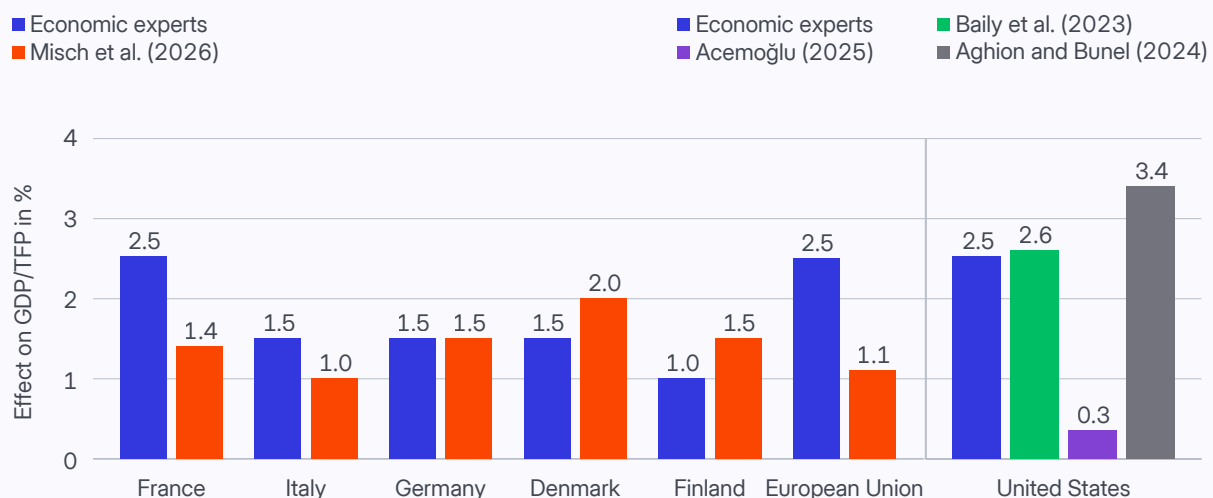
The pattern is clearer when considering skill levels: high-skilled and low-skilled workers tend to benefit, whereas middle-skilled workers are adversely affected. This pattern closely resembles the polarization dynamics observed during earlier waves of technological change (job polarization), such as computerization and robotization (Autor, Katz and Kearney 2006; Acemoğlu and Restrepo 2020). However, there is also growing evidence that, in contrast to software and robots, AI targets high-skilled tasks. Webb (2020) refers to AI as machine learning, supervised learning, and reinforcement learning algorithms. Under the assumption that historical patterns of long-run substitution will continue, he estimates that AI will reduce 90:10 wage inequality but will not affect the top 1 percent. Felten, Raj and Seamans

(2023) find the same pattern. They examine which occupations and professions are most affected by advances in generative AI language modelling and image generation, concluding that highly skilled, highly paid white-collar professions could be most affected by generative AI.

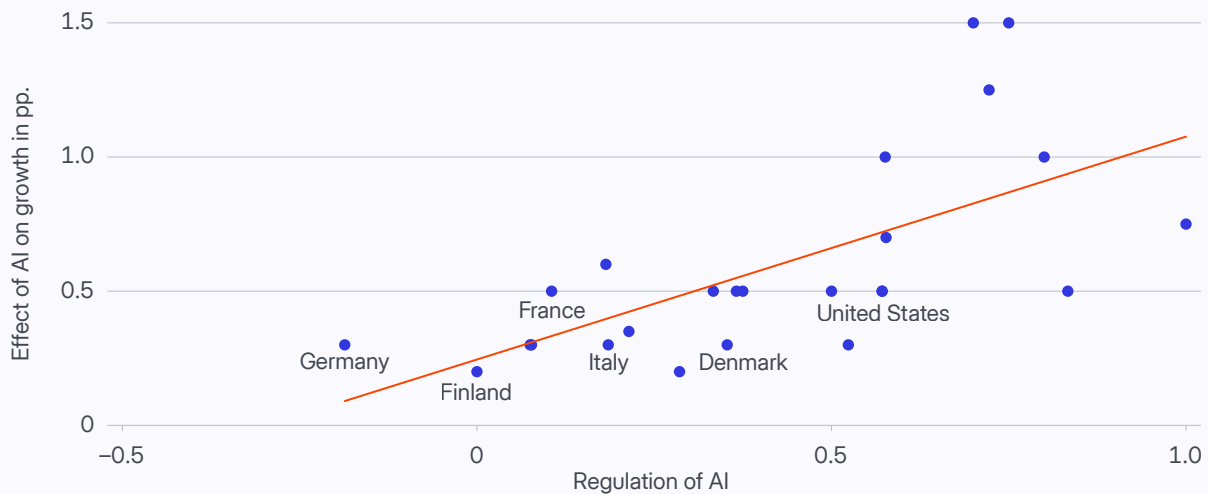
For Germany, a study from the Institute for Employment Research (IAB) points to significant structural changes in the labor market. While overall employment would remain broadly stable relative to the baseline development path, AI is projected to both eliminate and create approximately 1.6 million jobs over the next 15 years (Zika et al. 2025). AI primarily drives a structural transformation of the labor market. Future demand will focus on different tasks and skills, not less work. For example, AI is expected to increase labor demand in IT and information services while reducing it most sharply in business services. Changes are also anticipated in the skill requirements: demand for low-skilled workers is likely to remain stable, whereas the need for skilled workers is expected to decline relatively more sharply. For Germany, Wohlrabe (2025) draws on the ifo Business Survey to examine firm-level employment expectations. Around 27 percent of firms anticipate job losses over the next five years, against only 5 percent expecting gains, with particularly strong negative expectations in manufacturing (37 percent) and retail (30 percent). Yotzov et al. (2026) confirm the pattern of limited current effects in their cross-country comparison. Across the United States, United Kingdom, Germany, and Australia, over 90 percent

Figure 2

Expected Effects of AI on Economic Growth/TFP Growth over the Next Five Years^a



^a The figure reports the expected effects of AI on GDP and TFP over the next five years. Experts' estimates are based on GDP, while the estimates in the cited literature report effects on TFP. The estimates by Acemoğlu (2025) and Aghion and Bunel (2024) are rescaled to a 5-year effect.
Source: Acemoğlu (2025); Baily et al. (2023); Aghion and Bunel (2024); Misch et al. (2026); Economic Experts Survey Q4 2025.

Figure 3**The Relationship Between AI Effects on Growth and AI Regulation^a**

^a The figure plots the relationship between the experts' suggestions for future AI regulation and their expectations of the effect of AI on economic growth. AI regulation is calculated as the share of responses calling for more regulation minus the share of responses calling for less regulation in the respective countries. The effect of AI on economic growth is calculated as the median of experts' responses in the respective countries. The sample consists of countries in the European Union and the United States.
Source: Economic Experts Survey Q4 2025.

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of firms report no employment impact over the past three years. Looking ahead, German firms expect only a negligible employment reduction of 0.06 percent over the next three years – far below the expectations of US (–1.19 percent) and UK firms (–1.36 percent), a divergence the authors attribute in part to Germany's more regulated labor market.

The previous studies share a common feature: They make specific assumptions regarding the diffusion or exposure of AI. Plus, they are typically based on existing AI applications and extend current trends, reflecting a conservative perspective. In this paper, we present the results of a recent survey of experts on AI, focusing on their views concerning economic growth and employment. We compare these up-to-date expert opinions with projections from the economic literature to assess whether they reflect a more optimistic or pessimistic outlook. We also explore potential factors that may explain any divergences between current expert perspectives and prior research.

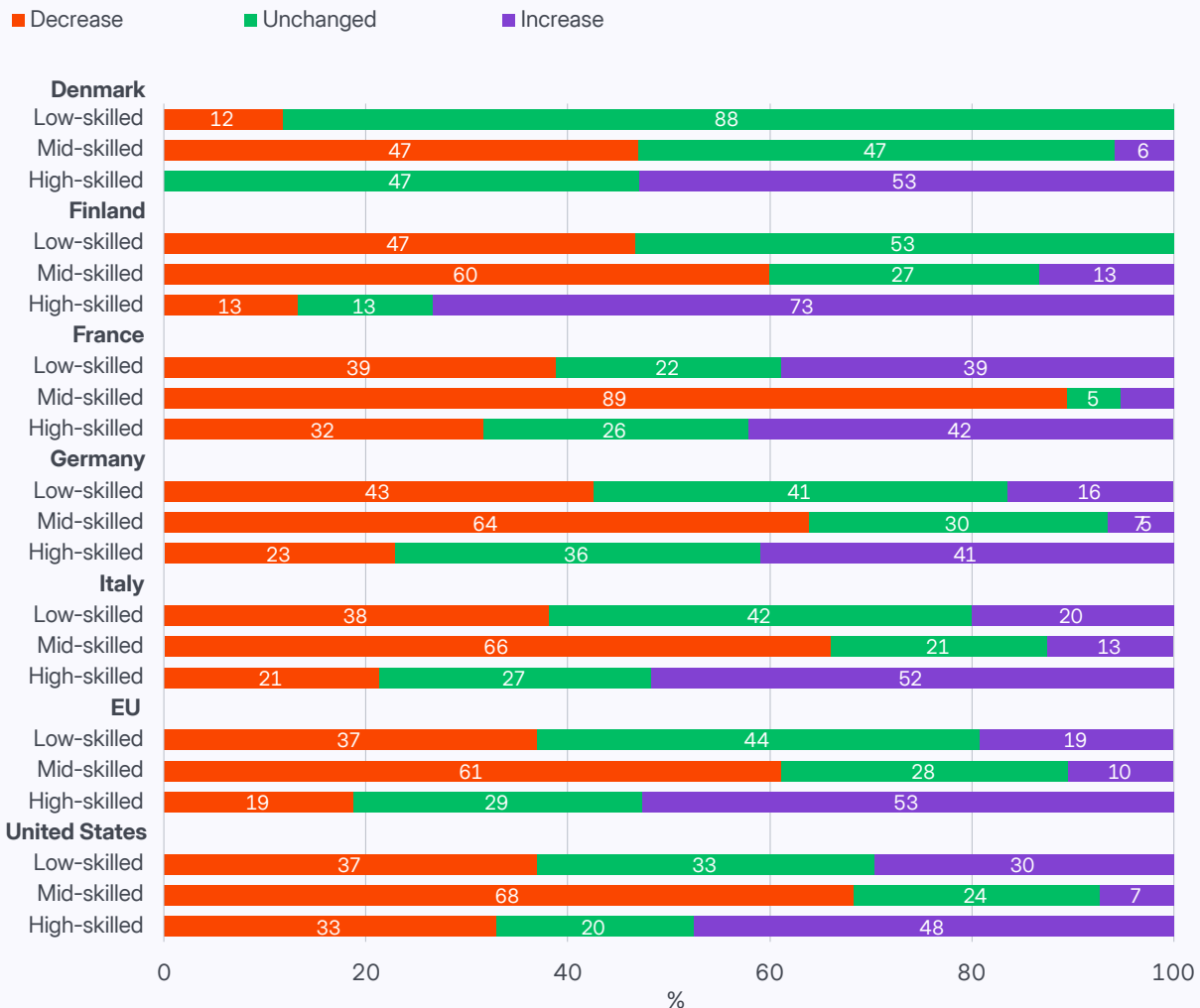
Survey Results: AI Effects on Economic Growth

In our questionnaire, we asked experts about the expected impact of AI on their own countries' annual GDP growth rates over the next ten years. Figure 1 shows the experts' responses regarding their assessment of how median annual GDP growth rates in their own countries will develop over the next ten years. The experts attribute a very high contribution to annual growth rates to AI, ranging from

0.2 pp per annum in Finland and Slovenia to 1.5 pp in Croatia and Romania. The European Union average and the estimate for the United States are on a par at 1.5 pp per annum.

Figure 2 compares experts' assessments of AI's effects on economic growth over the next five years with benchmark estimates for selected European economies and the United States. While the estimates in the literature refer to TFP growth, survey participants are asked for an assessment of economic growth. Under the assumption that AI adoption influences economic growth only through TFP growth, economic growth and TFP growth are directly comparable (in a simple growth accounting framework, output growth is the sum of TFP growth and the weighted growth rates of the factor inputs labor and capital). If the capital stock also increases due to AI, the GDP growth effects will be somewhat larger. With such investment effects incorporated, Acemoğlu (2025) estimates GDP growth of around 1.1 percent over the next ten years (as compared to 0.71 TFP growth). However, the evidence for an investment effect remains weak, as shown by Duso and Schiersch (2025) for cloud technology.

For France, Italy, and Germany, the experts anticipate growth effects that are similar to or exceed the projections by Misch et al. (2026). Experts' expectations in Denmark and Finland are, however, smaller than their calculations. Averaged across the EU, experts' expectations are sub-

Figure 4**Effect of AI on the Level of High-, Mid-, and Low-Skilled Employment over the Next Ten Years^a**

^a The figure plots the shares of experts in selected countries expecting employment to increase, decrease, or remain unchanged. Rounding differences.
Source: European Economic Survey Q4 2025.

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stantially higher, at 2.5 percent vs. 1.1 percent. This suggests that, in general, European experts are more optimistic about AI's potential impact than the estimates reported in the literature, although notable exceptions exist. For the United States, expectations (2.5 percent) align closely with the larger estimates in the literature (e.g., 2.6 percent in Baily, Brynjolfsson and Korinek 2023; 3.4 percent in Aghion and Bunel 2024) and are therefore significantly higher than more conservative projections (e.g., Acemoğlu 2025, 0.3 percent).

Experts were also asked whether current AI legislation in their country should be less, similarly, or more heavily regulated. Survey answers were aggregated at the country level and normalized to sum to 100 percent. The main find-

ing is clear: In all countries except Germany, a majority of experts call for more rather than less AI regulation in their country. In the United States, 64 percent of respondents favor more regulation, compared with only 7 percent advocating for less. Across the European Union, an average of 50 percent support stronger AI regulation, while just 19 percent favor deregulation. The countries with the lowest share of experts calling for more AI regulation are Germany (27 percent), Slovenia (29 percent), Belgium (31 percent), France (32 percent), Finland (36 percent), and Sweden (36 percent).

Germany exhibits the highest proportion of experts advocating for a reduction in AI regulation (46 percent), followed by Finland, Austria, Italy, and Belgium. Overall, in a compar-

ative perspective, Germany stands out as the only country where a larger share of experts favors less rather than more regulatory intervention in the AI domain. Moreover, Germany is one of the few major economies where experts perceive the potential effects of AI on global economic growth to be greater than on the domestic GDP. In the United States, for example, experts are more optimistic about the effects of AI on domestic growth than on global growth.

Figure 3 relates experts' views on the preferred direction of future AI regulation to their median expectations about AI's effect on economic growth. The horizontal axis reports a balance of regulation views, calculated as the share of respondents favoring more regulation minus the share favoring less regulation. Higher values therefore indicate a stronger net demand for tighter regulation. The positive relationship suggests that countries where experts anticipate larger growth gains from AI also tend to have experts who, on net, support more regulation going forward. This pattern suggests that while experts are very optimistic about the potential growth effects of AI, they also call for more cautious regulation in the future. One possible explanation for this pattern could be that experts are concerned that higher growth may come at the expense of negative externalities, ranging from ethical considerations to potentially undesirable labor market effects, which we examine next.

Survey Results: AI Effects on Employment

While the literature offers diverging perspectives on how AI influences employment – some of which emphasize significant displacement effects for high-skilled roles – the expert assessments gathered here largely align with the job polarization model. According to the experts' assessments, mid-skilled occupations are projected to experience the most significant contractions in employment due to AI (see Figure 4 for a selection of countries). Across the EU, an average of 61 percent of experts surveyed expect that AI will decrease employment for medium-skilled workers, while 28 percent anticipate no significant change. Consequently, only 10 percent foresee potential growth in this segment. Country-level assessments in Finland, Germany, and Italy broadly reflect this EU-wide trend in the medium-skilled segment. In France, experts project stronger negative employment effects of AI on mid-skilled employment. By contrast, Danish experts expect comparatively more mid-skilled jobs to remain unchanged. US experts assess the effects of AI on mid-skilled employment similarly to the average in the EU.

In the low-skilled employment segment, a majority of experts in each of the selected countries, as well as on average across the European Union, expect that employment levels will either increase or remain broadly unchanged as a result of AI adoption. In Denmark, only 12 percent

of experts anticipate a decline in low-skilled jobs, while in other countries, between 34 percent and up to 47 percent expect job losses in the low-skilled sector.

Finally, in the high-skilled segment, experts identify the greatest potential for AI-driven employment growth. Finland stands out most prominently, but Denmark, Italy, and the EU average also indicate a majority of experts expecting an increase in high-skilled jobs because of AI adoption. On the other hand, in France and the US, one-third of experts also expect a decrease for high-skilled employment.

