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FORUM

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While Europe's Geoeconomic Strategy Solidifies, Blind Spots Remain

Over the past few years, the European Union has responded to increasing threats to its economic security. It has moved beyond the previous consensus that the EU is an economic power to become a player that is less naïve and has the tools to deal with economic coercion, foreign investments in critical infrastructure and resource dependencies.

European Commission President von der Leyen highlighted in 2019 the need for a "geopolitical Commission" to respond to the challenges of a more unstable international environment. European Council President Michel also made the case for European strategic autonomy in 2020. The 2021 EU Trade Policy Strategy coined the term "open strategic autonomy" to emphasise the need to make trade openness compatible with strategic autonomy. Since then, major strides were made, including an anti-coercion instrument and a foreign direct investment screening mechanism, and anti-dumping and subsidy investigation instruments have been sharpened.

In January 2024, the European Commission unveiled five initiatives on European Economic Security. In particular, the initiatives aim to (1) strengthen the protection of EU security and public order by improving screening of foreign investment, (2) stimulate discussions for more European coordination in export controls, (3) consult on outbound investment screening to limit risks in certain technologies (4) support research and development in dual-use technologies, and (5) develop recommendations on research security.

Yet, despite this substantial shift in approach as well as the welcome concrete initiatives, the EU remains vulnerable to economic security risks and still has more limited capacities to act than large countries outside Europe. Three areas deserve further attention as Europeans go to the polls to elect their new parliament and shape the new European leadership. First, the overarching topic remains institutional reform to improve capabilities to align economic and security interests better in the EU. Second, the EU is unprepared for a second Trump presidency, and when it comes to economic risks it is particularly unprepared in the digital space. Third, European production of military equipment needs to progress more rapidly, and European synergies should increase.

The EU's institutional framework to deal with economic security risks does not allow the EU to be the effective player it should be given its economic size. While economic policies in terms of trade, single market and competition are clear EU competencies with decisions mostly taken by a qualified majority, questions on economic security are still mostly handled by member states. The approach so far has been to address this weakness by better coordinating action, as, for example, in the January 2024 package on export control, while also agreeing on some watering down of state aid control to reduce critical dependencies. Yet, this approach is not enough in a world in which security tensions may rise. To be an effective economic power that is proactive rather than just reactive, institutional reform that aligns decision-making across security and economic domains is needed.

Take investment screening as an example. Responsibility for screening investments into the EU market still largely falls to individual countries. In 2016, the Netherlands allowed major Chinese investments into the ports of Rotterdam. In 2023, China's Cosco took a share in Hamburg's port, leading to substantial debates on the security implications. But neither the Dutch nor the Ger-

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man decisions were made at the EU level that would have accounted for cross-country security spillovers. If such investments raise security concerns, the EU must come to a shared security assessment as the single market is too integrated and goods flow unrestricted across borders.

Another area concerns export restrictions and sanction policy. Take the example of sanction policy: while the EU has successfully been able to pass 12 sanctions packages against Russia, unanimity requirements have sometimes slowed decision-making. Moreover, enforcement of sanctions has been imperfect, and there are limited mechanisms to hold countries accountable. Meanwhile, weaker EU-level state aid controls without common EU resources for subsidies risk undermining the even playing field that is so central to a booming internal market.

Addressing these institutional weaknesses ultimately requires treaty reform to move beyond unanimity voting requirements on security matters. Intermediate institutional steps could include the formation of an economic security committee, where top national security officials work with European economic executives to come to a shared assessment and more effective decision-making.

Vulnerabilities in the digital economy stem from the EU's dependency on American and Chinese products. European countries manufacture relatively little of their own cloud-computing systems, key software, including AI, and telecommunications infrastructure. One area is the telecom infrastructure, where some European countries have a substantial share of Chinese products built into their systems. In a deepened political confrontation between China and the US, a Trump presidency could threaten major telecom operators with sanctions, with potentially major consequences for the EU telecommunications market. It is high time that EU countries reduce their dependence on Chinese telecom products to prepare for a tougher line from the White House.

A bigger vulnerability comes from cloud computing, where Europe relies heavily on US capacities. The US CLOUD Act of 2018 requires cloud computing companies to hand over data to law enforcement even if data is stored in Europe with little or no regard for EU data protection laws. EU and US policymakers have made some progress in dealing with the data protection challenge. But a second Trump presidency could make cooperative solutions on data protection impossible. To prepare, it would be advisable to discuss whether cloud computing services should be provided exclusively by firms headquartered in the EU. Yet, there are risks to that strategy: new cloud service providers will be smaller and probably more expensive, and they might find it more difficult to guarantee the same level of cybersecurity. Like geolocation services and satellite communication, cloud storage services also have a military dimension – after all, modern weapons often rely on data that must be stored. This is a further dimension where the EU will need to invest in its security.

To prevent a major fallout in digital transatlantic relations, the EU should develop a strategy to uphold cooperation with the US. The EU-US Trade and Technology Council might be the right forum for closer cooperation, but clearly risks remain in extreme political scenarios.

A final topic that has not yet received sufficient attention and deserves deeper discussions is cooperation across the EU on defence production and procurement. While some instruments exist, the EU needs a bold European defence industrial strategy. It has started the process with a consultation, and Commissioner Breton has called for a fund. In the short term, it will be crucial to enlist all EU countries to provide more military support to Ukraine to prevent a major geostrategic failure – a further weakening of Ukraine. Now is also the time to develop a strategy on how the EU can sustainably and cost-effectively boost its military production capacities.

It is time to move to a more proactive geoeconomic strategy. The EU should build on its strengths by deepening the single market and concluding trade agreements to boost the growth potential of Europe, the basis of its economic and military power. But it needs to go beyond a pure economic strategy by addressing institutional weaknesses, developing a more forceful digital strategy and, last but not least, boosting European military production capacity.

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Artificial Intelligence: Potential and Challenges for Europe

Artificial intelligence (AI) is a technology that is transforming every aspect of life from finance to transportation, health care and national security. It has already started to revolutionise the way we communicate, conduct research, analyse data and streamline labour processes. However, AI also requires understanding and regulation in order to address issues such as algorithmic bias, ethics, transparency and data access obstacles that will inevitably impact society, governance and the economy. To this end, the member states of the European Union endorsed the Artificial Intelligence Act in February 2024, a legal framework that aims to ensure that AI systems placed on the European market and used in the EU are safe and respect fundamental rights and European values. This is the first such agreement of its kind and may have implications for other countries currently working on similar regulations. This Forum explores some of the ways that AI is changing the status quo, the challenges of regulating this technology and the economic impact of the ongoing transition.