Policy Implications

AI adoption is expected to strengthen economic growth. At the same time, a majority of experts – across all countries except Germany – advocate for tighter regulation, reflecting concerns about potential negative externalities of rapid AI deployment. The central policy challenge is therefore clear: regulatory frameworks must enable innovation while effectively managing risks. Instruments such as the EU AI Act should strike a careful balance – avoiding both overregulation that stifles adoption and underregulation that fails to address societal and economic risks.

At the same time, fostering a dynamic AI ecosystem is critical. Start-ups play a key role in translating technological advances into productivity gains and new business models. Ensuring a start-up-friendly regulatory environment is therefore essential to support growth and strengthen Europe's international competitiveness.

Germany, where a comparatively large share of expert favors less regulation, offers an instructive case. Survey evidence (Eurostat 2025) suggests that regulatory uncertainty is a major barrier to AI adoption. In addition to skills shortages, firms primarily cite unclear legal frameworks and concerns about data protection and privacy as key obstacles. By contrast, technical feasibility and cost considerations are less frequently identified as binding constraints. This highlights the importance of clear, predictable, and innovation-compatible regulation.

The direction of AI development will be decisive in determining whether it complements or substitutes human labor. Expert assessments point to further labor market polarization, with medium-skilled workers particularly exposed. At the same time, emerging evidence suggests that AI may increasingly affect high-skilled, white-collar tasks. In the context of demographic change, however, AI should be seen less as a threat and more as part of the solution. The key policy priority is to support workforce adaptability: education, reskilling, and lifelong learning systems must be strengthened to facilitate transitions and mitigate adjustment costs.

Beyond labor markets, AI raises broader distributional and fiscal questions. These include the potential democratization of knowledge and skills, as well as debates on new policy instruments such as “robot” taxes or universal basic income. Despite recurring concerns about technological unemployment, labor force participation remains high. This underscores the need for policies that harness AI’s economic potential while addressing its social and distributional implications.

Recent productivity developments in the United States may signal the beginning of a broader AI-driven growth phase. For Europe, this should be understood as a strategic signal: the window for shaping the economic impact of AI is open – but will not remain so indefinitely. •

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Policy Debate of the Hour

AI and Europe's Labor Market

Key Messages

- Adoption of AI has accelerated in Europe, especially after 2022
- To adopt AI, firms need employees with data and AI skills, but small firms in particular lack the necessary expertise
- AI shifts skill demand in exposed occupations, requiring AI skills combined with judgment and decision-making skills
- AI changes what workers do on the job – it has not, so far, destroyed jobs
- Productivity gains from AI remain largely invisible in aggregate statistics – so far



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Artificial intelligence (AI) is no longer a prospect for European firms and workers – it is here, and its capabilities are evolving faster than most people would have predicted. In its wake, AI is beginning to change what skills employers need, what tasks workers perform on their job, and how work is organized. For years, the debate over AI and European work has been dominated by two competing fears: that machines would take away jobs, or that Europe would fall behind when they did. Neither story has played out as scripted. AI is not emptying European workplaces – it is reorganizing them, task by task, skill by skill. The logistics manager still comes to work; she just no longer spends her

mornings pulling together reports. Multiply that moment across millions of workers and hundreds of thousands of firms, and the picture that emerges is less dramatic than feared – but no less urgent.

Diffusion of AI Is Accelerating

In Europe, AI adoption has seen a notable acceleration after 2022, driven by the mainstream arrival of large language models (LLMs) and generative AI tools. AI technologies are no longer confined to a few early movers; they are spreading to enterprises across the economy. In 2025, about 20 percent of businesses reported using AI tools, compared to only 13.5 percent in 2024 (Eurostat 2025; Garbers and Gregory 2026). This growth reflects a broader recognition of AI's capabilities in enhancing business operations and efficiency. Among the most common applications are automated customer support (e.g., through chatbots and automated call agents) and written-language analysis (e.g., text mining), indicating that European firms are starting to invest in AI to improve service delivery and streamline processes.

Conversely, in the United States, the pace of AI adoption among firms was more rapid and widespread. Many US companies have integrated AI into various aspects of their

operations, including marketing, data analytics, and supply chain management. The emphasis is on leveraging AI to push innovation and improve competitive advantage. As a result, US firms are, on average, more advanced in their AI initiatives compared to their European counterparts. This disparity suggests that while Europe is advancing rapidly in AI adoption, US firms are further along in their implementation, reflecting differences in investment, infrastructure, and regulatory environments between the two regions.

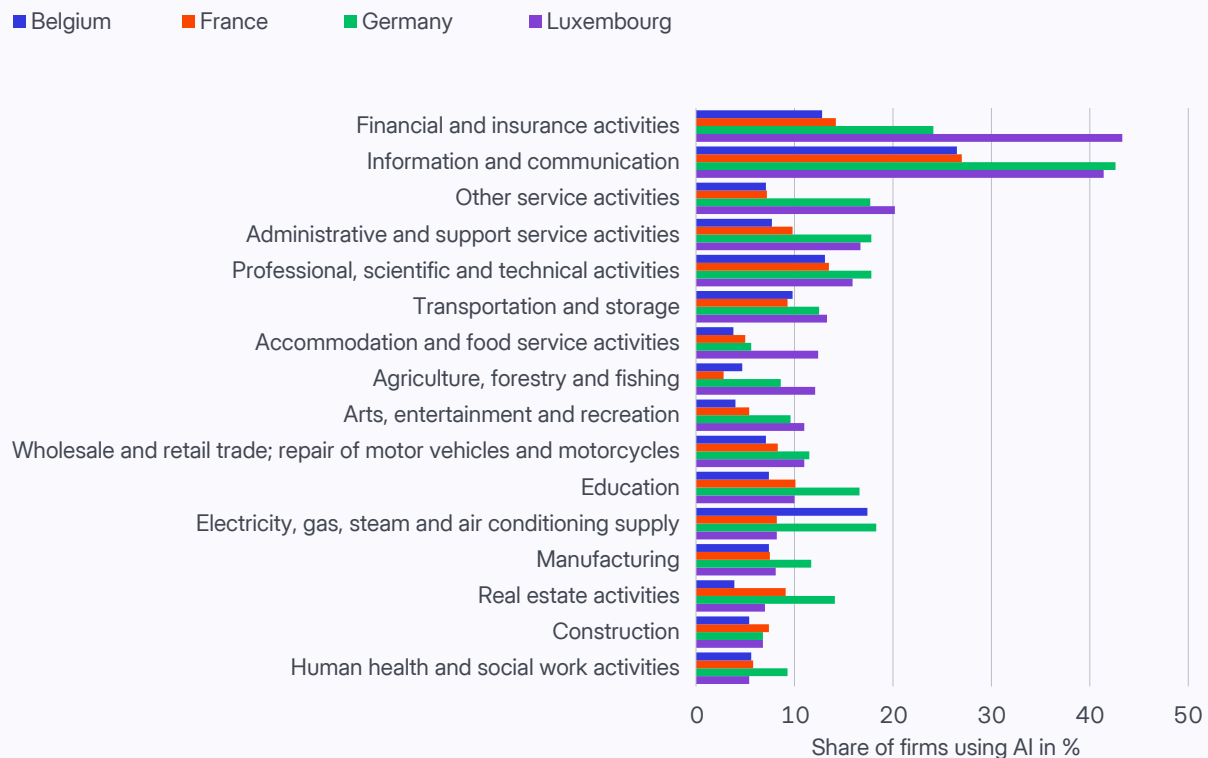
The nature of AI use is also changing qualitatively. In the early years, the ecosystem was dominated by core technology providers – the firms building AI from the ground up. Today, the fastest-growing category is firms that adopt and use AI by integrating existing AI tools into their products, services, and production processes. The technologies themselves are also shifting away from narrow, task-specific applications toward more integrated systems. Generative AI and conversational systems experienced substantial growth between 2016 and 2024, as did predictive and analytical applications. This development is expected to continue and will likely even accelerate with agentic AI tools. The overall picture is one of a maturing ecosystem, where broad

deployment increasingly complements foundational development (Garbers and Gregory 2026).

Large disparities remain in adoption rates across countries and sectors. In the European Union, Denmark, Finland, and Sweden are leading adopters with more than 30 percent of firms using AI, while adoption in Poland, Bulgaria, Romania, and Hungary stands at 10 percent or below (European Commission 2025). Sectoral differences are even more pronounced. Data from over 3 million firm websites across four European countries (Belgium, France, Germany, and Luxembourg) shows that in the ICT sector, where most AI tools and applications are developed, almost half of all firms already use AI. Knowledge-intensive industries – like banking and insurance, but also other professional services – have seen fast adoption rates as well. But the trend is not limited to high-tech sectors. Even non-knowledge-intensive industries show sizable absolute gains, signaling that technology spillovers are spreading AI across the broader economy. Adoption is much lower in sectors like health, construction, real estate, or manufacturing, where AI use is still below 10 percent (Garbers, Gathmann and Gregory 2026).

Figure 1

AI Adoption by Sector and Country (2024)



Source: Authors' calculations based on ISTAR.ai/Common Crawl website data linked to Orbis Europe.

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Who Is Adopting?

AI adoption is concentrated among larger, younger, knowledge-intensive firms located in urban innovation clusters. Crucially, the skills of the workforce matter for adoption: firms whose employees possess a higher share of AI-related and data-handling skills are substantially more likely to adopt. The single strongest predictor of AI adoption – more robust than firm size, sector, or location – is the presence of advanced data science tools (like machine learning, natural language processing, or Python) in the workforce. This finding has a direct implication: skills are not just a consequence of AI adoption; they are a precondition for it (Garbers and Gregory 2026). It is thus no surprise that the main reason firms do not adopt AI is a lack of relevant expertise; far fewer firms report legal uncertainty and data protection or privacy concerns as barriers to adoption.

Turning to the individual worker, recent surveys for Europe indicate a significant increase in the use of AI among workers, with approximately 30 percent reporting they utilized generative AI tools as of late 2025. Adoption is highest in countries like Denmark, Estonia, and Malta, where more than 40 percent of respondents engage with generative AI tools. These numbers are again lower than in the US, where 40 percent of the respondents used it at least once per week in mid-2025.

Only about 15 percent of respondents in Europe report using generative AI for work. These numbers suggest that

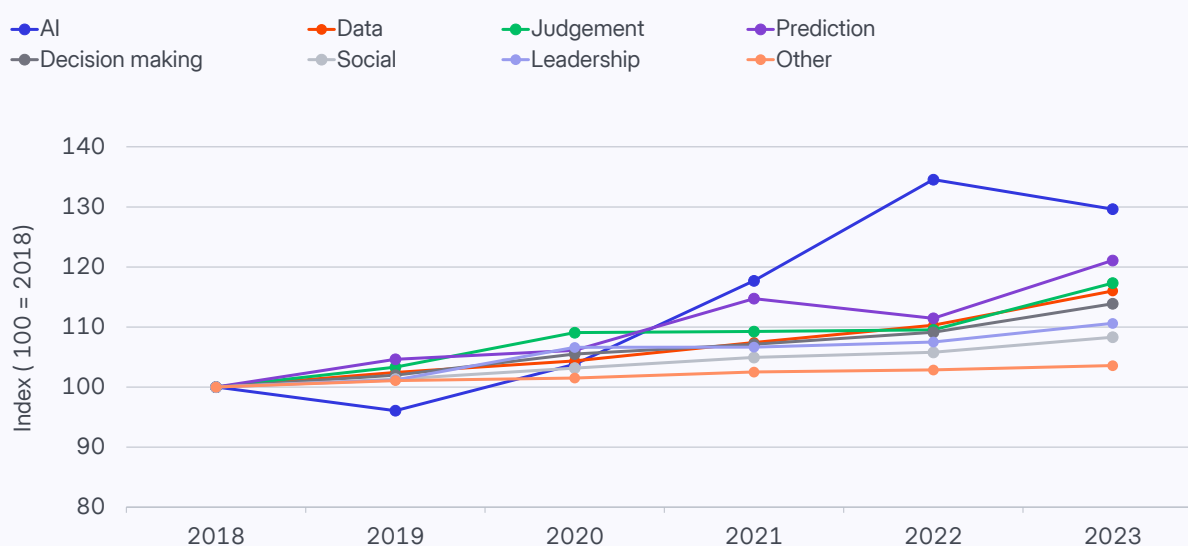
individuals have adapted more rapidly to the new technology than enterprises were able to absorb and integrate AI into their work processes. AI usage has grown even faster than users of earlier technological waves (like the internet) and will continue to diffuse rapidly in the coming years (Bick, Blandin and Deming 2026). As such, more and more Europeans, like their US counterparts, are integrating AI into their day-to-day tasks, particularly in written-language analysis, reflecting a growing recognition of AI's potential to enhance productivity.

Shifting Skill Demand

The diffusion of AI shifts what skills employers demand. Importantly, AI is not making human skills obsolete; it is changing the nature of those skills. Evidence from 75.5 million online job advertisements posted in Belgium, France, Germany, and Luxembourg between 2018 and 2023 provides a direct window into how employers are adjusting their skill requirements in response to AI. The findings reveal a dual pattern: while established social and cognitive skills continue to dominate job postings, AI-related technical capabilities are growing at a fast rate. Among all skill groups tracked – AI, data, prediction, judgment, decision-making, social, and leadership skills – AI skills exhibit the sharpest proportional growth, reflecting the rapid diffusion of AI tools into work environments and the rising premium for the ability to work with them (Feimi, Gathmann, Gregory and Marguerit 2025).

Figure 2

Skill Requirements in Job Postings



Source: Authors' calculations.

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Within occupations exposed to AI, the evidence points to a clear reorganization of skill requirements. Demand for prediction and data skills is rising, as is demand for AI-specific skills. AI skills appear to be complementary to AI technologies – the more AI-capable an occupation becomes, the more firms want workers who can manage, deploy, and interpret those systems. Data and prediction skills display a more nuanced pattern: they are partially substituted by AI (machines can now handle some forecasting and data processing), yet the scale of AI deployment leads to an overall increase in data-intensive tasks, sustaining demand for human data workers. By contrast, the relative importance of social skills – collaboration, communication, interpersonal coordination – is declining in AI-exposed occupations, consistent with the view that they are substitutable with AI capabilities or become less central when AI mediates more workflows.

A particularly significant finding concerns the structure of skill bundles. AI is not simply demanding more of one type of skill; it is reshaping which skills need to go together. Employers in AI-exposed occupations increasingly seek workers who combine technical capabilities (AI, data, prediction) with cognitive skills for judgment and decision-making but also interpersonal abilities. Demand for cross-domain skills, combining AI and data skills with decision-making and social skills, is rising strongly over time. This pattern points to a new type of worker that the AI economy needs: not a highly specialized technical expert, but someone who can bridge algorithmic outputs and human contexts – translating what AI systems produce into organizational decisions and actions and adapting as AI tools and capabilities expand.

So far, no evidence has been found that any broad skill category is becoming obsolete. Even the skills most frequently substituted by AI – such as prediction-related competencies – remain in demand through the expansion of AI-enabled workflows. However, the relative position of skills is shifting, and workers whose skill profiles are concentrated in AI-substitutable domains, without complementary judgment or cross-domain capabilities, face growing vulnerability to displacement within their occupations, even if not yet wholesale job loss.

Restructuring of the Labor Market Ahead

The diffusion of AI in the economy has profound implications for the labor market, which are only beginning to emerge. Aggregate employment figures do not yet reveal a large-scale reshuffling in the labor market. So far, the displacement effects of AI are modest. Evidence from social security records in Germany shows that AI exposure has re-

duced employment only marginally (Gathmann, Grimm and Winkler 2025). What it has caused instead is a significant increase in worker reallocation. About half of this mobility occurs within the same broad industry, with workers moving to similar industries that are less exposed to AI. Hence, the labor market has been absorbing AI mostly through mobility, not mass layoffs.

This pattern of reallocation has important distributional consequences. The mobility response to AI is stronger among low-skilled workers, who face more pressure to leave their original employer. The earnings picture confirms this inequality.

AI exposure has an overall modest effect on labor market earnings – but the distribution is asymmetric. Low-skilled workers experience earnings declines, while high-skilled workers are unaffected on average. The pattern is consistent with the idea that when AI primarily automates tasks that workers cannot easily replace with complementary activities, the result is a net wage loss rather than a productivity dividend. For early adopters among robots, in contrast, wage effects were mildly positive in the early phases – underscoring that the current AI experience is fundamentally different from prior waves of automation.

The heterogeneity goes beyond education. Older workers bear a disproportionate share of the burden: they see sharper declines in abstract tasks, stronger employment losses, and larger earnings reductions compared with younger workers in the same industries. This likely reflects a combination of factors – higher wages making them attractive candidates for automation, reduced ability to acquire complementary new skills, and longer careers invested in tasks that AI is now beginning to displace. Large firms are also driving much of the effect: AI has more pronounced impacts on tasks, employment, and earnings in large firms, which are the primary early adopters and have the scale to implement AI deeply across their operations.