Generative Artificial Intelligence – Foundations, Use Cases and Economic Potential

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Artificial Intelligence and Cybersecurity

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The Generative AI Challenges for Competition Authorities

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The Impact of Artificial Intelligence on Productivity and Employment – How Can We Assess It and What Can We Observe?

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Volker Brühl

Generative Artificial Intelligence – Foundations, Use Cases and Economic Potential

A key technology driving digital transformation is artificial intelligence (AI), which has gained a sudden momentum and a high degree of public attention with the initial release of the chatbot ChatGPT (where GPT stands for generative pretrained transformer) on 30 November 2022. ChatGPT is an AI-based application developed by Open AI that anyone can experiment with and use. Despite lots of deficiencies, ChatGPT demonstrates the capabilities of an AI-based application for everybody. Within a very short period, ChatGPT has triggered discussions about the economic and social impact of AI and whether the rapid diffusion of AI technologies is desirable. Nevertheless, it is quite apparent that AI is and will continue to evolve into one of the key meta technologies that will shape the future of industry and society in the coming years, if not decades.

This article provides a brief overview of the foundations of generative AI (GAI), including machine learning, important players in this emerging market, possible use cases and the economic potential as of today. Finally, it looks at the current status of the forthcoming European Artificial Intelligence Act (AI Act), which will be an important milestone in developing a regulatory framework for trustworthy AI in Europe and beyond.

Machine learning – A brief overview

There are a number of quite diverse definitions for the term "artificial intelligence". For instance, it may be understood as a generic term for technologies and systems with the ability to perform tasks that would otherwise require human intelligence. This presupposes certain skills that can be roughly broken down into "perceiving", "reasoning/decision-making", "acting" and "learning" (e.g. Russell and Norvig, 2022). According to these basic generic elements of an AI system, AI is often divided into different fields of technologies such as "speech recognition", "image/video recognition", "natural language processing", "computer vision" and "robotics". The perceived structured or unstructured data has to be transformed into knowledge ("knowledge representation"), forming the basis to find the optimal solution in a given environment ("knowledge reasoning and optimisation"). Performing a physical act (e.g. through actuators of robots) or providing digital information (e.g. text) usually leads to a change of the environment, which may feed into a learning process of the respective AI system. Hence, a key element of AI systems is usually a type of machine learning. Machine learning (ML) is a subset of AI that seeks to enable machines to perform tasks in an optimised way through experience (Mitchell, 1997).

For instance, ML is supposed to improve decision-making, forecasting or classification problems (see e.g. Murphy, 2022; Russell and Norvig, 2021). In data science, the concept of machine learning involves using statistical learning and optimisation methods that let computers analyse datasets and identify patterns (UC Berkeley, 2022).

It should be noted that ML systems do not operate on programmed solution algorithms but build a model themselves by learning from the available data. Machine learning algorithms ensure that the results of actions or changes in environmental conditions are used to optimise the system's performance in an iterative process. Hence, models based on machine learning must be trained and tested with given data sets before they can reasonably be used to draw conclusions from new data. ML is applied in many fields such as speech, image or natural language recognition. It may also be integrated into robotics, smart factories or smart home applications. Depending on the data availability and method of training, two basic learning categories – "supervised learning" and "unsupervised learning" – can be distinguished (see e.g. Goodfellow et al., 2016; Mitchell, 1997; Murphy, 2022).

Supervised learning refers to the development of a prediction model that is trained with the help of given input and known output data. By comparing the model-based predictions with the correct outputs, prediction errors can be identified and the model can gradually be optimised. As the volume of training data increases, prediction errors are reduced. Learning algorithms used in the context of supervised learning include decision tree techniques, regression analysis, support vector machines, discriminant analysis and k-nearest neighbours algorithms. These

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algorithms can be used for tasks such as classification or forecasting. Common use cases include spam filters, fraud detection systems, recommendation engines and speech or image recognition systems. Many virtual assistants, such as Apple's Siri or Amazon's Alexa, are trained with supervised learning algorithms to communicate with users through a natural language interface.

In unsupervised learning settings, algorithms analyse unlabelled data. The objective is to discover hidden patterns, relationships, or structures within the data. Common unsupervised learning techniques include Bayesian networks, hidden Markov models and clustering algorithms such as K-means or hierarchical clustering. Typical applications are clustering processes, e.g. for customer segmentation or in healthcare to gain a better understanding in diagnosis, prevention and treatment of diseases.

"Reinforcement learning" is a further category of machine learning in which intelligent agents attempt to optimise an output through a given incentive system. A particular form of reinforcement learning has been used in GAI by integrating human feedback during the training phase (reinforcement learning from human feedback).

Self-supervised learning refers to a category of machine learning in which the system trains itself by first structuring the given unlabelled data, then using this structure to further optimise the output of another task. As such, this process involves transforming the unsupervised problem into a supervised problem by auto-generating the labels.

Artificial neural networks (ANN) are used as a form of machine learning, both in the field of supervised and unsupervised learning. The way that the human nervous system transmits information serves as the conceptual model for ANN. Like biological neural networks, ANNs consist of a large number of artificial neurons (units). ANNs can be classified according to various criteria, such as the number of hidden layers. Conventional ANNs contain only a few hidden layers, while so-called deep ANNs contain numerous hidden layers. These ANNs, also known as deep learning models, require a high volume of training data in order to achieve a satisfactory prediction quality due to the large number of connections between the neurons. Different learning algorithms are used in deep learning, such as convolutional neural networks, long short-term memory networks, recurrent neural networks, generative adversarial networks, multilayer perceptrons, deep belief networks or restricted Boltzmann machines. Artificial neural networks are now being used or tested in many different fields. These include, for example, natural language processing and speech or image recognition. Common business applications include quality management, production or sales planning, maintenance processes and credit rating systems. ANNs also play a role in research and development, e.g. in autonomous driving or biotechnology.

Generative AI – What sets it apart?

Generative AI is a relatively new field of AI that has gained considerable public attention, especially since the release of ChatGPT in November 2022, which is easy to use and demonstrates the power of generative pretrained transformer systems (Cao et al., 2023). GAI is a category of AI systems that is capable of generating new text, images, videos or programming code in response to instructions (prompts) entered by the respective user. GAI applications such as the chatbot ChatGPT (OpenAI/Microsoft) are based on the large language model (LLM) GPT-3/GPT-4. This is similar to alternative solutions including Bard (Google) that use their foundation model LaMDA (Language Model for Dialogue Applications). LLMs are deep learning networks trained on huge amounts of text data to understand the syntax and semantics of human languages in different contexts. GAI systems apply "transformer" models, which are advanced LLMs using the "attention mechanism" to help identify the most informative parts in a text by perceiving associations and meanings of words and sequences of words.

Compared to traditional LLMs, transformers get a better and faster understanding of a task by analysing all words in a text simultaneously (rather than sequentially) while dynamically adjusting the "attention" (i.e. the perceived relevance of the word) during the solution process (Vaswani et al., 2017). The amount of training data and the number of parameters the neural network attempts to optimise are important factors for the performance of the system, for example in terms of comprehending text, generating answers to given questions, recognising images or generating code. For instance, GPT-3 is trained on 570 GB of text and can optimise up to 175 billion parameters to solve a specific task (Brown et al., 2020). Recent breakthroughs in GAI have been made possible by advances in computer hardware, especially in graphics processing units, enabling massive parallel processing of data in machine learning models.

Competitive landscape and expected market potential of generative AI

Table 1 provides a brief overview of the current important players in the field. Although this is only a snapshot that will certainly change in the coming years, it is striking that a substantial portion of the players belong to Big Tech companies. Most of these have their own GAI ac-

Table 1
Competitive landscape in generative AI (selection)

Category	Tool	Company	Country
Chatbots	ChatGPT	OpenAI (Microsoft)	USA
	Bard	Google	USA
	Bing AI	Microsoft	USA
	HuggingChat	Hugging Face	USA
	Jasper AI	Jasper	USA
	ChatFlash	neuroflash	Germany
Large language models	GPT-4, GPT-3.5	OpenAI (Microsoft)	USA
	Claude 2	Anthropic	USA
	Luminous	Aleph Alpha	Germany
	cohere command	Cohere	Canada
	PalM2	Google	USA
	LLaMA	Meta	USA
Code generation	AlphaCode	DeepMind (Google)	USA
	GitHub Copilot	GitHub(Microsoft)	USA
	Tabnine	Tabnine	Israel
	Open AI Codex	Open AI	USA
	Codebase	MutableAI	USA
	Replit AI	Replit	USA
	Codacy	Codacy	Portugal
Image/Videos	DALL-E2	OpenAI (Microsoft)	USA
	Imagen	Google	USA
	Stable Diffusion	Stability AI	UK
	Synthesia	Synthesia	UK
	Midjourney	Midjourney	USA
	Openart	OpenArt	USA

Source: Author's own analysis.

tivities, but they have also added to their portfolio through acquisitions of upcoming start-ups in the field. Examples include the investment of Microsoft in OpenAI and the takeover of DeepMind by Google.

It can be expected that further takeovers of promising start-ups on the list will follow. This is another warning signal underlying the severe antitrust issue related to the dominant market position of Big Tech companies and their deep pockets (see e.g. Brühl, 2023). European companies are, with a few exceptions, not among the leading players in a field that will most likely be a major area of growth in the next decade. This becomes especially clear when we take a look at a list of important use cases that can already be identified and which covers basically all industries and many components of their value chain (Table 2).

Table 2
Use cases of generative AI

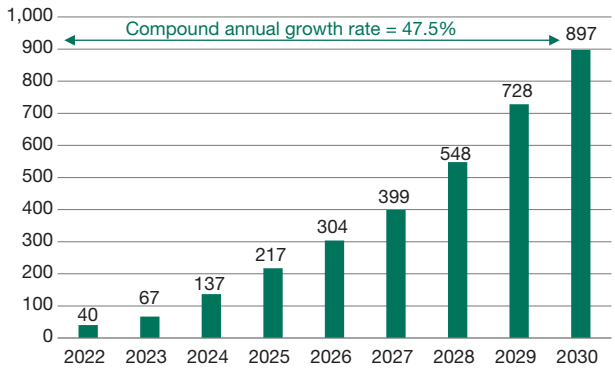
Modality	Fields of application	Use cases (examples)
Text/Audio	Customer communication	Content writing, personalised customer care, sales, marketing
	Data Analytics	Customer behaviour, segmentation, profiling
	Virtual Assistants	Sales support, technical support, process documentation
	Publishing	Editorial services, translations, creative writing
Images/Videos	Image recognition	Face recognition, cybersecurity services
	Image generation	Marketing, PR, Non-Fungible-Tokens (NFT)
	Video generation	Media production, PR
	Cross Media	E-commerce, E-learning
Code	Code generation	Agile software development/ engineering
	Code optimisation	Rapid prototyping, accelerated system integration
	Code testing	Quality assurance
3D	Virtual Reality	Product development with digital twins
	Augmented Reality	Industrial maintenance
	Metaverse	Gaming, new work, social metaverse

Source: Author's own analysis.

Potential fields of application cover not only the automation and acceleration of homogeneous workflows (e.g. text generation and processing in administrative functions). GAI can also support creative and technically complex activities, e.g. in IT, marketing or product development. Hence, the diffusion of GAI may lead to redundancies of low-skilled employees while at the same time the need for highly skilled personnel will further increase. Research on potential productivity enhancements through the use of GAI tools is still at an early stage. However, a recent study by MIT researchers found that the productivity of skilled employees could be improved by up to 37% when using chatbots such as ChatGPT in their daily writing routines (Noy and Zhang, 2023). Therefore, the smart adoption of AI tools could help to mitigate the shortage of skilled workers, especially in ageing societies. At the same time, human-machine interaction will become a key part of many people's work, including in corporate functions such as accounting, controlling or human resources, which were considered to be less affected than, e.g. product development, industrial manufacturing, logistics or maintenance.

At this early stage of development, it is very hard to seriously estimate the future market potential of GAI as it is

Figure 1
Market potential generative AI until 2030
in bn USD



Source: Bloomberg Intelligence (2023), own calculations.

currently unclear how quickly new use cases will be created and how soon users will be ready to adopt them in their private or professional environment. Nevertheless, if we look at the recent publication of Bloomberg Intelligence (2023), we see that the market may experience enormous growth (Figure 1).

The expected annual growth rate of approximately 47.5% until 2030 covers both incremental revenues from GAI infrastructure (e.g. AI servers, AI storage solutions, computer vision and conversational AI devices) as well as specialised GAI assistant software.

Regulatory framework

The European AI Act (European Commission, 2021) was published in its final draft by the European Commission as early as 2021. After long and intensive discussions, a political agreement was reached on 8 December 2023. Therefore, it can be expected that the EU AI Act will soon be officially adopted by the EU Parliament and the EU Council followed by the publication in the EU's Official Journal to enter into force. It should be noted that the majority of the Act's provisions will apply after a two-year grace period with some exceptions particularly with regard to prohibitions and foundation models.