Productivity Effects Not Yet Visible

The paradox at the heart of the European AI story is this: adoption is rising rapidly, demand for skills is changing rapidly, and workers are moving in response to these changes – yet the productivity gains that AI promises remain largely invisible in the aggregate economic data. Despite significant diffusion across firms and industries, there is little evidence of commensurate gains in wages, earnings, or employment in the industries most exposed to AI – quite the opposite, in fact. The predominant signal so far is disruption, not productivity gains. This is not cause for alarm, but it is reason for careful analysis.

One explanation is that AI adoption may still be in a transitional phase where reorganization costs – the time and resources required to restructure workflows, retrain workers, and integrate AI into production processes – dominate before the productivity payoff materializes. Historical precedent supports this view: it took decades after the introduction of electricity and computers before economy-wide productivity effects became measurable. The displacement patterns we are observing today may be the transitional friction that precedes a larger productivity wave. An alternative explanation is that the AI technologies that have diffused most widely so far may be mostly about automation and, on their own, are insufficient to generate broad productivity gains without complementary investments in organizational redesign and worker training. Moreover, the distribution of gains also matters: even if some adopting firms benefit substantially, the productivity gains may remain concentrated among a small group of leaders, with limited spillover to the broader economy.

Evidence from the United States offers a cautious tale that productivity gains may take time to emerge (McElheran, Yang, Kroff and Brynjolfsson 2026). In US manufacturing firms, AI adoption is even associated with short-term productivity losses. Over time, adopters grow but productivity gains are unequally distributed: older firms find it more difficult to benefit from AI. Whether Europe, which lacks the large digital companies of the US, will witness a similar J-curve and heterogeneity remains to be seen.

The absence of visible productivity gains also has implications for the politics of AI. If the primary observable effects of AI are changes in skill demand, worker reallocation, and wage losses for the vulnerable – while the promised gains remain diffuse or delayed – public trust in the technology transition will erode. Policymakers face a narrow window to ensure that the benefits of AI become as visible and broadly shared as the costs. This requires immediate action, before the second wave of AI adoption – driven by generative and agentic AI tools that are far more capable than anything measured in most of these studies – arrives in full force across European labor markets.

Policy Implications

The evidence points to a transition that is already underway but not yet well understood. AI is reorganizing European work quietly and unevenly – shifting skill demand, redesigning jobs, and reallocating workers across employers – while productivity gains remain elusive and adjustment costs harm vulnerable groups. Three priorities stand out.

Broaden the Base of Adoption

AI adoption is currently concentrated among large, knowledge-intensive firms in urban clusters. The majority of European workers are employed in small and medium-sized firms that are being left behind – not for lack of interest, but for lack of expertise. The single strongest predictor of AI adoption is the presence of data and AI skills in the workforce; the single most commonly cited barrier to adoption is precisely their absence. Supporting SMEs through subsidized access to AI tools, tailored advisory services, and skills partnerships with higher education institutions is essential if the benefits of AI are not to remain confined to a few large players.

Build the Workforce That an AI Economy Requires

Skills are not just a consequence of AI adoption – they are a precondition for it. Skill formation policy must therefore be proactive rather than reactive.

- **Invest in AI literacy and digital skills pipelines** to expand the supply of workers capable of working alongside AI systems. ICT specialist shortages are already a binding constraint on both adoption and productivity.
- **Strengthen on-the-job retraining.** Most adjustment happens on the job, not through a change of profession. On-the-job training programs that help workers acquire complementary skills – judgment, decision-making, cross-domain capabilities – are essential for firms that want adoption to translate into genuine productivity gains rather than disruption.
- **Support job mobility.** Where reallocation across employers is unavoidable, job search assistance, portability of social benefits, and mobility support reduce friction and help workers find good matches in a changing labor market.

Seize the Opportunity – For All Workers, Not Just Some

The evidence that AI is reorganizing work rather than eliminating it is, at its core, good news: it means there is time and space to shape how this transition unfolds. Workers who successfully combine technical AI capabilities with judgment, decision-making, and cross-domain skills are already seeing that demand for their abilities is rising fast. Firms that manage to reorganize their business model around AI rather than just using it to automate some tasks will see larger benefits in the long run. The policy challenge is to extend that opportunity broadly – equipping low-skilled

workers and older employees, as well as small and medium-sized firms, with the complementary skills they need to move with the transition rather than against it. This is not just a matter of fairness. Economies that let large shares of their workforce fall behind in the AI transition will forfeit the productivity gains that make it worthwhile in the first place. Investing in people, skills, and organization is not the cost of managing AI – it is the prerequisite for benefiting from it.

Underlying all of this is a structural challenge that requires urgency at the EU level. The European Commission's own assessment puts enterprise AI take-up at 18 percent against a 2030 target of 75 percent – a gap so large that closing it requires a qualitative shift in pace, not incremental improvement. The United States holds approximately 40 percent of global digital companies and 53 percent of corporate R&D investment in the digital sector; the EU operates with roughly a third of the US's data center capacity. Closing this structural gap demands coordinated investment in digital infrastructure, AI ecosystem development in lagging regions and countries, and a serious reckoning with why Europe's most ambitious technology targets are already drifting out of reach. •

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Policy Debate of the Hour

When AI Enters the Game

Cooperation and Predictability in Repeated Interactions

Key Messages

- Algorithms do not inherently promote collusion or increase competition
- Human cooperation declines when strategic counterparts are algorithms
- Human behavior becomes more predictable and aligned with equilibrium selection theory when interacting with algorithms
- Social preferences weaken in human-machine interaction, especially without a human beneficiary
- Policy should focus on market conditions, not just algorithmic presence



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Artificial intelligence (AI) is increasingly embedded in strategic economic environments, from algorithmic pricing to automated bidding and digital platform competition. A central policy concern is whether algorithms facilitate tacit collusion and weaken competition. The literature on algorithmic collusion is expanding across the areas of economics, law, and computer science, yet there is no theoretical consensus on whether algorithms systematically make coordination more likely. While simulation and laboratory studies show that sophisticated algorithms can learn to coordinate under

certain conditions (Calvano, Calzolari, Denicolò and Pastorello 2020; Klein 2021), it remains unclear whether such outcomes arise in practice. Field evidence is still limited, though recent work on the German retail gasoline market documents increasing margins following widespread adoption of pricing algorithms (Assad, Clark, Ershov and Xu 2024). Reflecting these concerns, recent reports by the OECD (2025a, 2025b) have highlighted the potential for algorithmic systems and generative AI to stabilize coordinated outcomes even without explicit communication. At the same time, researchers such as Schwalbe (2018) caution that coordination in real-world environments may face substantial frictions.

Yet much of the existing debate focuses on whether *algorithms* can collude. How algorithmic counterparts affect human strategic behavior is studied less frequently. Do *humans* cooperate differently when facing machines? Does interaction with algorithms make outcomes more predictable – or more unstable?

We address these questions within the framework of the infinitely repeated prisoner's dilemma, one of the most funda-

mental models of strategic interaction in economics. In this model, each player has two possible actions: to cooperate or to defect. In a one-shot interaction, each player has an incentive to defect, even though mutual cooperation would make both better off. When the same players interact repeatedly and do not know exactly when the interaction will end, cooperation can nevertheless be sustained as a stable behavioral pattern. The key factor in repeated interactions is the “continuation probability,” i.e., how likely it is that today’s interaction will be followed by future encounters. If future interaction is sufficiently likely, the long-term benefits of cooperation can outweigh the short-term temptation to defect, making cooperation a rationalizable outcome.

This setting mirrors key features of modern digital markets. Firms using pricing algorithms interact repeatedly, observe each other’s actions, and adjust strategies over time. The repeated prisoner’s dilemma captures the core tension between short-run competitive incentives and long-run collusion possibilities. It therefore provides a clean and transparent framework for modeling and studying how AI affects cooperation, competition, and the stability of market outcomes. It further provides a sharp theoretical benchmark for cooperation based on equilibrium selection and strategic risk (Blonski, Ockenfels and Spagnolo 2011; Blonski and Spagnolo 2015). In Blonski, Klockmann, Eibelshäuser, Hegemann and von Schenk (2025), our key question is: does interaction with algorithmic opponents change how closely human behavior aligns with equilibrium-selection predictions?

This is central to understanding the broader economic and societal impacts of AI. Algorithms do not merely replace human decision-makers but alter the structure and outcome of the strategic interaction itself.

Algorithms and Prosocial Behavior

The debate about the economic impacts of AI regarding cooperation has largely been framed around a binary question: will algorithms make markets more competitive or more collusive? More recent research has shifted attention from the question whether algorithms *can* cooperate to the question how cooperation arises under different learning regimes. Yet a crucial dimension remains underexplored: predictability. Market outcomes are shaped not only by whether cooperation occurs, but also by how stable, robust, and foreseeable strategic behavior becomes once AI is introduced.

In human-human interaction, behavior is often heterogeneous and noisy. Decades of experimental research show systematic deviations from equilibrium predictions in repeated games (Dal Bó and Fréchette 2018; Mengel 2018). These are often driven by social preferences, i.e.,

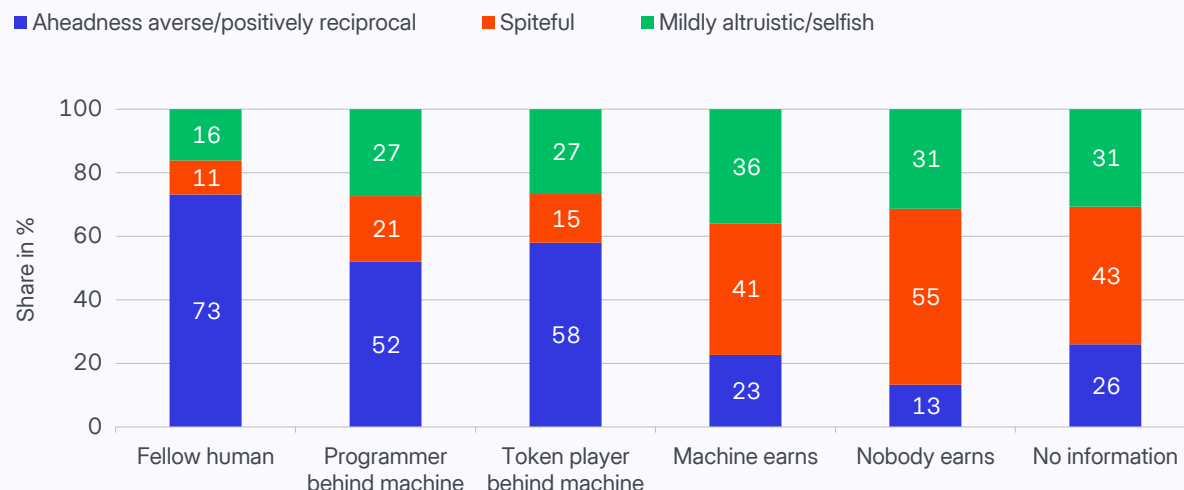
fairness concerns, reciprocity, and other-regarding motives. In our recent systematic experimental study (von Schenk, Klockmann and Köbis 2025), we shed further light on how social preferences differ in human-machine interaction. Participants play incentivized games to quantify prosocial behavior and revealed preferences under six experimental conditions that vary both the type of counterpart (human vs. machine) and the implementation of machine payoffs. In some conditions, a human beneficiary receives the machine’s earnings; in others, the machine keeps the payoff, or no one receives it. The design allows a structural estimation of social preference parameters, including disadvantageous and advantageous inequality aversion, as well as positive and negative reciprocity.

Three central findings emerge. First, individuals share significantly less with machines than with humans, i.e., they show less prosocial behavior toward machines. Second, when a human beneficiary stands behind the machine, fairness concerns and reciprocity largely persist; when no human benefits, these social preferences nearly vanish. Third, in treatments without information about what happens to machine payoffs, participants behave similarly to situations in which no human earns, suggesting that individuals form self-serving beliefs in the absence of transparency.

Figure 1 shows the distribution of estimated behavioral types across treatments, categorized based on their revealed preferences. In human-human interaction, a substantial share of participants can be classified as fairness-oriented or reciprocal types. When interacting with machines without a human beneficiary, the composition shifts markedly toward self-interested types. The share of strongly other-regarding individuals declines, while payoff-maximizing behavior becomes more prevalent. This shift in the distribution of types confirms that the presence and design of algorithmic counterparts reduce average sharing by altering the behavioral composition of the population rather than merely shifting overall levels of cooperation.

The evidence therefore indicates that social preferences in human-machine interaction are not eliminated but context-dependent. Compared to direct interaction with a human counterpart, they persist when a “human behind the machine” is present and salient but weaken when the interaction is perceived as purely technological and detached from interpersonal considerations.

Algorithms, in contrast to human behavior influenced by various motives, will frequently be optimized for consistent payoff maximization. If humans adapt to this consistency, the introduction of AI may reduce behavioral dispersion and strengthen the role of strategic thresholds derived from equilibrium selection theory (Blonski et al. 2011, 2015).

Figure 1**Distribution of Behavioral Types Across Alternative (Algorithmic) Counterparts and Implementation of Machine Payoffs^a**

^a The figure shows the share of different behavioral types classified by finite mixture estimation based on revealed preferences across experimental conditions.

Source: von Schenk et al. (2025).

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This shift from a world shaped by heterogeneous social motives to one increasingly governed by incentive-aligned learning systems has broader societal implications. Greater predictability may enhance efficiency, reduce volatility, and simplify regulatory assessment. At the same time, stable and predictable strategies can facilitate tacit coordination if the underlying incentives permit it.

Why Predictability Matters in the Age of AI

Understanding whether AI increases the alignment between observed and predicted behavior is central to evaluating its long-run economic impact. In repeated strategic environments, cooperation depends critically on expectations about future interaction. When future interaction is sufficiently likely, coordination can be sustained; when it is not, it collapses.

However, infinitely repeated games contain many, if not infinitely many, equilibria. For decades, this multiplicity has limited the predictive power of theory. Strategic-risk-based equilibrium selection provides a sharper benchmark. The δ^* criterion developed by Blonski et al. (2011, 2015) predicts a discontinuous increase in cooperation once the continuation probability δ exceeds a critical threshold δ^* , determined by the payoff parameters of the stage game.

Empirically, human behavior often deviates from such sharp threshold predictions. Cooperation typically changes more

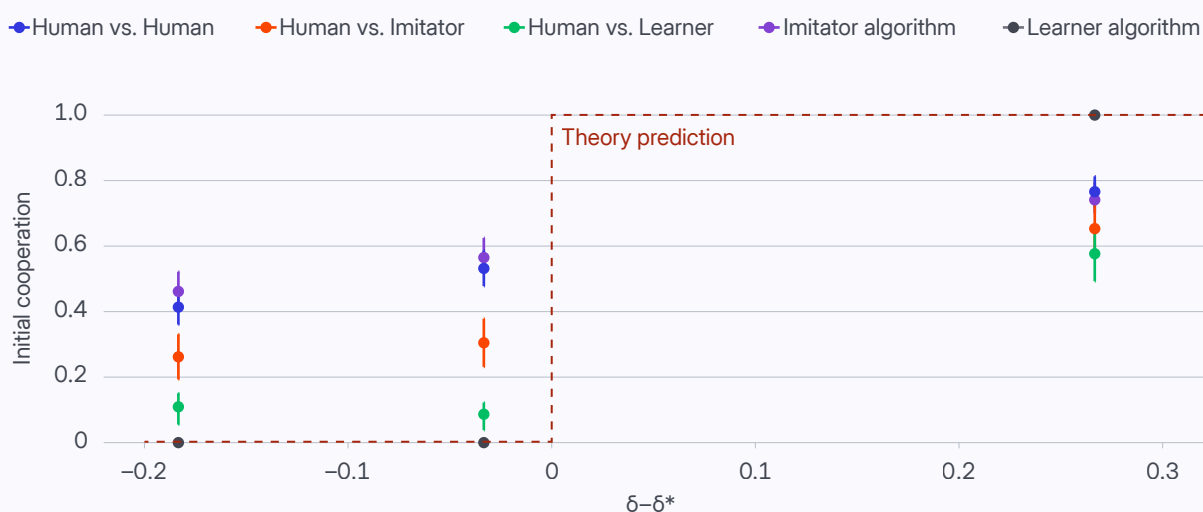
gradually, reflecting heterogeneity in beliefs, risk attitudes, and social preferences. The introduction of algorithmic counterparts therefore raises a central question: do machines reduce these behavioral deviations and strengthen incentive-based predictability? If so, AI may increase the structural determinacy of market outcomes. This could enhance stability and predictability of the conditions under which coordination can be sustained.