The forthcoming AI Act will establish a European regulatory framework for providers and users of AI systems. The obligations will depend on the level of risk associated with the respective systems. The regulation will differentiate between uses of AI that create an unacceptable risk, a high risk, a limited risk and a low or minimal risk. Some AI systems may fall into the prohibited "unacceptable risk" category as they could potentially harm or disadvantage people, e.g. through cognitive behavioural manipulation, social scoring or (with very few exceptions) real-time biometric identification systems in publicly accessible spaces.

Another category of AI systems shall cover "high risk" applications that could negatively affect safety or fundamental human rights. Such AI systems include AI technologies used in critical infrastructures, safety components of products, educational or vocational training, certain aspects of employment, essential private and public services (e.g. credit scoring) or border control management. The approval of such high-risk AI systems will be subject to strict obligations, including

- adequate risk assessment and mitigation systems
- high quality of the datasets feeding the system to minimise risks and discriminatory outcomes
- logging of activity to ensure traceability of results
- detailed documentation providing all information necessary on the system and its purpose for authorities to assess its compliance
- clear and adequate information to the user
- appropriate human oversight measures to minimise risk
- high level of robustness, security and accuracy.

Operators of high-risk AI systems need to undergo a conformity assessment procedure conducted by competent institutions and, if needed, implement corrective actions before putting the system into service. Each member state has to designate or establish at least one national competent authority to serve as the national supervisory authority, the notifying authority and the market surveillance authority.

However, most GAI applications, such as chatbots, will probably be categorised as "limited risk" AI systems, which are primarily subject to transparency obligations. Hence, users have to be made aware when they are interacting with a machine so they can decide whether or not to continue using the AI system. In addition, the AI system must be designed in such a way that it prevents the generation and diffusion of illegal content. Finally, AI systems considered to be of minimal or no risk, such as many gaming apps or spam filters, will largely remain outside the scope of the AI Act. Many AI systems currently used in the EU will fall into this category.

It should be noted that, in particular, the regulatory treatment of foundation models (e.g. large language models)

underlying many downstream AI applications has been the subject of much debate. Leading AI scientists have demanded in an open letter of concern (KIRA, 2023) to the German government that foundation models need to be included in the AI Act due to their potentially high safety risks. Alternative proposals have advocated for leaving foundation models outside the scope of the AI Act and addressing their risks with a system of self-regulation rules.

The political agreement achieved stipulates a differentiated approach to the regulatory requirements of foundation models that belong to the category of general-purpose systems or models (GPAI). All providers of GPAI have to adhere to specific transparency requirements on training data and technical documentations. If GPAI are designated as encompassing systemic risk, additional obligations like e.g. model evaluations, risk assessments, testing and reporting have to be fulfilled.

Conclusions

Given that Europe lags behind in many areas of digital technology (e.g. AI in general, digital platforms, blockchain technology or cloud computing), it is worrying that once again the European corporate sector is about to miss out on an important digital technology. The potential risks include becoming even more dependent on the well-known Big Tech companies, as they will certainly combine GAI solutions with their existing technology franchise, e.g. cloud providers, search engines or social media platforms. Furthermore, we have to be aware that AI in general may dramatically change our way of creating, processing and consuming content of any kind. The already significant potential to distribute "fake news" as well as discriminatory, racist or manipulative content will be multiplied by these new technologies. Besides, the chances of prosecuting over illegal content on social media, for example, could become slimmer when the producer or owner of such harmful content is a machine. The enhanced risks of hidden plagiarism and infringements of intellectual property rights are obvious.

This is not to argue against investing heavily in these new applications of GAI, but we must not neglect the technological, social and political risks associated with them while harnessing the economic benefits. It is crucial that the regulatory framework keeps up with the accelerated development of digital technologies. Therefore, the upcoming AI Act, together with the recently adopted Digital Markets Act and the Digital Service Act, will be an important milestone in developing a regulatory framework for trustworthy AI in Europe and beyond. As AI becomes more advanced, humans face the challenge of comprehending how the algorithm came to a certain result. Many AI applications lack transparency in the internal calculation processes, making the generated results more or less a "black box" for the users. However, if even the data scientists who create the algorithms are not able to precisely understand and explain the AI processes applied, trust in the output and the controllability of the system is diminished. Trustworthiness and explainability of AI systems are essential features in order to establish, monitor and enforce a regulatory framework for AI. Without these characteristics, organisations cannot adopt a responsible approach to AI development that requires the system to be compliant with the regulatory standards and ensures that those affected by a decision are able to challenge or change that outcome. Hence, the AI Act shall support European start-ups and established technology firms in participating in these fast-growing markets, enabling society to benefit from these new technologies, while simultaneously avoiding irresponsible risks, ensuring public safety and preserving human rights. The implementation of transparent and clear guardrails for AI systems that balance opportunities with the elimination or mitigation of risks could be a chance for the European technology sector to catch up with its global competitors.

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Carolina Polito and Lorenzo Pupillo

Artificial Intelligence and Cybersecurity

Artificial intelligence (AI) is increasingly being incorporated into business operations and is extensively used in various applications. In the field of cybersecurity, the role of AI is becoming vital for managing cyberthreats. The AI market in cybersecurity is projected to grow at a compound annual growth rate of 21.9% between 2023 and 2028, attributed to the growing revenue of US $60.6 billion by 2028 (Marketsandmarkets, 2023). Nonetheless, AI adoption is not without its risks.

AI, being a versatile and dual-purpose technology, presents both opportunities and challenges in cybersecurity.

The role of AI in cybersecurity is akin to a double-edged sword (Taddeo et al., 2019). On the one hand, it offers advanced tools for enhancing security measures, detecting threats more efficiently and responding to attacks swiftly. These capabilities stem from the ability of AI to analyse large volumes of data quickly and identify patterns that might indicate a security breach. On the other hand, AI also empowers cybercriminals by providing them with sophisticated methods to execute attacks. Machine learning and deep learning are facilitating more sophisticated and damaging cyberattacks that are faster, more targeted and more destructive. The influence of AI on cybersecurity is expected to broaden the threat landscape, introduce new threats and change the typical nature of threats (Brundage et al., 2018). Besides, AI systems are not only vectors for attacks but are also vulnerable to manipulation.

Hence, AI is employed for offensive (supporting malicious attacks) and defensive (combating cybersecurity risks) purposes. However, while the defensive use of AI faces regulatory constraints, especially with governments, including the European Union, aiming to regulate high-risk applications and encourage responsible AI use, its offensive use is growing more prevalent. The cost of developing applications is decreasing, and the "attack surface" is expanding, making defence increasingly difficult.

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Manipulation risks to AI systems

Manipulation of an AI system can occur in various forms, such as input attacks and poisoning attacks.