Experimental Design: Separating Identity from Objective

To answer these questions and isolate the mechanisms at work, we independently vary two dimensions: opponent type (human vs. machine) and algorithmic behavior (human-like vs. payoff-maximizing). Unlike many experimental studies (see reviews by March 2021; Chugunova and Sele 2022), our design separates opponent identity from strategic sophistication.

We implement three experimental conditions: (i) Human: subjects interact with other human participants; (ii) Imitator: subjects face an algorithm trained on data from human treatment that mimics observed human behavior; and (iii) Learner: subjects interact with a reinforcement-learning algorithm pre-trained to maximize its own payoff against the human-imitating algorithm. The Learner is not programmed to cooperate or defect. Instead, cooperative or non-cooperative behavior emerges endogenously from

Figure 2

Initial Cooperation Across Opponent Types and Continuation Probabilities^a

^a The figure shows first-round cooperation rates by continuation probability δ (below, near, and above the theoretical δ^* threshold) and by experimental condition varying opponent type and behavior. The whiskers show 95% confidence intervals using the number of participants per treatment. Whiskers for the Learner algorithm are missing due to zero variation in its play.
Source: Blonski et al. (2025).

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payoff-driven learning. We study each of the three experimental conditions under three continuation probabilities spanning the region below and above the theoretical δ^* threshold.

Cooperation Depends on Opponent Type and Objective

Consistent with theory, cooperation increases as the continuation probability and thus the expected game length rises. Yet even at low and medium continuation probabilities, a significant proportion of human subjects cooperate with one another, replicating patterns observed in previous experimental studies (Dal Bó and Fréchette 2018).

When human opponents are replaced by algorithms, cooperation declines. Participants cooperate significantly less when facing the human-imitating algorithm than when facing another human. Cooperation falls further in the Learner treatment. This three-stage pattern holds across all continuation probabilities.

This reduction in cooperation is consistent with the evidence discussed above that social preferences may be attenuated in human-machine interaction, particularly when machines are perceived as autonomous entities without a human beneficiary (von Schenk et al. 2025). In such settings, strategic choices become less influenced by social motives and more responsive to material incentives.

Thus, humans respond differently to algorithmic counterparts. Participants in our study who were paired with algorithms (Imitator or Learner) placed significantly less emphasis on cooperation or equality and focused more on maximizing their own payoff than those paired with humans. Social and reciprocal motives appear to be less influential in human-machine interaction, especially when the opponent is perceived as a payoff-maximizing algorithm.

AI Strengthens the Predictive Power of Equilibrium Selection

Our findings extend this previous insight, with our most important finding concerning predictability: not only does cooperation decline, but behavior becomes more sharply aligned with equilibrium-based threshold predictions. In other words, as social preferences recede, structural parameters such as continuation probability gain explanatory power.

The δ^* criterion predicts a discontinuous increase in cooperation once the continuation probability exceeds the threshold δ^* (Blonski et al. 2011, 2015). We assess alignment with this prediction by examining stability of cooperation on either side of the threshold and the separation of cooperation rates across it.

Figure 2 shows the rate at which cooperation is initiated in the first round of interaction across three continuation probabilities (low, medium, high). It compares three en-

vironments: human-human interaction, humans facing a human-imitating algorithm, and humans facing a payoff-maximizing reinforcement-learning algorithm. The figure also shows the cooperation rates of the Imitator and Reinforcement Learner themselves. In human-human interaction, cooperation increases more smoothly than predicted. In contrast, when interacting with algorithms – especially the Learner – cooperation aligns sharply with the theoretical discontinuity. Cooperation becomes more stable below and above δ^* , and the jump at the threshold becomes more pronounced.

These findings complement evidence that many human subjects systematically deviate from equilibrium predictions in repeated interaction and that algorithms respond differently to strategic risk (Kasberger, Martin, Normann and Werner 2024). The presence of algorithms thus increases the predictive power of equilibrium selection theory.

A striking result is that the payoff-maximizing algorithm behaves exactly as predicted by the strategic-risk threshold, despite not being programmed with equilibrium theory (see Figure 2). In simulations where two such algorithms interact, alignment with the theoretical boundary becomes nearly perfect. Equilibrium-aligned behavior thus emerges not only from analytical reasoning but also from data-driven adaptation.

Policy Implications

Our findings suggest that AI does not uniformly increase or decrease cooperation. Instead, it reduces behavioral noise and strengthens incentive-based responses. Humans interacting with algorithms become more predictable and more responsive to strategic thresholds.

Whether this development is socially beneficial depends on the underlying incentive structure. If incentives favor competitive pricing, algorithms may stabilize competition. If incentives favor tacit coordination, the same predictability may stabilize collusion. The degree of algorithmic integration and the parameters of the strategic environment therefore determine whether cooperation is increased or reduced.

While behavioral responses to technology may evolve over time and change across cultures, the disciplining effect of algorithmic interaction on cooperation patterns may prove more persistent than such attitudinal shifts.

From a policy perspective, AI should not be evaluated in isolation, since algorithms primarily amplify the incentive structures in which they operate. Competition policy should therefore focus on market design, transparency, and stra-

tegic risk rather than on the mere presence of AI systems. Markets with frequent interaction and high observability deserve particular attention, since these environments are most prone to threshold-based coordination. Reinforcement-learning systems can converge to coordination boundaries even without explicit collusion programming, underscoring the need for careful oversight.

Policy analysis should also account for behavioral adaptation, since AI shapes both machine actions and human responses. As algorithmic participation expands, strategic environments may become more stable, predictable, and closely aligned with structural incentives. For policymakers, the key implication is that effective competition policy lies not in banning algorithms, but in shaping the environments in which they operate. •

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Economic Policy and Its Impact

Benefits of Early Integration

Birthright Citizenship and Youth Crime*

Key Messages

- Despite making up a relatively low share of the population, adolescents account for a disproportionately high incidence of registered offenders
- An innovative empirical approach finds causal evidence that a reform of citizenship law has a significant impact on reducing youth crime
- Birthright citizenship (*jus soli*) reduces crime among second- and third-generation immigrant youth by about 70 percent
- The positive effect on crime may be due to improved educational outcomes and greater career opportunities
- Given the debates in several countries on restricting or even abolishing access to citizenship, these findings are highly relevant

Youth crime poses a significant social and economic problem, as adolescents – despite making up a comparatively low share of the population – account for a substantial proportion of registered offenders (Baier and Prätör 2026). High social costs are incurred primarily in areas such as crime prevention, health services, and compensation of victims, as well as through lost productivity, damage to property, and the costs of police investigations and criminal proceedings (Glaubitz, Steglich, Koch, Klodt, Klatt, Bergmann and Bliesener 2016).

Following a familiar pattern, the response in media coverage and by politicians is to focus mainly on tougher law enforcement – for example, through initiatives such as the Operational Taskforce GRIMM (Europol 2025b) and criminal law measures such as lowering the age of criminal responsibility in Sweden (Pedersen 2026). In contrast, calls for more funding for preventive measures – like high-quality child

daycare and education, mental health care, school social work, or youth welfare services – receive far less attention. Yet there is evidence that early prevention can, in the long run, contribute more effectively to a sustainable reduction in crime (Baron, Hyman and Vasquez 2026).

There are many indications that prevention should begin as early as possible. In our latest working paper (Andres, Bauernschuster, Dahl, Rainer and Schüller 2026), we analyze a policy measure that takes effect immediately at birth. This allows us to gain new insights into the impact of preventive interventions in reducing youth delinquency. Specifically, we examine whether youth crime can be lowered by automatically granting citizenship to children from immigrant families at birth.

The potential of early interventions to reduce youth crime is particularly high among children with a migration background, as they often face the dual pressure of integrating into the host society while maintaining ties with their par-

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ents' country of origin. Policy measures that grant rights and recognition from birth – such as citizenship – can shape identity formation, strengthen social trust, and improve perceived opportunities for education, employment, and political participation. These factors are frequently discussed in the literature as key mechanisms for preventing (youth) crime (Putnam 2000; Lochner and Moretti 2004). By fostering a sense of belonging and future prospects at a young age, citizenship by birth can reduce the appeal of criminal life paths and support positive social and economic integration, thereby serving as an effective tool for preventing youth crime.

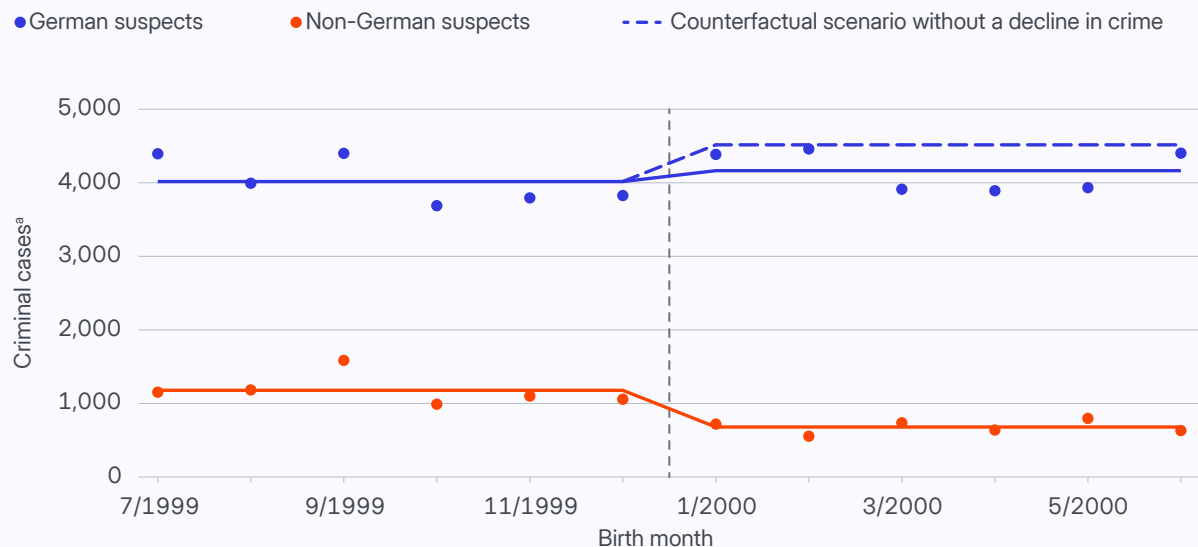
We analyze the causal effect of citizenship by birth (*jus soli*) on youth crime with reference to a rare reform of citizenship law in Germany. Since 2000, children born to foreign parents in Germany automatically acquire German citizenship at birth under the principle of birthright citizenship (*jus soli*) if at least one parent has had their habitual residence in Germany for eight years and holds a residence permit. Prior to 2000, only children with at least one German parent obtained citizenship at birth (*jus sanguinis*). As a result of this reform, the proportion of second-generation immigrant children holding German citizenship from birth has risen from 20 percent to 72 percent (Felfe, Rainer and Saurer 2020).

We examine the effects of the reform using data on offenses reported to the police in the federal states of Baden-Württemberg and Hesse, as well as in the city state of Berlin. These regions are home to around a quarter of Germany's population. They are particularly well-suited for our analysis because, compared to the rest of the country, they have some of the highest proportions of immigrants, meaning that a relatively large number of newborns were impacted by the reform. Our dataset contains linked microdata from German police crime statistics (2012–20) and the police's case management system. It includes information on the type of crime, the time and location of the offense, as well as the year and month of birth, gender, and nationality of the registered suspects.

Empirical Design

A simple approach to identifying the reform's causal effect would be to compare crime rates among second- and third-generation immigrant youth who were born shortly before or shortly after January 1, 2000, and whose parents each met the above-mentioned residency requirements. However, since the suspects' migration background is not recorded in the police crime statistics, we cannot clearly identify whether the data relates to second- and third-generation immigrant youth.

To get around this data-related limitation, we use a simple observation: because of the 2000 reform, the citizenship status of affected children changes from non-German to German at birth. As shown in Figure 1, this results in a purely mechanical decline in the offenses attributed to non-Germans born at the time of the reform (solid red line). If citizenship by birth had no influence on criminal behavior, we ought to see a commensurate increase in offenses attributed to Germans (dashed blue line). If, however, German citizenship reduces youth crime, the increase in offenses among Germans after the reform must be lower than the blue dashed line suggests.

Figure 1**Effect of Birthright Citizenship on Youth Crime**

^a Adjusted for birth season effects.
Source: Andres et al. (2026).

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We implement this identification strategy by estimating two difference-in-differences models and summing their estimated effects. These models estimate the change in the number of offenses separately for Germans and non-Germans born between January and June 2000, compared with those born between July and December 1999 – that is, after and before the reform took effect. Seasonal birth effects are factored out by using the same groups one year earlier – namely, those born between July 1998 and June 1999 – as a reference.

As a measure of crime, we use the cumulative number of offenses recorded for a cohort by birth month between the ages of 14 and 19. If the reform had no effect, the sum of the two difference-in-differences estimators would be zero; if the reform reduced crime, it would be negative.

Results

The study's results show that acquiring German citizenship by birth has a significant crime-reducing effect. Second- and third-generation immigrant youth who have had German citizenship since birth, following this reform, were registered by the police as suspects around 70 percent less often than comparable youth who previously did not hold German citizenship. In Figure 1, this decline corresponds to the difference between the dashed and solid blue lines. We also show that the reduction in youth crime is primarily due to fewer property and drug-related offenses.

A gender-disaggregated analysis shows that the crime-reducing effect is entirely attributable to boys, while a positive effect on crime is estimated for girls. This pattern is consistent with Dahl, Felfe, Frijters and Rainer (2022), who show that the reform of citizenship by birth has, on average, worsened life satisfaction, integration, and educational attainment among girls with a migration background. Dahl et al. find this negative effect is due to intra-family tensions in some Muslim families, where parents tend to expect their daughters to conform to traditional gender roles rather than take advantage of the new educational and career prospects opened up by German citizenship. Since boys commit crimes significantly more often than girls, they determine the reform's aggregate crime-reducing effect.

Robustness Checks

We demonstrate the validity of our results with numerous robustness analyses. Since the law change was enacted on July 15, 1999, decisions regarding family planning may have been influenced from that date onward. Automatic granting of German citizenship at birth could therefore have altered the number of children in immigrant families, resulting in differences in birth rates before and after the reform. To counter this, we narrow the estimation window around the date the reform came into effect to up to eight months and still obtain the same effect from the reform.

Furthermore, immigrant families, aware of the reform, could have deliberately influenced their child's date of birth, for example, by slightly postponing the birth. However, a donut regression excluding the birth months of December and January also shows an unchanged effect due to the reform. It therefore seems implausible that our results are confounded by such strategic planning of birth dates.

A possible concern with our empirical approach is that there could be differential changes in cohort sizes around the reform cutoff for Germans versus non-Germans. To address this concern, we estimate a Poisson difference-in-differences model that converts the analysis to one of crime rates, and find that the estimated effect of the reform is nearly identical.¹

Finally, we show that the reform's effect is significantly stronger in districts with a higher proportion of *jus soli* births. The decline in youth crime is especially stark where many children benefit from the reform. This pattern provides further important evidence that we are identifying actual effects of the reform and that the results cannot be explained by confounding regional developments.²

Mechanisms

The theoretical foundation for explaining how citizenship at birth affects youth crime is Gary Becker's (1968) economic model of rational crime. According to this model, individuals compare the expected utility from criminal acts – that is, illegal gains minus the expected punishment – with the expected utility from legal activities, such as work or education. They commit a crime when the expected utility of the crime exceeds that of legal alternatives.

Opportunity costs play a key role here: they are the losses incurred in the event of conviction when someone chooses the criminal option over the legal one. For example, if the prospects for legal employment, higher wages, or better educational opportunities improve, the expected returns from legal activities increase. This raises the opportunity costs of crime, as the loss from "rejecting" legal opportunities becomes greater. According to the model, a criminal offense also leads to long-term negative consequences. For instance, a criminal record can make it more difficult to find good employment in the future. Consequently, the relative advantage of criminal behavior decreases, and the incentives to commit crimes diminish.

If citizenship by birth therefore improves access to education and employment and reduces discrimination, the legal alternatives increase and, consequently, the opportunity costs of criminal behavior rise.³ As a result, the likelihood that young people will opt to commit a crime is lower.

Felfe et al. (2020) show that the introduction of birthright citizenship improves the educational outcomes of children with a migration background across multiple stages of the education system, from early childhood through adolescence. Specifically, it increases the likelihood that adolescents will attend high school and thus gain higher educational qualifications, which, in turn, improve their prospects in the labor market.

An additional mechanism that could explain lower delinquency can be derived from Felfe, Kocher, Rainer, Saurer and Siedler (2021). In their study, the authors examine how the citizenship reform affects the cooperative behavior of young people affected by the reform and conclude that German citizenship significantly increases the willingness of young male immigrants to cooperate with German natives. The cause of this change in behavior is an increase in trust toward German youth without an immigrant background. In turn, trust is the foundation for forming friendships. This suggests that young people affected by the reform are more likely to be friends with German youth without a migration background. Since the crime rate among German adolescents – due to their higher average socioeconomic status – is lower than among non-German adolescents (regardless of origin) (Grüne, Hoops and Willems 2025; Pfeiffer, Baier and Kliem 2018), the crime rate among youth affected by the reform could decrease as a result of peer group effects – that is, through a change in composition of their circle of friends.