Input attacks focus on the data fed into the machine learning (ML) system. In these attacks, the attacker introduces an attack pattern into the input data, like placing tape on a stop sign or subtly altering the pixels in an image. These modifications alter the way the ML system interprets the data, leading to its failure.

Poisoning attacks, in contrast, target the development stage of the ML system. These attacks aim to disrupt the construction of a viable ML model by compromising its training phase. The attacker manipulates the training data or process, resulting in a deployed ML model that is fundamentally flawed from the outset. Poisoning attacks occur during the phase where the model's parameters and learning processes are being established. To poison the ML system, the attacker compromises its training and learning process so that it can perform the tasks that are requested by the attacker (Comiter, 2019).

The need for reliable AI

Against this backdrop, the distinction between trustworthiness and reliability in AI systems is of paramount importance. Indeed, it would be crucial to ensure the robustness of an AI system, so that it continues to behave as expected even when the inputs or model are perturbed by an attack. Assessing the robustness of a system would require testing for all possible input disruptions, which would present a significant challenge primarily due to the vast number of potential perturbations that can affect their performance.

The sheer number of potential disturbances in real-world applications makes exhaustive testing unfeasible. This complexity, in turn, makes it nearly impossible to fully test and validate AI systems against all possible scenarios. Such limitations hinder our ability to fully trust AI systems.

As Taddeo et al. (2019) point out, the inability to thoroughly assess AI robustness directly impacts the trustworthiness of these systems. Philosophical analyses qualify "trust" as the act of delegating a task without exerting any form of control or supervision over its execution. In essence, trust implies a reliance on the system to perform its task autonomously.

Therefore, if trustworthiness is about gauging the probability that the trustee – here the AI system – will behave as expected, the unpredictable nature of attacks on these systems makes it nearly impossible to reliably determine their consistent performance in varied contexts.

Consequently, it becomes essential to implement certain control measures to ensure the reliable functioning of these systems. Policies should mandate a cautious evaluation of the level of control on an AI system based on the tasks against which it was designed. Therefore, the concept of reliability should be preferred to trustworthiness.

Ensuring effective human control over AI systems necessitates a significant degree of expertise from human operators, who must be capable of exercising effective oversight. This involves a comprehensive understanding of how to manage various degrees of automation. This task is fraught with challenges, as exemplified by the half-automation problem (Lorenzo et al., 2022), a phenomenon that arises when tasks are highly automated but not entirely so, leading human operators to overdepend on the AI system as though it were fully autonomous.

The half-automation problem highlights a critical issue in the interaction between humans and AI systems. Operators may become complacent or less vigilant when they perceive that AI is more capable or autonomous than it is. This over-reliance can lead to a decrease in human engagement and a potential increase in errors, especially in situations where human intervention is still crucial. Addressing this problem requires careful design and training strategies that emphasise the importance of maintaining human engagement and awareness in semi-automated systems.

Relevant would be the inclusion of "kill switches" in AI systems, as they provide a mechanism for humans to override automated processes and regain control, particularly in the context of automated responses. However, the feasibility of kill switches as a universal solution is debatable. In certain scenarios, such as with autonomous vehicles or aircraft autopilot systems, the decision about when and how to transfer control back to a human operator remains a complex and unresolved issue. Research into handover scenarios, where control shifts from the AI system back to the human, suggests that abrupt requests for human intervention should generally be avoided (Zhang et al., 2019). The reasoning is that in emergent situations, a driver or pilot may not have the capacity to rapidly assess the situation and take appropriate action if only given a few seconds to respond. Hence, in high-stakes environments, where split-second decisions are crucial, such as in critical medical systems or military applications, the design of kill switches must consider the operator's ability to respond accurately under pressure. While applying kill switches in AI systems is, therefore, non-trivial, some form of control over those systems, such as security gates, must be established.

More generally, supporting the reliability of AI implies envisaging forms and degrees of operational control adequate to the learning nature of the systems and the dynamic nature of the attacks, but also attainable in terms of resources, especially time and computational feasibility. This implies ensuring a degree of control over the data fed into the algorithm and over the software. This means having cybersecure pedigrees for the data libraries used for training any machine learning algorithms used as well as cybersecure pedigrees for all software libraries linked to that code (Lorenzo et al., 2022).

Cybersecurity and generative AI

This very complex landscape of regulatory challenges has been further complicated with the advent of generative AI. Generative AI is a form of artificial intelligence technology that can produce various types of content such as text, imagery, audio and synthetic data. It starts with a prompt like a text, an image, a video, a design, musical notes, or any input that the AI system can process. Then, various AI algorithms return new content in response to the prompt (Lawton, 2023). It does this by learning patterns from existing data and then using this information to generate new and unique outputs.[1] Therefore, contrary to other forms of AI used for purposes such as analysing data or helping in airplane flight control, the purpose of generative AI is to generate new and original content.

This form of AI is called large language models (LLMs) and entails the use of machine learning to understand and generate human language. These models are trained on large amounts of text data, such as books, articles, and websites, (this is why they are called large) and are capable of generating new text that is similar to what a human would write or say.

1 See https://generativeai.net.

In particular, LLMs use a subset of machine learning architecture deep learning techniques, specifically neural networks, to learn the patterns and structure of languages. The larger the model, the more data it has been trained on and the better it is at understanding and generating human language.

Generative AI is becoming very popular because of programmes such as ChatGPT or AI image generator DALL-E and is showing great potential – but also peril as its use in cybersecurity is a double-edged sword.

Among the promises of generative AI in cybersecurity is the possibility of automating repetitive tasks, freeing up time for cybersecurity experts to focus on more complex issues; identifying anomalies and trends that could be neglected by human analysts; creating cyberthreat scenarios for training and simulation purposes; and predicting future cyberthreats based on historical data (Boopathy, 2023).

However, generative AI with its ability to create content, from text to images and videos, introduces an entirely new dimension of cybersecurity risks. Deepfakes, or AI-generated videos that can mimic real individuals, have already highlighted the potential misuse of this technology: the use of deepfake for committing a new type of identity fraud or the use of tools like ChatGPT to create more powerful phishing programmes. Generative AI models could be used to create malware, for instance, polymorphic malware, able to change its code to bypass detection by security tools.

Furthermore, some recent research shows that the widespread integration of LLMs like ChatGPT in applications such as search engines has generated critical vulnerabilities that "when coupled with how they are developed and distributed by commercial providers and as open-source releases risk creating a systemic cybersecurity crisis" (Tsamados, 2024).

Indeed, similarly to what has been described for "classic" AI systems, two types of threats could lead to a cybersecurity crisis: those generated by LLMs' vulnerability to attacks conducted via natural language, and those deriving from how the LLM models are developed and distributed.