Policy Implications

When youth crime rises, policymakers often advocate tougher law enforcement. However, our analysis shows that early interventions – such as granting citizenship at birth – can reduce youth crime effectively by strengthening opportunities, a sense of belonging, and trust.

Building on a reform of citizenship law, newly available crime data, and an innovative empirical strategy, we demonstrate that birthright citizenship significantly reduces crime among

¹ Here, we use the number of crimes as the dependent variable and the population at the time the crimes were committed as the exposure variable.

² Further robustness checks can be found in our study Andres et al. (2026)

³ German citizenship significantly expands the rights of second- and third-generation immigrant youth affected by the reform. It allows them to find employment as a civil servant, enables them to work in other EU member states under the EU's freedom of movement for workers (relevant for children of parents from non-EU countries), and gives them the right to vote at both the local and national levels (relevant for children of parents from EU and non-EU countries).

second- and third-generation immigrant adolescents. Given the substantial social costs of crime (Bindler, Ketel and Hjalmarsson 2020; Bindler and Ketel 2022), greater attention should be paid to previously underestimated early prevention measures, and these should be fostered in a more targeted manner to strengthen opportunities, a sense of belonging, and trust among children and youth. Such measures can have a lasting impact on the opportunity costs of criminal behavior long before adolescence, for example, through improved integration into the education system and the higher educational attainment that entails (Felfe et al. 2020).

Moreover, research shows that an inclusive migration policy also has crime-reducing effects even in later stages of life for individuals with an immigrant background. Pinotti and Mastrobuoni (2015), as well as Pinotti (2017) and Baker (2015), demonstrate that migrants who are granted legal residency status are less likely to commit crimes. Regular residency status improves their chances on the labor market and thus increases the opportunity costs of criminal conduct.

There are regular calls in the political debate to restrict, or even abolish, birthright citizenship, for example, in the United States (Drenon and Halpert 2025) and in France (Der Spiegel 2025). Given our research findings, however, such a proposal could inadvertently increase youth crime. Since the German reform from 2000 mainly affected second-generation immigrants, the decline in crime we observe is largely due to this group. Because second-generation immigrants have, on average, higher crime rates than the first and third generations (Dreißigacker, Schröder, Krieg, Becher, Hahnemann and Gröneweg 2023; Walburg 2023), our findings could inform discussions about extending birthright citizenship to the second generation in countries with more restrictive rules, such as those that follow a double *jus soli* principle and therefore grant citizenship at birth automatically only from the third generation onward. •

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Institutions Across the World

Corporate Tax Spillovers in an Interconnected Economy

Investment Effects Within Multinationals and Along Global Supply Chains

Key Messages

- Corporate tax reforms generate cross-border investment spillovers through multinational subsidiary networks and along global supply chains
- Within multinational firms, production linkages can lead to negative cross-border investment spillovers following tax increases
- Along global supply chains, tax shocks propagate between firms through cost transmission and changes in demand, amplifying the reach of domestic tax reforms
- International tax coordination and reform efforts should account for real investment transmission across networks, not only profit shifting
- When evaluating tax reforms, cross-country spillover effects need to be taken into account



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Corporate tax effects on investment are still debated largely in national terms. Governments are concerned about how changes in corporate tax rates affect domestic investment, employment, wages, and tax revenue. The effects of corporate taxes on corporate investment (e.g., Djankov, Ganer, McLiesh, Ramalho and Shleifer 2010; Romer and Romer 2010; Ljungqvist, Zhang and Zuo 2017; Bethmann, Jacob and Müller 2018; Langenmayr and Lester 2018; Giroud and Rauh 2019; Lester 2019; Dobridge 2021; Jacob 2022; Gallemore, Jacob, Hollander and Zheng 2025; Hillmann and Jacob 2025), wages (e.g., Suarez Serrato and Zidar 2016; Fuest, Peichl and Sieglöcher 2018;

Dyreng, Jacob, Jiang and Müller 2022) and consumer prices (e.g., Baker, Sun and Yannelis 2020; Jacob, Müller and Wulff 2023) within a country have been well documented. Yet firms do not only operate within national economies. Production is organized through multinational enterprises or through cross-border supply chains that connect otherwise unrelated firms across jurisdictions.

In such an environment, corporate tax policy's effects on investment cannot be fully understood through a purely domestic lens. A tax reform in one country may alter investment decisions in other countries – not only through capital mobility or profit shifting, but through the real structure of production itself. This article examines two distinct but complementary channels through which corporate tax changes spill over across borders:

1. **Spillovers within multinational firms**, transmitted through the internal network of subsidiaries (see De Vito, Jacob, Schindler and Xu 2025)
2. **Spillovers along global supply chains**, transmitted through arm's-length input-output relationships between independent firms (see Bonetti, Jacob and Ormazabal 2026)

These two mechanisms differ in institutional structure and economic transmission, yet both imply that corporate tax policy generates real cross-border effects that extend beyond traditional tax competition narratives.

The first mechanism operates inside the firm. Modern multinationals are not simply collections of independent affiliates. They are internally integrated production networks. Subsidiaries in different countries are often vertically linked: Upstream affiliates produce intermediate inputs used by downstream affiliates in other countries. When one affiliate faces a corporate tax hike, the consequences propagate within the firm's internal network. Crucially, this propagation may not follow the standard tax competition logic of capital reallocation toward low-tax locations. Instead, production linkages can transmit profitability shocks across affiliates, potentially leading to negative spillovers.

The second mechanism operates between firms connected only through supply chain links. Global value chains connect suppliers and customers across borders even in the absence of ownership links. If a firm in country A experiences a tax-induced increase in costs or a reduction in profitability, it may adjust its prices and quantities. These adjustments affect trading partners abroad. Through such arm's-length relationships, tax shocks can travel along supply chains, altering investment decisions in connected firms.

The common thread across both mechanisms is that corporate taxation interacts with institutional features of the modern global economy, namely cross-border links in production, whether organized within groups or across unrelated firms. As a result, national tax reforms can have unintended cross-border consequences.

This perspective is especially relevant in the current policy environment. Many countries are grappling with high public debt, fiscal consolidation pressures, and the implementation of coordinated reforms such as the OECD's Pillar Two global minimum tax. Policymakers tend to evaluate such reforms in terms of revenue and competitiveness. Yet the real-economy spillovers through production networks may be equally important.

The remainder of this article explains the two spillover channels in turn and concludes with policy implications for international tax design and coordination.

Spillovers Within Multinational Firms

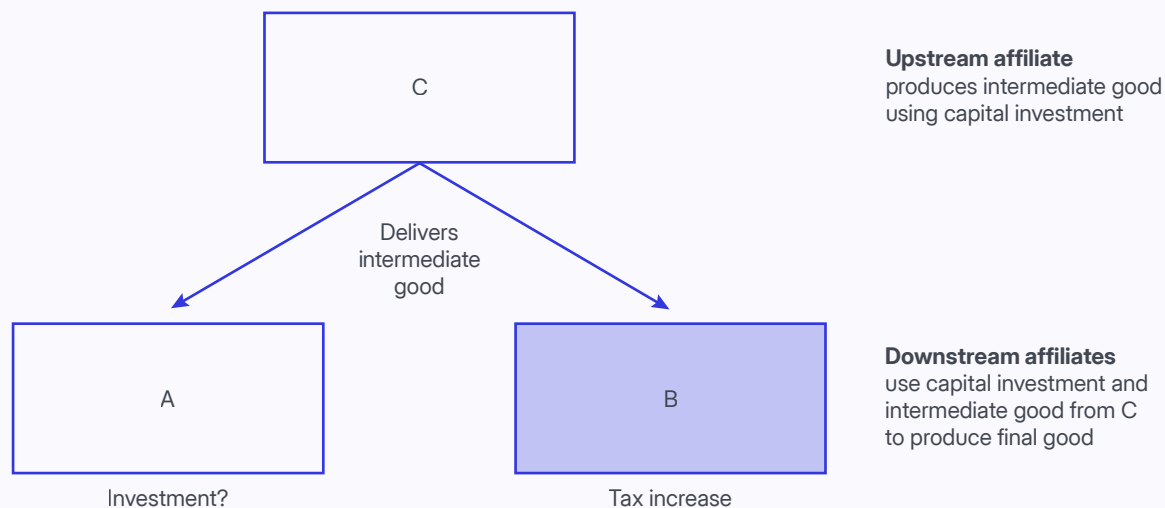
Multinational enterprises (MNEs) account for a substantial share of global production and trade. A large fraction of international trade consists of intra-firm transactions – transfers of intermediate goods, services, and intangibles between subsidiaries located in different jurisdictions.

These internal networks generate strong economic interdependencies. Subsidiaries often specialize in distinct stages of production. An upstream affiliate may produce a key component that is shipped to downstream affiliates in other countries, where final assembly and sales take place. Capital allocation decisions are frequently centralized at a firm's headquarters, and internal capital markets reallocate funds across affiliates in response to shocks. In this setting, a corporate tax increase in one country can influence investment in other countries through two opposing forces: tax competition and production linkages.

Explaining Spillover Effects within Multinationals

We use the following setting to describe spillover effects within multinationals. All entities (or affiliates) are from the same multinational group. Affiliate C from Country C produces an intermediate good, which it delivers to Affiliate A in Country A as well as to Affiliate B in Country B. Let us assume, for example, that there is a tax rate increase in country B, and ask how investment in Country A (or in country C) responds to the tax hike.

Following the arguments in De Vito et al. (2025), the standard theory of international tax competition predicts that

Figure 1**Spillovers Within Multinationals, Tax Hike in the Downstream Affiliate**

Source: Based on Figure 1 from De Vito et al. (2025).

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higher corporate tax rates reduce investment in the taxed jurisdiction and encourage capital to flow toward lower-tax locations (e.g., Keen and Konrad 2013). Within a multinational, this logic translates into internal reallocation: if Affiliate B faces a tax hike, the firm may scale down investment in Country B and increase investment in Affiliate A, due to the higher tax rate in Country B.

This mechanism generates positive spillovers across affiliates. A tax hike in one jurisdiction may stimulate investment in another.

Tax competition effects may operate through two channels:

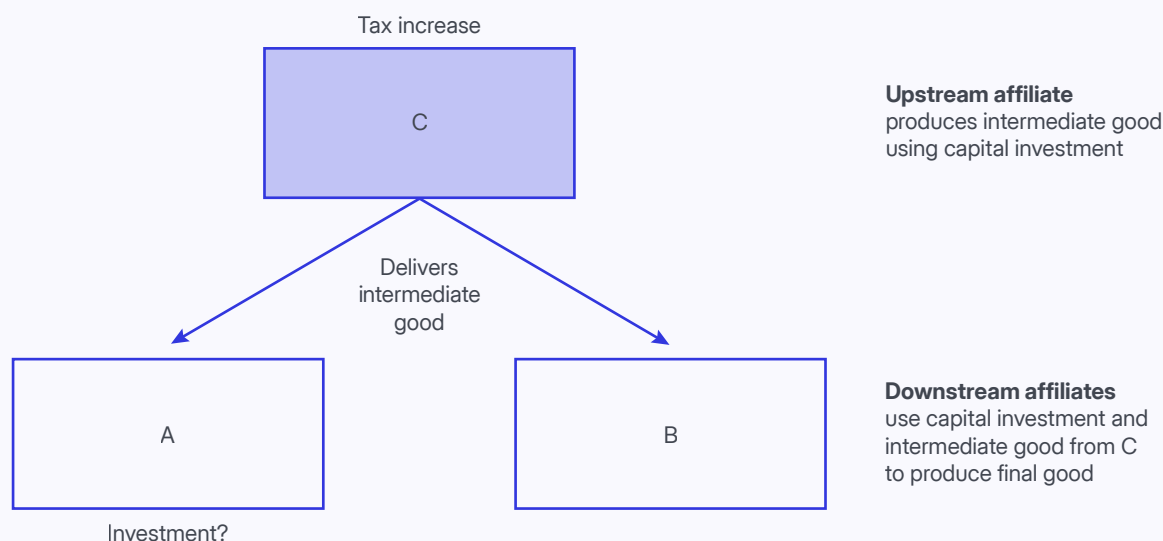
- Direct reallocation of internal funds: the corporate headquarters shifts investment budgets toward subsidiaries with more favorable tax conditions.
- Capital market equilibrium effects: in integrated capital markets, large tax increases in major economies can reduce global demand for capital, lowering the world interest rate and indirectly stimulating investment elsewhere.

This view is deeply embedded in policy debates. It underpins concerns about “capital flight” and motivates international coordination efforts to avoid harmful tax competition.

However, the tax competition narrative overlooks an essential feature of modern multinationals: their internal production structure and *production linkages*.

Subsidiaries are often vertically integrated as illustrated in Figures 1 and Figure 2. There is an upstream affiliate in Country C that produces an intermediate input used by downstream affiliates in Countries A and B. Profits are allocated across affiliates according to transfer pricing rules and accounted for separately. When Country C raises its corporate tax rate as shown in Figure 2, the after-tax profitability of the upstream affiliate declines. This decline affects downstream affiliates in at least two ways:

1. Reduced intermediate supply or higher effective input cost: if upstream investment declines, the supply of intermediate inputs shrinks, reducing downstream productivity.
2. Transfer price allocation effects: Because profits are allocated to the upstream affiliate via arm’s-length transfer prices, a higher tax rate in Country C in Figure 2 increases the effective tax burden on the marginal return to production. This higher tax burden reduces investment incentives throughout the entire Group, that is, also in Affiliate A.

Figure 2**Spillovers Within Multinationals, Tax Hike in the Upstream Affiliate**

Source: Based on Figure 1 from De Vito et al. (2025).

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As a result, downstream affiliates in Country A may reduce their investment, even though their own statutory tax rate remains unchanged. Similarly, a tax hike in a downstream affiliate can reduce demand for upstream inputs, lowering upstream investment. This production linkage channel generates negative spillovers across affiliates.¹

Which Force Dominates Within Multinationals?

The empirical evidence in De Vito et al. (2025) is based on subsidiary-level data for European multinationals. The authors show that, on average, production linkages dominate tax competition using large tax hikes. These foreign tax hikes reduce investment in related subsidiaries in other countries rather than increasing it. In economic terms, they find that a 1 percent increase in foreign taxes reduces investment in connected affiliates by roughly 0.5 percent. While smaller than the direct domestic effect of a tax hike, this spillover is economically meaningful. The dominance of production linkages implies that corporate tax changes can depress overall multinational activity rather than simply reallocating it geographically.

Tax Spillover Effects Along Global Supply Chains

Internal multinational networks are only one part of the story. Global production networks connect millions of legally independent firms across borders through arm's-length relationships. In fact, about half of the world's trade occurs between independent parties. Modern production is organized in cross-border supply chains in which firms buy critical inputs from foreign suppliers and sell to foreign customers. When taxes change in one country, the resulting cost shock does not necessarily stop at the border. If part of the corporate tax burden is passed along in the form of changed prices – upstream via higher input prices or downstream via lower purchase prices – firms in other countries can see their profits decline and may therefore scale back investment.

Corporate Taxes Travel Along Supply Chains

The mechanism builds on standard tax incidence logic. Consider a supplier in Country A and a firm in Country B (see Figure 3). When Country A raises the corporate tax rate, the supplier's after-tax return on investment declines; in response, the supplier in Country A reduces its investment and (through lower capacity or higher marginal costs) effectively raises the price of the input it sells to the firm in Country B. The foreign firm in Country B, which uses these inputs, then has higher input costs, lower operating profits,

¹ Note that such negative spillover effects can also arise if the tax hike occurs in Country B as shown in Figure 1.

and weaker incentives to invest. Hence, the firm in Country B reduces its investment in response to Country A's tax hike. This is illustrated in Figure 3. Of course, the extent to which prices, output, and investment respond depends on the relative elasticities and bargaining power of the involved trading partners. Figure 3 implicitly assumes that neither trading partner is fully elastic or inelastic so that there can be cross-border spillover effects.

A parallel argument applies in the opposite direction, which is also shown in Figure 3: A tax increase that hits a customer can reduce the customer's demand and profitability, which then propagates upstream to suppliers. Suppose the firm in Country B has a customer in Country C. Country C increases its tax rate. In response to this tax rate increase, the customer in Country C decreases its investment and thus also its demand for input goods. The customer produces less and thus needs fewer input goods. Due to this reduced demand, the price for the good declines (as lower demand results in lower prices). This has consequences for the firm in Country B: it realizes lower profits and, because of these lower profits, the firm in Country B reduces its investment.