The first category is characterised by the natural language as a universal attack vector and entails attacks such as prompt injection attacks or attacks based on the automatic generation of adversarial suffixes. Furthermore, natural language can also be used for more complex attacks like model poisoning.

Prompt injection attacks are made possible by end-users injecting adversarial instructions – through written, audio, image, or video format – into an AI chatbot interface, or through data accessed by the model itself, for example, through web searches. The outcome is the hijacking of the model and the control of its outputs.

The attacks based on the automatic generation of adversarial suffixes are more sophisticated and require more skills and knowledge to be implemented.

Conclusions

Cyberattacks are on the rise, and they are increasingly using AI. Overall, the barrier to entry for cyberattackers has been significantly lowered, implying that even individuals with average technical skills could potentially instigate a prompt injection attack, particularly with Generative AI technologies. The gamification of such techniques on social media and forums can lead to a collaborative effort among users to explore and exploit these vulnerabilities, potentially leading to an increase in the number and variety of cyberthreats. This democratisation of hacking capabilities poses a significant challenge for cybersecurity professionals and necessitates the development of more robust defences against these emerging forms of cyberattacks.

While AI could even help companies manage cybersecurity risks, a number of conditions must be met. It is essential to develop ad hoc cybersecurity practices to mitigate the threats stemming from AI adoption, such as building AI-specific threat models based on the mapping of the different LLM vulnerabilities and threats. Furthermore, authorised and qualified auditors should be allowed to have regular access to LLM providers and data sets to avoid a single point of failure.

In terms of research, as mentioned by the latest ENISA (2023) report on AI and cybersecurity, further studies should be promoted on the application of AI and ML in cybersecurity. These include, among others, creating test beds to evaluate and enhance the performance of ML tools and technologies in cybersecurity, developing penetration testing tools that can discover and leverage security vulnerabilities through the simulation of attackers' behaviour, and creating standardised frameworks for assessing the confidentiality of information flows.

In light of these developments, achieving consensus on the regulation of generative AI systems within the trialogue negotiations of the AI Act has been key. On 9 December 2023, the Council Presidency and the European Parliament's negotiators reached a provisional agreement on the AI Act proposal.

Distinct guidelines have been established for foundation models. The provisional agreement mandates that foundation models adhere to particular transparency requirements before entering the market. A more rigorous framework is applied to "high impact" foundation models, characterised by being trained with extensive data sets, possessing advanced complexity and superior performance, and having the potential to propagate systemic risks throughout the value chain (Council of the EU, 2023).

However, the definitive measure of the AI Act's success will be observed through its execution. Although a provisional agreement on the AI Act's proposal has been established, complete with specific provisions for foundation models and stringent requirements for high-impact foundation models, the real test lies in the implementation phase. It is during this stage that stakeholders will discern the practicality and efficiency of the Act in regulating generative AI systems. The effectiveness of the AI Act will ultimately be judged by its ability to mitigate risks and ensure compliance with transparency obligations. One critical area in which the EU could have further impact on the premise of what has been established in the AI Act would be the creation of a specific unit focused on curating large-scale data sets (CEPS Think Tank, 2023). This would allow the EU to foster a more secure AI ecosystem.

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The Generative AI Challenges for Competition Authorities

Generative artificial intelligence (GenAI) has been a catalyst for market and regulatory developments. Since the launch of the chatbot ChatGPT in November 2022, the tech industry has frequently released new products and services. These range from chips, machine learning models, cloud computing, and software to answer engines, showcasing the impact of GenAI in fostering competition, innovation, and the creation of markets and technologies.

Nevertheless, running and deploying GenAI requires developers to access three main components in the value chain: computing resources, machine learning models and data (Carugati, 2023b). Despite various players in the field, certain sectors face competition concerns due to market features and potential issues, such as tying.

Computing resources, including graphic cards and cloud computing, are pivotal in the development and deployment of machine learning models. However, access to these resources is primarily provided by a limited number of tech firms. To secure access, some model developers enter into partnerships with large cloud computing providers, exchanging access to their models for access to cloud computing resources. Although these collaborations might foster competition, they may also give rise to problematic practices such as tying (Carugati, 2023c).

Machine learning models generate output based on input data, such as text, images, videos or music. Despite claims that models are concentrated in the hands of a few large online platforms (Coyle, 2023), there is no substantive evidence supporting this assertion. On the contrary, thousands of closed-source and open-source models compete on various parameters like task requirements, language specifications and model size.

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Data, another essential component, raises concerns about a potential competitive advantage for models provided by large online platforms with access to vast proprietary datasets (Riekeles and von Thun, 2023). However, as in the case of models, there is no substantive evidence supporting this concern. Model developers can leverage thousands of public and proprietary datasets, differentiated based on task requirements, language specifications and domain specificity.

Furthermore, GenAI developments grapple with unsolved regulatory challenges related to the use of copyrighted data (intellectual property rights), personal data (data protection), AI risks (AI governance) and competition.

Competition authorities around the globe, including those in the United Kingdom,[1] Portugal,[2] India,[3] Hungary,[4] Europe,[5] the United States,[6] and soon France,[7] are closely monitoring GenAI developments.

In this context, GenAI poses challenges for competition authorities due to emerging markets and technologies coupled with regulatory instabilities. New products and services are shaping new and existing markets, like answer engines and advertising. Regulatory uncertainties are influencing competition in GenAI.

At the current developmental stage, competition authorities should focus on understanding market and regulatory developments through cooperation among themselves and relevant competent authorities. They should exercise formal enforcement powers and potentially update competition tools only when necessary and justified, guided by the insights gained from these market studies.

Emerging markets and technologies

GenAI requires developers to have access to three main components. As mentioned above, this value chain includes computing resources, machine learning models and data (Carugati, 2023b). Then, application developers integrate GenAI into their products and services.

1 Competition and Markets Authority (2023a).
2 Autoridade da Concorrência (2023).
3 Press Trust of India (2023).
4 Hungarian Competition Authority (2024).
5 European Commission (2024b).
6 Federal Trade Commission (2024b).
7 Autorité de la concurrence (2024).

Computing resources

Computing resources enable the development and deployment of machine learning models. The two main components include graphic cards for computation and AI workloads and cloud computing for running and deploying models at scale over the internet.

The graphic card sector is the main driver of running models. However, the sector faces card shortages due to high demand and low supply of components (Carugati, 2023c). In this sector, Nvidia is the leading supplier, especially in graphics processing units (GPUs), which perform several computations simultaneously. Competition authorities in France, Europe, the United States and China are currently investigating Nvidia's business practices (Nvidia, 2023).

However, new players have entered the graphic card market, challenging Nvidia's position. Advanced Micro Devices (AMD) and Intel have announced graphic cards dedicated to AI (Intel, 2023; AMD, 2023). Meta, Amazon and Alphabet have also developed in-house chips to improve AI workloads.[8] However, the extent to which chips provided by new players and in-house chips exert competition pressure on Nvidia deserves in-depth scrutiny in the graphics card sector, and it is thus out of the scope of this paper.

The cloud computing sector is an essential infrastructure for deploying models (Carugati, 2023c). Cloud computing providers and model developers nurture a close, interdependent relationship. Model developers need cloud computing providers to run and deploy their models at scale without investing in the infrastructure. In turn, cloud providers see the model developer as a business driver. Accordingly, some cloud providers have established partnerships with model developers (see, e.g. Microsoft Corporate Blogs, 2023).

Partnerships take various forms. Some are exclusive, like the partnership between Microsoft and OpenAI, while others are non-exclusive, like the partnership between Amazon and Anthropic (Anthropic, 2023). The partnership generally enables the cloud computing provider to invest in cloud infrastructure. Some providers even develop an infrastructure dedicated to the partners' needs, as Microsoft did by developing a specific computer to run OpenAI models (Langston, 2020). In exchange, the cloud provider can host, exclusively or non-exclusively, the partner on its cloud service and use the models in related services. For instance, Microsoft exclusively hosts OpenAI models on its Microsoft Cloud Azure and uses OpenAI models on its services, including Office 365, Edge, Bing and Windows.

The cloud sector is competitive, with several global, regional and national players, including Microsoft, Amazon, Google, OVH, Orange and Scaleway. However, the sector is under intense scrutiny by competition authorities worldwide, including South Korea, the Netherlands, Japan, France, the United Kingdom, the United States and Spain (Carugati, 2024). They are concerned with a trend towards concentration in the hands of a few global hyperscalers, including Amazon, Microsoft and Google, due to their scale and investment capabilities. Those hyperscalers are also the main partners with model developers. As the demand for GenAI increases, the partnership might intensify the trend towards concertation. They are also concerned with potential competition issues arising from barriers to switching, like data transfer fees, software licensing practices and interoperability, that make it more difficult for a customer to change a cloud provider. Partnerships with hyperscalers might raise additional competition issues from vertical integration, like tying and self-preferencing.

Machine learning models

Machine learning models derive output from input data, such as text, image, video or music. Models are either closed or open-source models. Developers of closed-source models might license the use of their models to third parties, allowing them to develop commercial applications. By contrast, developers of open-source models make them publicly available for free for research and/or commercial use. They might release various model elements, including the model and training data. This enables third-party developers to modify the model. While some developers might improve the model, others might revise it for malicious use (OECD, 2023).

In addition, model developers compete on various factors, including task requirements, language specifications and model size.

First, models differentiate on the intended generated output. A non-exclusive list of models includes text-to-text models (e.g. OpenAI GPT, Google PaLM, Anthropic Claude), text-to-image models (e.g. OpenAI DALL-E, Google Imagen, Adobe Firefly, Midjourney), text-to-video models (e.g. Runway Gen-2, Meta Make-A-Video) and text-to-music models (e.g. Google MusicLM, Meta MusicGen, Stability AI Stable Audio). As of January 2024, the community website Hugging Face counts more than 477,000 open-source models on its model repository.[9]

8 For Meta, see Janardhan (2023); for Amazon, see AWS (2024); for Alphabet, see Google (2024).

9 See https://huggingface.co/models.

Second, the language of the training dataset is an important quality parameter of the output. If the training dataset does not contain a given language, it might provide a poor result due to the difficulty of deriving output from little or no input data. To address this issue, model developers created multilingual models (e.g. OpenAI GPT) by training them on input data containing various languages, including English, French, German and Spanish. Others developed monolingual models for a specific language (e.g. Meta CamemBERT for French). Monolingual models sometimes perform better than multilingual ones (OECD, 2023).

Third, models have different sizes. The size refers to the number of parameters required to adjust the model to provide the appropriate output from input data during the training session. The parameters thus encode the knowledge of the model (Competition and Markets Authority, 2023a). The performance of the model and its cost depend on the number of parameters (Rae et al., 2022). The more parameters, the more the models can learn from datasets. The downside is that more parameters require more data and computing power, thus increasing the model's cost. Large models with a high number of parameters are therefore called large language models (LLMs). LLMs can perform various tasks even if the dataset contains general domain data, as they are zero-shot reasoners. They can thus generate output without having specific input on the prompt (Kojima et al., 2023). Some models are also fine-tuned on specific datasets to achieve specific tasks better than LLMs with general domain data, like Meta Code Llama, which generates code. Researchers and developers are already proposing smaller models with fewer parameters to reduce financial and environmental costs; these are called small language models (SLMs).[10] Some SLMs perform similarly to LLMs (Schick and Schütze, 2021). Finally, some models, like Google Gemini Nano, can even run on a device and are thus called edge language models or on-device models. These models can perform on-device tasks offline and do not require cloud computing resources, thus reducing financial costs while ensuring greater privacy as data do not leave devices (Alizadeh et al., 2024).

However, the way competition between models of similar characteristics works deserves in-depth scrutiny with quantitative and qualitative data, especially on model performance and user preference, and is thus out of the scope of this paper.

10 For instance, Meta open-source Llma2 is available in three model sizes, 7 billion, 13 billion, and 70 billion parameters. See https://ai.meta.com/llama/.

Data

Finally, model developers require data to run and deploy their models. Data is thus the indispensable input to derive output. As in traditional data-driven markets, the volume (scale), variety (scope), velocity (freshness) and quality of the dataset determine the quality of the generated output (Stucke and Grunes, 2016; Carugati, 2023b).

Model developers train their models on publicly available data from the internet or open-source repository. As of January 2024, the community website Hugging Face counts more than 99,000 open-source datasets on its dataset repository.[11] Developers also use proprietary datasets from their own first-party or third-party services, such as data brokers, data marketplaces and publishers.

In addition, models compete on various dataset factors, including task requirements, language specifications and domain specificity.

First, the dataset determines the generated output. There are thus various datasets for various task requirements, including text-to-image, text-to-video and text-to-music datasets.

Second, the language of the training dataset determines the output of multilingual or monolingual models. A non-exhaustive language dataset includes majority languages, such as English, French, German and Spanish, and minority languages, such as Italian, Greek and Dutch.

Third, the domain specificity of the dataset is an important quality factor in specifying the intended task. Thus, datasets contain specific data for various intended tasks, such as code, legal, finance and art.