This basic logic implies an important symmetry: Under tax incidence, the investment response depends on relative elasticities and bargaining positions; it is not tied to whether the tax is levied on the buyer or the seller. Whether

the supplier in Country A or the customer in Country C is taxed, the investment of the firm from Country B is sensitive to tax rate changes of the supplier as much as of the customer.

This perspective is particularly relevant for Europe. European firms are deeply integrated into global value chains. When a large economy – either within or outside Europe – adjusts its corporate tax rate, the consequences may reach investment through supply relationships that policymakers do not explicitly consider in distributional and macroeconomic assessments.

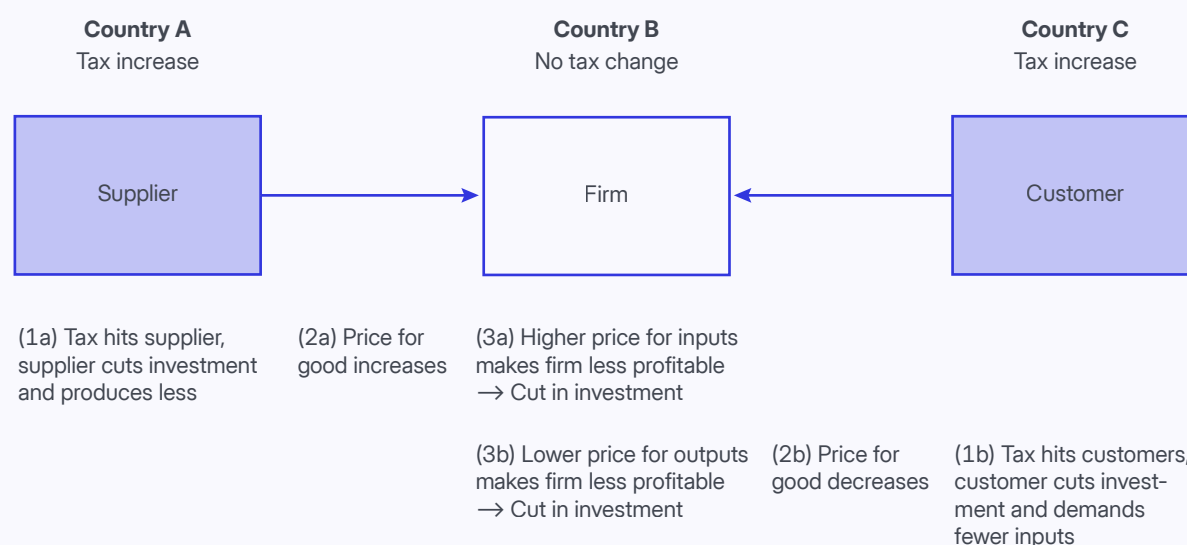
Measuring Exposure to Foreign Tax Shocks

Testing these spillovers empirically requires two ingredients: (i) detailed firm-to-firm supply chain linkages across borders and (ii) credible variation in corporate tax rates that is not mechanically driven by firms simultaneously reorganizing their supply chains. In Bonetti et al. (2026), we overcome these limitations.

Our paper combines worldwide supply chain data (constructed from sources such as shipment-level records and firm disclosures) as used, for example, in Bonetti et al. (2024) with financial statement data for a large set of listed firms from Compustat North America and Compustat Global. Our sample covers over 18,000 publicly traded

Figure 3

Cross-Border Spillover Effects Along Supply Chains



Source: Extension of Figure 1 on Bonetti et al. (2026).

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firms and millions of supplier-customer relationships across 54 countries over the period 2009–23.

A key empirical concern is endogeneity: if firms rewire their supply chains in response to tax changes, then a contemporaneous measure of “supplier tax rates” or “customer tax rates” may partly reflect firms’ own choices rather than tax changes in foreign countries. To address this, the approach uses a shift-share design that fixes each firm’s foreign supplier and customer network at a pre-determined baseline in December 2008. Then, we track how supplier-country and customer-country tax rates evolve over time. This ensures that changes in measured foreign tax exposure arise from policy changes abroad, not from firms’ endogenous reweighting of suppliers or customers in the same period.

How Large Are Investment Spillovers?

The core results focus on firm investment measured by capital expenditures. The empirical analysis evaluates two directions of spillovers:

1. Customer-side spillovers (upstream tax shocks): customer investment as a function of suppliers’ corporate tax rates
2. Supplier-side spillovers (downstream tax shocks): supplier investment as a function of customers’ corporate tax rates

The results shown in Table 1 support the theoretical predictions of cross-border spillover effects. Note that the findings in Table 1 are robust to various tests (see Bonetti et al. 2026). We find that higher taxes on suppliers or on

customers reduce a given firm’s investment. The coefficient estimate can be interpreted as follows: an increase in the tax rate by 1 percentage point reduces corporate investment by 0.0561 percent of total assets. Bonetti et al. (2026) also translate this estimate into an implied elasticity of investment with respect to suppliers’ tax rates, which can be calculated using the sample average tax rates and investments and amounts to –0.31: a 1 percent increase in suppliers’ tax rates is associated with a 0.31 percent decrease in customer investment.²

Looking from the supplier side, the elasticity of supplier investment – based on the coefficient of 0.0604 and the sample average investments and tax rates – with respect to customers’ tax rates is –0.35. A striking feature is that these spillover elasticities are similar in magnitude to the estimated direct effect of a firm’s own corporate tax rate on its investment in the same framework. The elasticity of investment with respect to the firm’s own tax rate based on the coefficient estimates of –0.0521 and –0.0588 and using the unreported sample average tax rate and investments is about –0.3. Rather than being implausible, this pattern is consistent with tax incidence theory: For tax incidence, and thus also for real outcomes like investment, the key question is how the tax changes effective prices and margins along the chain – and for this effect, it is irrelevant

² In their footnote 14, Bonetti et al. (2026) explain that elasticity is obtained by dividing the percentage change in investment by the percentage change in the tax rate. The investment change in response to a 1 percentage point tax rate change is -0.0561×0.01 , or -1.106 percent of the average investment (0.0507) in the sample. Moreover, a 1 percentage point change in the tax rate represents a tax increase of 3.520 percent ($=0.01 / 0.2841$) as the average tax rate of suppliers is 28.41 percent. This results in an elasticity of $-0.31 = -1.106 \text{ percent} / 3.520 \text{ percent}$.

Table 1

Cross-Border Spillover Effects of Taxes on Investment

Level of observations	Customer investments	Supplier investments
<i>Weighted tax rate of all suppliers</i>	–0.0561** (0.0260)	–
<i>Weighted tax rate of all customers</i>	–	–0.0604*** (0.0145)
<i>Firm’s own tax rate</i>	–0.0521*** (0.0045)	–0.0588*** (0.0043)
Controls	Yes	Yes
Firm fixed effects	Yes	Yes
Industry-year fixed effects	Yes	Yes
Observations	217,153	239,962
R-squared	0.495	0.496

Source: Excerpt of Table 3 from Bonetti et al. (2026).

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which side of the market you tax (see Section 19, Gruber 2022). This is akin to the results for value added tax and their investment effects (see Jacob, Müller and Michaeli 2019) or for the investment effect of emission taxes (Jacob and Zerwer 2024).

To reinforce credibility, the analysis in Bonetti et al. (2026) also examines a large discrete reform – the 2014/15 corporate tax cut in Japan – and finds that non-Japanese customers with greater pre-reform exposure to Japanese suppliers increased investment after the reform, consistent with supply-chain transmission of tax shocks.

When Are Spillovers Stronger?

Tax incidence predicts heterogeneity: the ability to pass the tax burden along the supply chain depends on the market structure and relative elasticities. The evidence aligns with this view. Spillovers are more pronounced when firms are less able to buffer shocks through alternative trading partners or internal resources and when market structure limits substitution. For example, the results are stronger for firms facing higher switching costs – proxied by a smaller set of potential suppliers or customers in their country-industry-year – consistent with the idea that limited outside options increase exposure to counterparties' tax-induced price changes.

This heterogeneity matters for policy: The same foreign tax change can have very different investment consequences depending on how concentrated an industry is or how "locked-in" a firm's supply chain is. In practice, this suggests that spillover effects on investment will be especially relevant for specialized intermediate inputs, more competitive markets, and sectors with relationship-specific investments.

Do Firms Rewire Their Supply Chains?

Investment is not the only margin of adjustment. If foreign tax shocks materially affect costs and profitability, firms may respond by altering their global supply chain structure – terminating relationships in high-tax locations and searching for alternative partners.

Evidence from a large-scale analysis of supplier-customer links shows precisely this pattern. In Bonetti et al. (2026), we find that higher tax rates in a supplier (or customer) country are associated with a higher probability that the relationship will be terminated and a lower probability that new relationships will be initiated. The economic magnitudes are meaningful. A 1 percentage point increase in the supplier (customer) tax rate raises the likelihood of terminating a relationship by about 1.05 percent (5.66 percent)

of the sample mean, and reduces the likelihood of initiating a new relationship by about 2.10 percent (1.86 percent) of the sample mean.

This extensive-margin response has two important implications. First, it corroborates that foreign corporate tax changes are costly enough to induce organizational adjustment, not merely accounting changes. Second, it means that supply chains are themselves an endogenous object of tax policy: over time, tax differentials can reshape production networks, potentially affecting resilience, concentration, and exposure to future shocks.

Policy Implications

Corporate Tax Incidence Can Be International

Distributional and macro-assessments of corporate tax reforms often focus on domestic owners, workers, and consumers. The evidence suggests that part of the burden (or benefit) of corporate tax reforms can be transmitted abroad through supply chain prices, affecting foreign profits and investment. Policymakers should therefore treat corporate tax changes as potentially generating cross-border investment spillovers – especially for countries tightly linked to high-tax or low-tax trading partners.

National Reforms Can Generate Unintended "Investment Externalities"

A tax increase in one country may depress investment in partner countries connected through supplier-customer relationships. Conversely, tax cuts in large economies can "trickle down" to linked foreign firms and stimulate investment abroad. This strengthens the case for explicitly incorporating supply chain linkages into ex-ante policy evaluation, including in Europe-wide discussions where corporate tax settings interact with deep trade integration.

The Structure of Supply Chains Shapes Vulnerability and Policy Transmission

Spillovers are stronger when firms have limited ability to switch suppliers or customers. Policies that reduce unnecessary switching frictions – through competition policy, trade facilitation, and lowering regulatory barriers to entry into intermediate input markets – can increase resilience to foreign tax shocks. At the same time, policymakers should recognize that "resilience" policies that intentionally concentrate sourcing in a narrow set of partners may amplify exposure to tax and regulatory shocks in those partner locations.

Corporate Taxation Can Influence Network Resilience and Concentration

If firms respond to tax differentials by terminating and avoiding relationships in high-tax countries, tax policy may gradually reallocate parts of supply chains across jurisdictions. This may affect strategic autonomy debates: policies aimed at strengthening domestic capacity could be undermined if the domestic tax system indirectly pushes firms to reorganize away from local suppliers or customers. One implication of this is that – taking the empirical results at face value – if Germany were to cut its corporate tax rate, German firms would find more trading partners, that is, they would become more attractive as suppliers or customers for other international firms.

Coordination Debates Should Consider Real-Side Linkages, Not Only Profit Shifting

International corporate tax coordination is often motivated by profit shifting and attempts to combat corporate tax avoidance. The evidence discussed in this article highlights additional real-effects: corporate tax changes can propagate through arm's-length supply chains across otherwise unrelated firms as well as through internal networks of multinational firms.

Incorporating cross-border effects of corporate taxes on investment could change how policymakers weigh the broader costs and benefits of unilateral reforms versus coordinated approaches. Along supply chains, price transmission and demand linkages propagate tax-induced profitability shocks across independent firms. Within multinationals, production linkages propagate tax changes to other countries.

These findings challenge the purely national perspective on corporate tax policy. They also suggest that international coordination debates should incorporate real-side spillovers in addition to profit shifting and fiscal competition. In a world of deeply integrated production networks, corporate tax policy and its investment effects are no longer confined within national borders. The tax effects on investment travel along the architecture of global firms and supply chains. •

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Big-Data-Based Economic Insights

Under Strain

International Insights into Electricity Grid Outages

Key Messages

- Major recent blackouts underline the severe economic, health, and social costs of outages on households and firms
- Unplanned outages show strong seasonality linked to weather, hinting at climate-related risks for electricity grids
- Poorer municipalities tend to face systematically higher outage rates, revealing possible inequities in grid resilience
- Climate change amplifies outage risk through both extreme weather damage and heat-driven grid overload
- Frequent, detailed, and harmonized outage reporting is essential for evidence-based grid resilience policy



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Electricity markets are a crucial part of any modern economy's infrastructure, particularly in times of digitization, yet electricity has historically not been a salient product (Hortaçsu, Madanizadeh and Puller 2017). Recently, however, Europe has been reminded on multiple occasions how vital reliable and affordable electricity provision is to daily life. The energy crisis of 2022, for example, has prompted

new discussions on supply security (ACER 2024). Further, a total loss of electricity supply in Spain and Portugal in April 2025 served as a stark reminder of how dependent economies are on electricity infrastructure. This incident was the largest blackout in Europe in more than 20 years (ENTSO-E 2026) and was preceded by a similar complete grid collapse in Chile in February of the same year, which

had caused an estimated USD 450 million in economic cost (IEA 2025). These blackouts had widespread impacts on other infrastructure: for example, they caused disruptions to traffic and transport services, telecommunications, and the operation of shops and businesses, and severely impacted the operation of healthcare services.

Outages can be categorized into different types, based on the reason and the pattern of occurrence. Planned outages typically arise due to scheduled maintenance. Unplanned outages can occur for multiple reasons, such as faulty infrastructure or operation, environmental factors (e.g., extreme weather), or systemic imbalance of supply (electricity injection into the grid) and demand (electricity withdrawal from the grid) (Veloza and Santamaria 2016; Shield, Quiring, Pino and Buckstaff 2021; Hines, Apt and Talukdar 2009).

Grid operators have a large incentive to prevent uncontrolled grid collapses, since it often takes multiple days to restore grid service afterward. Hence, uncontrolled, complete grid shut-downs, such as those that recently occurred on the Iberian Peninsula and in Chile, are very rare events. This is because grid operators usually take mediation measures to contain outages geographically and to stabilize the grid. Such mediation measures target, for instance, the reduction of supply or demand, depending on which of the two is in excess. Possible measures include, but are not limited to, reducing the output of renewable generators (curtailment), lowering the grid voltage (brownouts), and cutting off some consumers from the grid (load shedding). Brownouts and load shedding can also be applied in geographic rotation, so that the duration of service disruption is limited for individual consumers. These are then referred to as rolling brownouts and rolling blackouts, respectively.

While outages are relatively rare in Europe, they are a frequent phenomenon in many other parts of the world. The World Bank's 2025 Enterprise Survey reveals significant differences in firms' experiences with power outages. While 23 percent of firms in the European Union reported outages in 2024, this figure stood at 39 percent in the East Asia & Pacific region, 46 percent in South Asia, 71 percent in Sub-Saharan Africa, 29 percent in the Middle East, North Africa, Afghanistan, and Pakistan, 28 percent in North America, and 55 percent in Latin America and the Caribbean. Aggregate outages loosely correlate with country income classifications, with low-income countries experiencing the highest (76 percent) and high-income countries experiencing the lowest outage rates (24 percent).

The Social Cost of Outages

Importantly, electricity outages come at a significant economic and social cost. Blackouts can disrupt firms' business operations, leading to property damage and lost

profits (Zambrano-Monserrate 2026). They may also entail physical health impacts, including injuries and deaths from accidents, carbon monoxide poisoning, or fires caused by unsafe indoor heating and unsafe operation of electricity generators, air pollution impacts from wide-spread use of electricity generators, failure of at-home and hospital medical devices, mental health effects, and health impacts from the consumption of spoiled food (Andresen, Kurtz, Hondula, Meerow and Gall 2023; Lin and Kassem 2025). Criminal activity can also rise, for example, due to fraud, theft, and looting (Andresen et al. 2023). Studies have also emphasized socio-economic disparities in outages, the restoration of infrastructure, and vulnerability, with minorities, poor income groups, the elderly, and rural populations often more heavily affected (e.g., Grineski, Collins, Chakraborty, Goodwin, Aun and Ramos 2023; Liévanos and Horne 2017; Mitsova, Esnard, Sapat and Lai 2018).

Quantifying the social cost of outages is, however, not trivial. A well-established metric consists of determining private individuals' and firms' willingness to pay for avoided outages. This is conceptually coined as the value of lost load (VOLL). Over the years, there have been numerous studies employing different methods to quantify VOLL. It is determined at around USD 5,000 per MWh in Brown and Muehlenbachs (2024) to avoid wildfire-related outages in California, with many other studies estimating VOLL at a similar magnitude in the range of three-to-five-digit USD amounts per MWh, emphasizing the large social cost of electricity service disruptions.¹ Sue Wing and Rose (2020) also show that the economic damage of prolonged power outages depends less on the blackout itself than on how flexibly firms and households can adapt. Their analysis highlights two important buffers against economic losses: the ability of producers and consumers to substitute inputs, and prior investment in backup infrastructure. The stakes become clear in a case study on Commonwealth Edison (ComEd), the largest utility in Illinois. A sustained outage would trigger steep regional losses: a one-day blackout cuts the quarterly GDP of Illinois by USD 1.8 billion (1.3 percent), a three-day disruption by USD 3.7 billion (2.6 percent), and a fourteen-day interruption by a staggering USD 15.2 billion (10.4 percent). Strikingly, these losses are driven not primarily by the direct shock itself, but by cascading shortages and broader disequilibrium effects that ripple through the economy (Sue Wing et al. 2025).

To avoid the social and economic cost of outages, electricity grid operators employ the afore-mentioned grid stabilization measures. However, these measures are costly. For instance, grid operators have to financially compensate large industrial consumers for temporarily halting their consumption, or they have to remunerate firms for providing

¹ See literature surveys in Brown and Muehlenbachs (2024) and Schröder and Kuckshinrichs (2015).

backup electricity supply. Such grid balancing costs are eventually charged to consumers via grid fees as a component of electricity prices. The same holds for investment costs for preventative measures, such as laying grid lines underground to reduce their exposure to environmental hazards. Hence, outage risk has very tangible economic impacts on electricity prices for households and firms, thus burdening consumer electricity bills.

International Data Insights

To inform policymakers about the drivers and consequences of grid disruptions, access to high-frequency data on distribution outages is essential. In our analysis, we employ daily outage data for a diverse set of countries, namely Australia, Belgium, Brazil, China, Germany, and Mexico, drawing on peer-reviewed studies and data from regulatory agencies and distribution system operators (DSOs). The data contains detailed information on the timing and reported causes of outages. By covering countries at different stages of economic development – from emerging economies to advanced industrialized systems – we are able to gain some comparative insights from descriptive analyses.

Seasonality Matters for Unplanned Outages

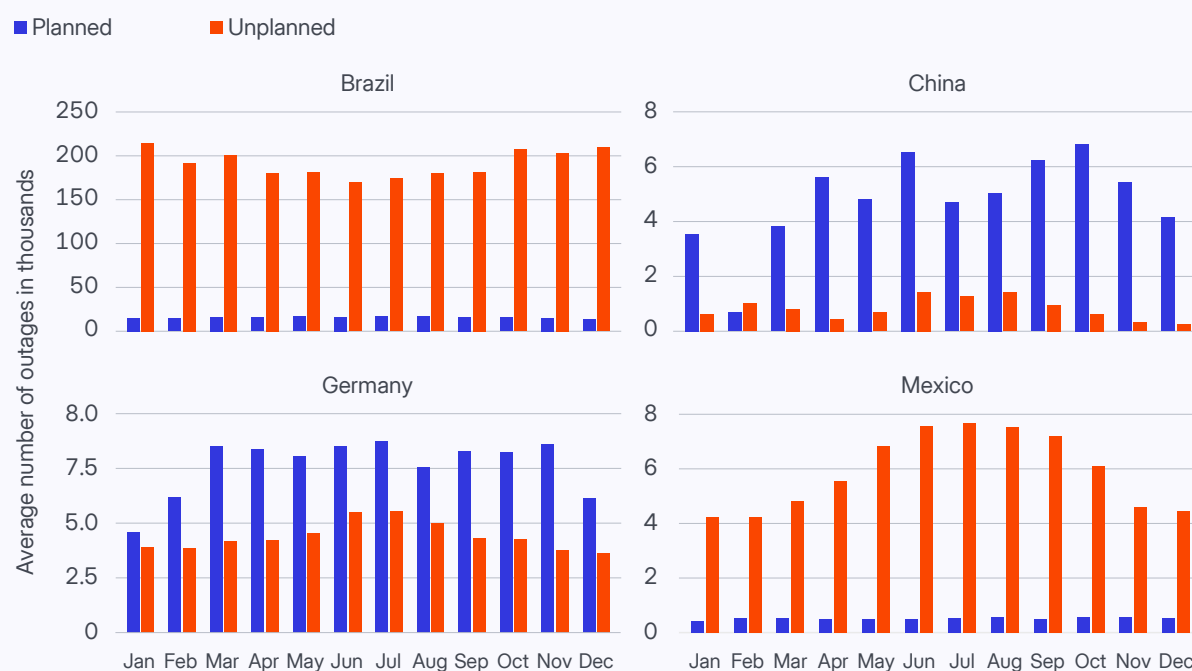
We begin with a high-level analysis of four countries that exhibit markedly different within-year compositions of planned and unplanned outages. Figure 1 reports the average monthly number of planned and unplanned distribution outages in three emerging economies (Brazil, China, and Mexico) and one advanced economy (Germany). While planned outages do not display a clear seasonal pattern, unplanned outages exhibit pronounced seasonality in all four countries.

In China, planned outages exceed unplanned outages by more than an order of magnitude.² However, focusing only on unplanned disruptions reveals substantial seasonal variation. The average number of unplanned outages is lowest in December (246 events per month) and rises sharply to 1,437 events in June – an increase of approximately 584 percent. Germany shows a similar, albeit less pronounced, pattern. Unplanned outages reach a minimum

² Data for China is taken from Wang et al. (2025). Since the data is obtained from web-scraping DSOs websites, it is possible that unplanned outages are underreported.

Figure 1

Planned and Unplanned Outages in the Electricity Distribution Grid in Selected Countries^a



^a Average monthly number of planned and unplanned outages in the electricity distribution grid in Brazil (2017–24), China (2019–21), Germany (2013–23) and Mexico (2017–21).

Source: Adelowo, Colelli, Pavanello and Sarmiento (work in progress).

in December (3,616 events per month) and peak in July (5,546 events), corresponding to an increase of 53 per cent.

Brazil records a substantially higher absolute number of outages throughout the year compared to the other countries in our sample. Average unplanned outages consistently exceed 160,000 events per month and peak above 210,000. In inverted systems relative to the Northern Hemisphere, the highest averages of unplanned outages occur between October and December, while the lowest values are observed around June, corresponding to the austral spring-summer and winter, respectively. This pattern is consistent with Brazil's exposure to convective storms, heavy rainfall, and heat-related demand spikes during warmer months. Moreover, large-scale climate oscillations such as El Niño can further amplify weather volatility in parts of Brazil, increasing the frequency of intense rainfall and storms that stress electricity distribution infrastructure.

Mexico exhibits a similarly pronounced seasonal pattern. Unplanned outages gradually increase from January onward, peak in July and August with monthly averages above 7,500 events, and decline toward December. Planned outages remain relatively stable throughout the year, averaging between 427 and 579 events per month, suggesting a relatively modest maintenance schedule compared with the volume of forced disruptions. Seasonal peaks in

Mexico coincide with periods of extreme heat and the Atlantic hurricane season, both of which are influenced by El Niño–Southern Oscillation dynamics and can exacerbate grid stress through storm damage and elevated electricity demand.

Duration of Unplanned Outages Exhibits Strong Cross-Country Variation

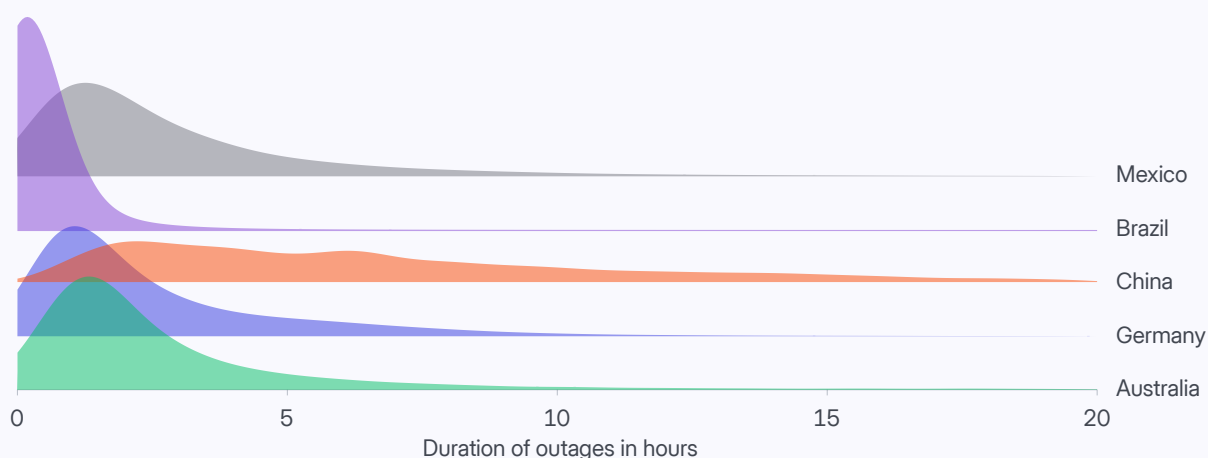
Figure 2 illustrates the distribution of unplanned outages (in hours) in electricity distribution networks across Australia, Germany, China, Brazil, and Mexico. It is evident that the shape and dispersion of the distributions of outages differ between countries.

Focusing first on the median duration, Brazil exhibits the shortest by far, with a median of approximately 7 minutes. Germany, Australia, and Mexico show longer median durations ranging from 1.5 to 2 hours. However, the variance in power outage duration in Mexico is somewhat greater, resulting in a thicker tail compared to Germany and Australia.

In contrast, China stands out with a markedly higher median outage duration above 6 hours, indicating that typical outages last considerably longer than in the other countries. A comparison of the different modes makes these differences particularly clear. Only 1 percent of electricity outages in Brazil last longer than 3.6 hours, and in Germany

Figure 2

Distribution of Unplanned Outage Duration (in Hours) in Electricity Distribution Grids in Selected Countries^a



^a Distribution of unplanned outage duration (in hours) in electricity distribution grids in Germany (2013–23), China (2019–21), Australia (2016–21), Mexico (2017–21), and Brazil (2017–24). Data in Australia includes only unplanned outages in the service area of the distribution network operator Ausgrid in New South Wales.

Source: Adelowo et al. (work in progress).

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only 1 percent exceed 18 hours. In Australia and Mexico, however, the longest 1 percent of outages extend beyond 23.3 hours and 29.5 hours, respectively. China again differs markedly: the longest 1 percent of outages last more than 73 hours. These figures highlight how unplanned electricity interruptions are considerably more prolonged in some countries than in others.

Extreme Outages in the Spotlight

Figure 3 shows the time series of the country-level total number of outages by day for Germany, Mexico, and Brazil. We also highlight the dates on which the highest number of outages occurred. Widespread outages in Mexico between February 15 and 17, 2021, were primarily caused

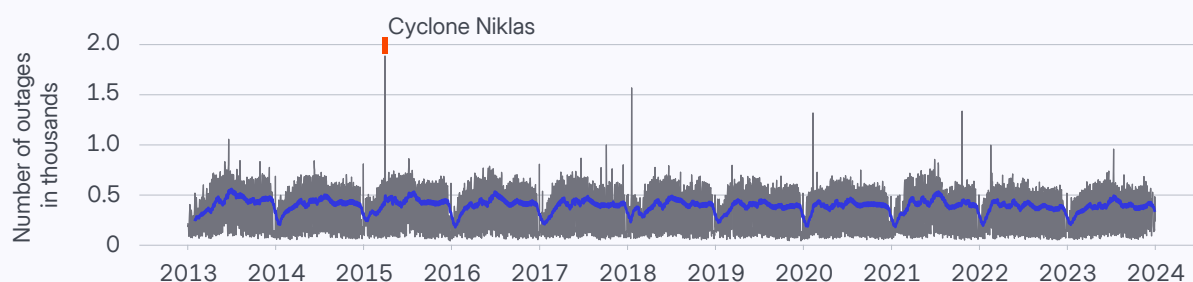
by the severe winter storm that affected large parts of North America (Kemabonta 2021). The extreme cold led to disruptions in natural gas supply from the United States, on which Mexico heavily depends for electricity generation. As gas shortages intensified, power plants were forced of-line, resulting in rolling blackouts across several regions. The event exposed the vulnerability of Mexico's electricity system to weather shocks and cross-border fuel supply constraints.

On November 3, 2023, more than 50,000 outages in Brazil were triggered by an unusually powerful storm that swept through the state of São Paulo and nearby regions, bringing very strong winds that uprooted trees and downed distribution lines (Dugan, Gonçalves, Costa, Dutra, Souza

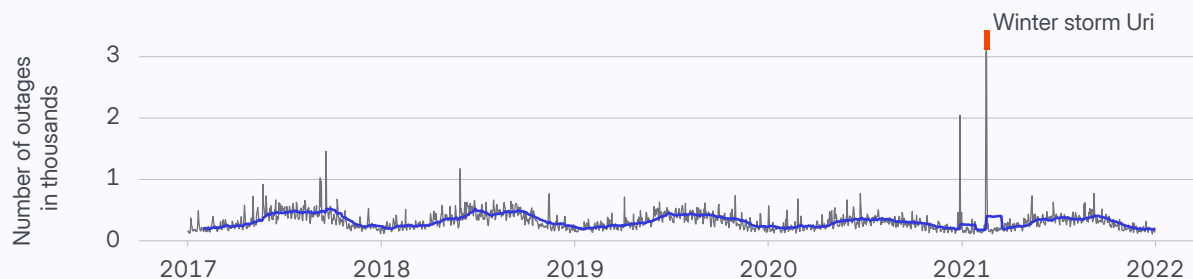
Figure 3

Time Series of Daily (Planned and Unplanned) Outages in Germany, Mexico, and Brazil^a

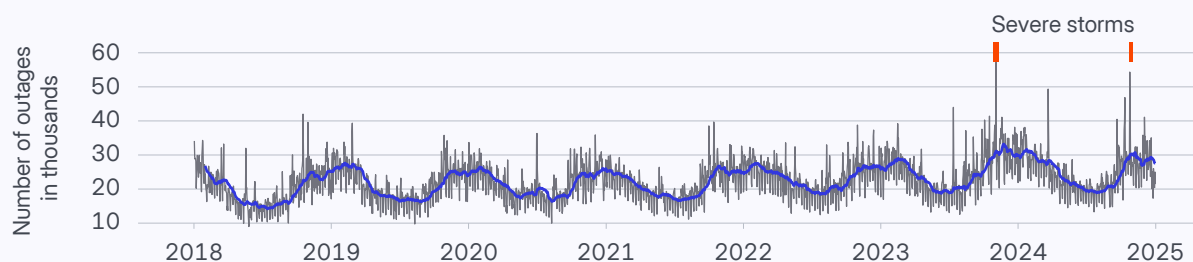
Germany



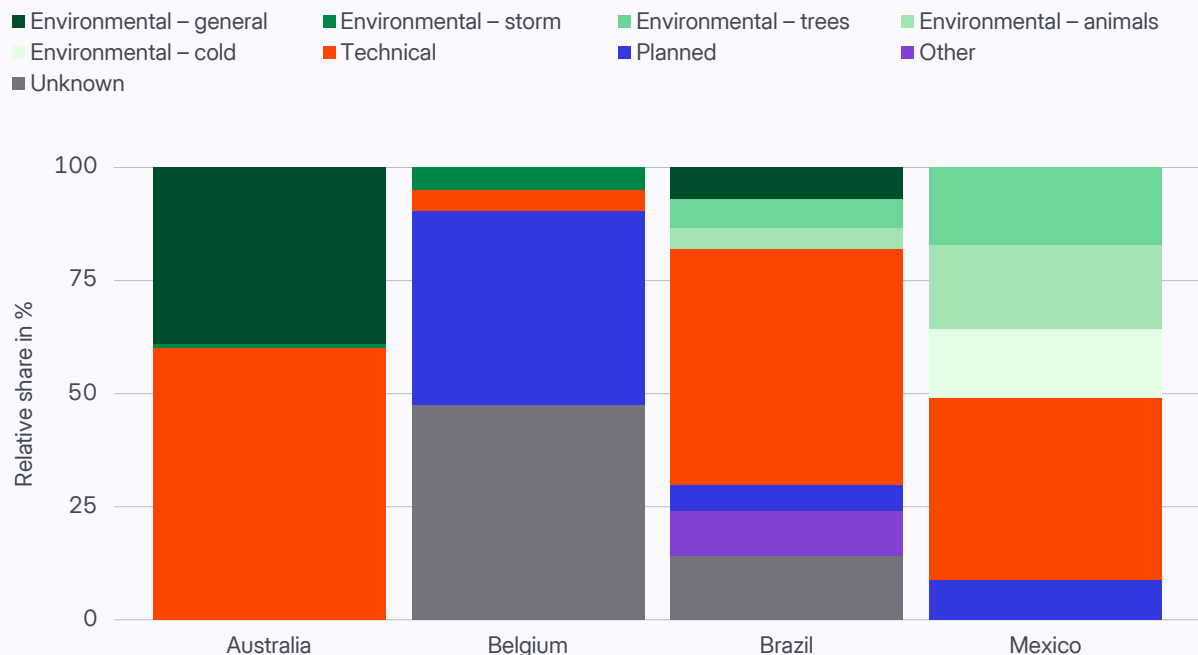
Mexico



Brazil



^a Time series of daily (planned + unplanned) outages in Germany, Mexico, and Brazil. Black lines show the country-level total daily outages; the blue line shows the monthly moving average. Major weather events, highlighted in orange, correspond to the days with peak outage records.
Source: Adelowo et al. (work in progress).

Figure 4**Reported Outage Reasons by Country – Australia, Belgium, Brazil, and Mexico^a**

^a Relative distribution of outage reasons by country. Stacked bars show the share of outages attributed to environmental, technical, planned, unknown, and other reasons.

Source: Adelowo et al. (work in progress).

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and Mohagheghi 2025). The severe weather damaged critical parts of the electricity distribution network, leaving over 11 million customers without power, corresponding to around 5 percent of the national population.

In Germany, the largest event occurred on March 31, 2015, with 1,887 registered outages whose cause could not be identified. The most plausible, widely documented explanation for these power outages is the impact of the severe European windstorm Cyclone Niklas, which crossed large parts of Germany on that exact date (Pantillon, Lerch, Knippertz and Corsmeier, 2018). The storm produced hurricane-force winds, in some locations exceeding 200 km/h, and caused widespread infrastructure damage, including fallen trees, structural damage, and power outages across affected regions. The event also generated major disruption across transport and energy systems and led to fatalities (BBC News 2015). The combination of extreme wind and physical damage to grid infrastructure is consistent with large numbers of distribution line outages during that period.

Overall, the three countries all show intra-annual patterns disrupted by individual extreme outage events. While there

seems to be no clear long-term trend in average outages in Germany and Mexico, the data for Brazil suggests a rising trend in average reported outages in the last years.

Tracking Why Outages Occur

Figure 4 illustrates how detailed outage reasons vary across countries, reflecting differences in infrastructure, reporting practices, and environmental exposure. In Australia, technical failures account for around 60 percent of outages, with environmental factors contributing to the remaining 40 percent. In Belgium, planned maintenance accounts for around 43 percent, and environmental events and other minor categories comprise around 5 percent. Importantly, 47 percent of outages are not reported as being associated with any specific cause. In Brazil, technical failures make up more than 50 percent of outages, while environmental events such as storms and tree falls contribute around 20 percent. Still, in Brazil as well, around 15 percent of outage reasons are unknown. In Mexico, environmental events are more salient than in other countries, with storms, extreme cold, animals, and trees accounting for around 50 percent in combination, while technical failures and planned outages contribute the remaining half.

Overall, our data indicates that tropical countries such as Brazil and Mexico may be relatively more exposed to environmental disruptions. Australia also exhibits a substantial share of environmentally driven outages, although the broad classification of causes prevents a more granular assessment. At the same time, the high proportion of unknown outages in Belgium and Brazil highlights the challenges power companies may face in accurately attributing distribution outage causes.

Finally, we observe notable cross-country differences in reporting standards and data availability. Some countries, such as Mexico, provide highly detailed classifications of outage causes, whereas others rely on broader categories or aggregate multiple causes into general groupings. For China, we can only differentiate between planned and unplanned. In other countries beyond the scope of this work, detailed cause-specific information is often not available at all. For instance, in the United States, the Energy Analysis

and Grid-Level Evaluation (EAGLE) database primarily reports outage events without consistently disaggregating their underlying causes (Brelsford et al. 2024).

Within-Country Patterns: Evidence from Mexico

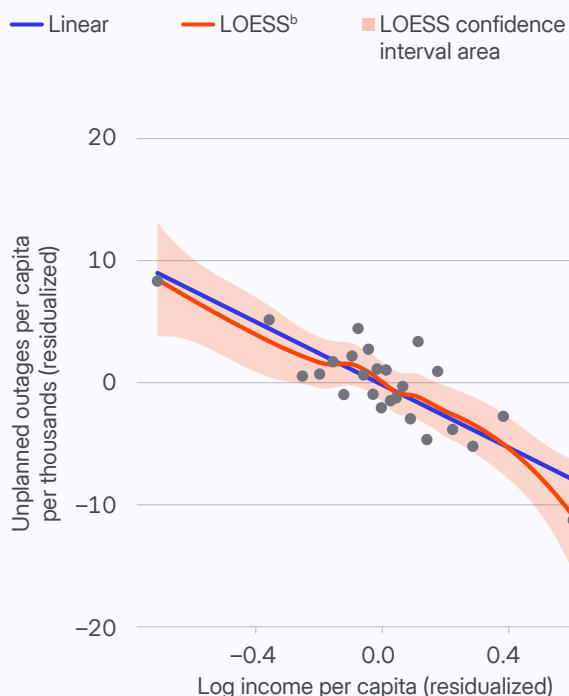
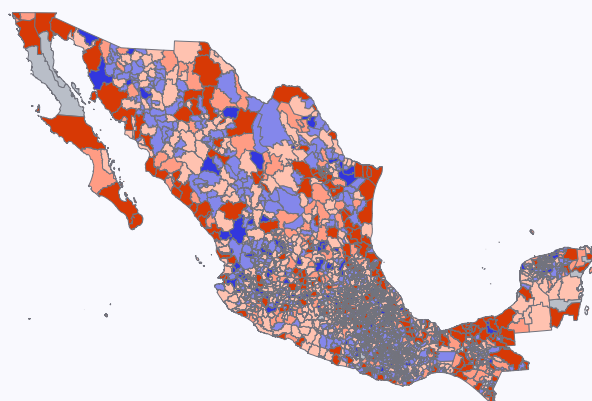
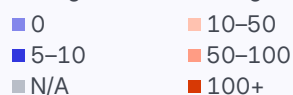
While planned outages may reflect maintenance and investment activities aimed at improving grid performance, unplanned interruptions provide a more direct measure of grid reliability. A natural question is whether, within a country, exposure to abrupt and unplanned electricity outages varies systematically with local economic development – even though the electricity network constitutes a publicly regulated infrastructure.

The left panel of Figure 5 maps the average annual number of unplanned outages at the municipal level in Mexico. A striking pattern emerges: most municipalities experience more than 100 unplanned outages per year, with partic-

Figure 5

Distribution of Unplanned Distribution Grid Outages and Their Relationship with Income in Mexico^a

Average number of outages



^a The left graph represents the yearly distribution of unplanned distribution grid outages in Mexico. The right graph shows a binned scatterplot with 25 bins, a linear regression, and a local polynomial regression on the underlying data. The depicted correlation between residualized outages per 100,000 people and income per capita (in logs) is net of municipality and state-year fixed effects and municipality-level controls. For both panels, the reference period is 2017–21.

^b Locally Estimated Scatterplot Smoothing.
Source: Adelowo et al. (work in progress).

ularly high incidence in coastal, tropical, and northern regions. These spatial patterns are consistent with differential exposure to extreme weather events. Coastal and tropical areas, for example, are more frequently affected by hurricanes, tropical storms, and strong winds, all of which place substantial stress on overhead grid infrastructure.

The key question, however, is whether economic development is associated with differences in grid resilience. The right panel of Figure 5 plots the residual relationship between municipality-level annual unplanned outages per 100,000 inhabitants and (log-transformed) income per capita. The relationship is approximately linear and strongly negative: richer municipalities experience significantly fewer unplanned outages.

This pattern suggests that grid reliability, despite being embedded in a publicly regulated network, is systematically correlated with local income levels. Differences in maintenance, infrastructure quality (e.g., underground vs. overhead lines), enforcement, or political economy mechanisms may translate into heterogeneous resilience across municipalities. At the same time, lower-income households might be more likely to live in disaster-prone areas and could therefore be more exposed to outage risk from environmental impacts.

Grid Resilience in a Climate Change Context

Climate change is increasing not only average temperatures but also the frequency, intensity, and volatility of extreme weather events, such as hurricanes, typhoons, and storms. As a result, the reliability of energy infrastructure would emerge as a critical vulnerability.

Recent episodes illustrate the magnitude of these risks and their broader implications. In February 2021, an extreme cold spell triggered a widespread grid failure in Texas. The combination of freezing temperatures and prolonged power outages for heating resulted in hundreds of deaths, due both to hypothermia and carbon monoxide poisoning, the latter stemming from the indoor use of cars and generators. More recently, in July 2024, a compound event in Houston, combining hurricane damage with an intense heat wave, left over one million households without power and severely strained emergency services (Feng, Lin, Gori, Xi, Ouyang and Oppenheimer 2025). In September 2024, an unusual heat wave in the Mexican state of Tabasco led to repeated blackouts and transformer failures; one prolonged outage affecting rural communities near Villahermosa prompted residents to block a major federal highway in protest. In Rome, the local power distributor ARETI reported a EUR 60 million (a 20 percent year-over-year) rise in 2024 grid re-

silience costs and employed more than 800 technicians to restore the local distribution grid during the 2025 heat-wave (Roma Capitale 2025). These incidents underscore the substantial social, health, economic, and political costs associated with climate-induced power disruptions.

In response to the growing salience of these events, there is a slowly emerging empirical literature linking grid resilience to climate change and natural disasters. However, existing studies predominantly focus on large-scale disruptions in the United States. For example, Hines et al. (2009) examine major blackout events in the United States, defined as affecting at least 50,000 customers or 300 MW of demand. The authors document that the frequency of such events is higher during peak hours and in late summer and mid-winter. Shield et al. (2021) combine multiple datasets to analyze major weather-related power disruptions in the United States, finding that weather accounts for roughly 50 percent of all these outage events and 83 percent of affected customers. Among weather-related causes, thunderstorms account for 47 percent of events, winter storms for 31.5 percent, and tropical cyclones for 19.5 percent. They also estimate median utility restoration costs during major storms of approximately USD 12 million. Finally, Adelowo (2025) shows that the 2021 Texas cold-wave blackout led to a subsequent increase in permits for private backup generators and solar-battery systems, suggesting household-level adaptation in response to grid unreliability.

However, climate change may also operate through small-scale, high-frequency disruptions that are less salient but can entail relevant socio-economic costs. Leveraging daily distribution-grid outage data from Mexico, Colelli, Pavanello and Sarmiento (2026) show that extreme temperatures substantially increase the incidence of unplanned technical power outages, primarily through grid overload. They estimate that 30 percent of overload outages are attributable to temperature shocks, rising to nearly 70 percent during the summer months. The mechanism is intuitive: higher electricity demand for cooling appliances places additional strain on distribution infrastructure, increasing the likelihood of overload failures. Moreover, the authors find that when outages coincide with hot days, heat-related mortality increases in the subsequent week.

This aligns with recent findings from Ai, Crago and Mullins (2025), who employ monthly county data in the United States to examine the amplification effects of power outages on heat-related mortality. They estimate that each hour of power outage on a hot day (80°F, about 27°C) increases the harm from the hot day by 61 percent. The channels are again straightforward. Without electricity, households cannot operate air conditioners, fans, or re-

frigerators, limiting their ability to cope with extreme heat. At the same time, power disruptions can impair the functioning of healthcare facilities and other critical services. Together, these effects amplify heat exposure risks and translate grid unreliability into measurable health consequences.

Overall, existing evidence suggests that while expanding access to electricity – and to electric adaptation options like air conditioning – remains a central development objective, the reliability of supply is equally critical for welfare and productivity in a warming climate.

Policy Implications

In modern economies, policymakers have incentives to contain outage risks and electricity service disruptions, while simultaneously strengthening system resilience to outages. One motivation is to avoid the social and economic costs associated with electricity supply disruptions, which, in the age of digitization and electrification, are becoming increasingly consequential. At the same time, investments in outage prevention and grid management are costly, and they eventually place upward pressure on electricity prices for firms and households.

Our analysis of unplanned outage patterns reveals seasonality, hinting at a relationship of outage risk with climate and weather conditions. With climate change already in motion, these risks can be expected to worsen in the next years. Hence, policymakers face the additional challenge of dealing with both an expected rise in outage risk and associated prevention costs.

We identify three main areas of required policy action, which are laid out in more detail below, and outline the European case.

Investments in Outage Prevention and Resilience

In some regions, policymakers are already implementing targeted interventions against weather-related and climate change-associated outage risks. A prominent example is the wildfire prevention measures in California. Climate change is increasing temperatures, while reducing rainfall in California. The resulting dry vegetation can easily ignite and spread fire, supported by strong winds. Electrical infrastructure can act as an ignition source when vegetation or debris comes into contact with overhead lines. To avoid such risks, Californian utilities perform public safety power shutoffs (California Public Utilities Commission 2026a). During these shutoffs, grid operators temporarily cut off parts of the grid that are exposed to strong winds during dry periods to prevent electrical ignition of vegetation. While

effective in reducing fire risks, these measures result in widespread temporary outages, with potentially severe social and economic costs (Brown and Muehlenbachs 2024).

Two other preventive measures undertaken for wildfire prevention in California are the installation of sensors that automatically trip a specific powerline upon detected contact, as well as the burial of power lines underground (Warner, Callaway and Fowlie 2025). However, such retrofits not only come with their own technological difficulties but are also highly capital-intensive and significantly ramp up consumer electricity prices. For instance, undergrounding all remaining overhead grid infrastructure in California (about 67 percent) would cost around USD 260 billion (California Public Utilities Commission 2026b).

More broadly, with climate change increasing the likelihood of extreme floods and strong wind events (e.g., hurricanes, cyclones) in other world regions, policymakers in these affected countries will have to develop strategies to reduce exposure of grid infrastructure to environmental damages, such as by undergrounding power lines. At the same time, rising temperatures create a different but equally pressing challenge for policymakers: grid overload driven by surging electricity demand for cooling during heatwaves. This pattern has already emerged as a systematic source of outages in regions such as the southern United States and Mediterranean Europe, including Italy.

Equitable Distribution of Costs and Risks

A central policy challenge concerns the equitable allocation of the substantial investment costs required to enhance resilience, both across socio-economic groups and across generations. Beyond infrastructure investments, policymakers may also consider mechanisms to distribute outage exposure more evenly during periods of grid stress. Reguant and Wagner (2025) propose a rationing mechanism that imposes temporary, uniform power limits on households, thus reducing electricity consumption at the intensive margin, rather than implementing rolling blackouts that disconnect consumers entirely, that is, the extensive margin. Their analysis shows that this approach decreases the number of households experiencing power shortages. Rationed households could still maintain basic electricity services such as refrigeration, while higher-income households are more likely to be limited in the use of convenience services such as cooling.

Strategic, Data-Driven Analysis

The core prerequisite for each grid operator to undertake appropriate outage prevention investments is to understand

how and why outages are caused in the first place. This requires detailed reporting and collection of outage statistics. However, the availability, detail, and quality of such statistics strongly vary across countries. For instance, our analysis of outage reasons revealed that in Belgium, an extraordinarily high share of outages is classified as “unknown.” This can cause blind spots for regulators and grid operators in becoming aware of and identifying systematic outage risks. Furthermore, many regulators only collect aggregate annual statistics (such as the total outage duration experienced by the average customer), which do not provide the level of detail needed for more sophisticated analysis. This, in turn, prevents targeted outage management measures.

Leveraging high-frequency data on outages could provide a unique opportunity to identify spatial and temporal patterns of grid stress across diverse climatic and infrastructural contexts. Such evidence can help policymakers identify resilience gaps and prioritize investments in grid infrastructure under increasing climate pressure. We therefore recommend that policymakers take the initiative to monitor outage exposure, outage reasons, and timing more closely, ideally with internationally harmonized standards. The existing heterogeneous reporting of outage statistics makes comparisons of outage risks and exposure across countries very difficult. However, joint reporting standards are crucial, because many countries – for example, in the EU – have interconnected electricity grids, where outage risks can quickly cascade across borders. Policymakers should therefore engage in coordinated efforts to improve international electricity supply security.

European Integration

Greater integration of European electricity grids could, in principle, enhance resilience by increasing system redundancy and broadening the pool of resources available to absorb supply-side shocks, such as extreme weather events that simultaneously stress generation and transmission infrastructure. At the distribution level, deeper integration of decentralized assets, including local renewable generation, may further buffer localized disruptions. At the same time, tighter interconnection introduces well-documented risks of cascading failures, whereby stress in one national grid propagates rapidly across borders, a concern that underscores the importance of coordinated governance frameworks alongside physical integration. The net welfare effects of deeper grid integration therefore also depend on whether institutional capacity, including harmonized data sharing and joint operational protocols, keeps pace with the expansion of physical interconnection. •

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