The training dataset has a time limitation, as it only contains data up to a certain date. Model developers can retrain the dataset on updated data. However, retraining the dataset is costly. Model developers can deploy the model on real-time data to deal with this issue. For example, Microsoft Bing generates real-time output from the internet by deploying GPT models on Microsoft Search and Index data (Ribas, 2023).

In traditional data-driven markets, data is an important factor of market power (Cabral et al., 2021). Data is a competitive advantage that benefits large online platforms like Alphabet and Meta (Competition and Markets Authority, 2020). Users also benefit from data due to data-driven network effects when the user utility changes

11 See https://huggingface.co/datasets.

with improved learning from data, creating value for users (Gregory et al., 2021). Some models, such as GPT, improve by learning from user dialogue data, suggesting that the more model users there are, the higher the model quality is.[12]

However, the validity of these claims in model markets deserves in-depth scrutiny. Indeed, no evidence suggests that data is a source of market power or that models developed by large online platforms benefit from data advantages. Indeed, available research suggests that some SLMs, like the Koala model trained on high-quality open-source datasets, perform similarly to LLMs trained on much larger volumes of proprietary datasets (Geng et al., 2023). Besides, there is not yet evidence that models developed by large online platforms, such as Google PaLM, Google Gemini, or Meta Llama, outperform models from newcomers, such as OpenAI GPT, Anthropic Claude, Mistral AI MISTRAL 7B. Finally, there is no widely available empirical research on the importance of data-driven network effects on model performance.

Applications

Models enable the development of applications for intended tasks, such as generating text. Model developers either develop their own first-party AI-powered applications (e.g. OpenAI ChatGPT) or enable third-party ones (e.g. Hervey AI).

Then, some applications enable first-party and third-party add-ins that complement the app. For instance, OpenAI ChatGPT allows the development of tailored GPTs dedicated to a specific domain. These complementors are then available at an app store.[13]

Applications raise several competition issues at both downstream and upstream levels that deserve in-depth scrutiny.

At the upstream level, model and application developers use a cloud provider that hosts the model. They then become customers of the cloud provider. The latter might develop an infrastructure dedicated to the hosted model. The cloud provider might thus have the ability and an incentive to impose technical and commercial conditions to recover the investment cost. For instance, a condition might make it more difficult to move the model and/or application from one cloud provider to another by limiting interoperability between cloud providers. This condition might negatively impact competition in the cloud sector and reinforce the position of the cloud provider hosting the model.

At the downstream level, some model and application developers might provide other services in several markets. They might have the ability and incentive to integrate their own AI-powered applications with other services. For instance, Google is integrating its AI-powered solutions into Google Search (Reid, 2023), Google Chrome (Tabriz, 2024) and Google Workplace (Voolich Wright, 2023). Microsoft is doing the same with its AI-powered Copilot applications in its search engine Bing, browser Edge, productivity software Office and operating system Windows. These vertical integrations pose potential competition issues related to tying, bundling and self-preferencing, as the firm has the incentive to promote its own services over third-party ones. For instance, Google promotes its AI-powered Search Generative Experience (SGE) in Google Search to generate an answer in direct competition with third-party chatbots, like OpenAI ChatGPT. Vertical integration also poses issues related to refusal to deal. It will be the case if a dominant firm prevents third parties from offering competing services in the dominant market. For instance, a hypothetical problematic scenario would be if Microsoft prohibits a third party to provide a competing version of Copilot in Microsoft Windows and Microsoft Office.

Moreover, these new AI-powered applications impact how competition works in several sectors, including advertising and cloud computing, to name a few. For instance, search engines are moving from providing search results with links that redirect to a publisher's website to answer engines that generate answers with citations. When the search engine offers search and answer results, the generated answer might substitute or complement the publisher's content. Whether it leads to substitutability or complementarity requires in-depth scrutiny and implies different considerations for publishers and advertisers. In case of a substitution, the user will most likely not click on the publisher's website or will click significantly less. In turn, publishers might lose traffic and advertising revenue (Hagey et al., 2023). Advertisers might then direct their spending to the answer engine, as users will remain on it (Carugati, 2023a).

Regulatory instabilities

GenAI raises several regulatory concerns that impact how competition works. The four main concerns are intellectual proprietary rights, data protection, AI governance and competition (Carugati, 2023d).

Intellectual proprietary rights

Model developers train and deploy their models on public and proprietary datasets, including copyrighted data. Copyright protection requires the data owner's consent

12 See https://help.openai.com/en/articles/7730893-data-controls-faq.
13 See https://openai.com/blog/introducing-the-gpt-store.

to use data, which might decide to license its dataset against a fee.

Around the globe, there have been concerns that some model developers use datasets without consent, leading to litigations in several countries, like the ongoing lawsuit by the *New York Times* in the US against OpenAI and Microsoft (Grynbaum and Mac, 2023). In this case, OpenAI declined any wrongdoing because it considers that it can fairly use the publisher's content without consent under US copyright law (OpenAI, 2024). To address this issue, some model developers, including OpenAI and Google, propose opt-out mechanisms, allowing publishers to proactively block model developers from collecting their content to train their models.[14] Some model developers also conclude partnerships with publishers for the use of their content, like the partnership between OpenAI and Axel Springer (2023).

In response, legislators and regulators have proposed several initiatives to address copyright concerns, including an obligation to publish summaries of copyrighted data used for training models in the forthcoming European AI Act (European Parliament, 2023), a code of practice on copyright and AI in the UK (UK Government, 2023), workshops with content creators in the US (Federal Trade Commission, 2023a) and a proposal to amend the EU copyright directive by some French politicians (Hartmann, 2024).

These regulatory developments directly impact GenAI, as data access is primordial to the development of models. OpenAI even argued that prohibiting using copyrighted data to train models would prevent GenAI development (Titcomb and Warrington, 2024).

Data protection

Training datasets contain personal and non-personal data. The collection and use of personal data raises data protection and privacy concerns, especially regarding the user's consent.

Data protection authorities worldwide are increasingly looking at how models use personal data and their implications in terms of regulatory requirements, like the ongoing consultation on GenAI and data protection in the UK (Information Commissioner's Office, 2024). Some regulators even took enforcement actions by preventing the use of AI-powered applications due to alleged data protection infringements, like the temporary ban of ChatGPT in Italy in April 2023 (Bertuzzi, 2023).[15]

These regulatory developments also impact GenAI, as data protection requirements have important implications for the lawfulness of the training datasets. Non-compliance could potentially result in bans and fines.

AI governance

AI models give rise to new governance issues, such as addressing risks associated with their use, including manipulation and biometric identification. In this context, AI governance is the priority of legislators around the globe. As of January 2024, the OECD counts 646 legislative initiatives worldwide that are about AI governance only (OECD.AI, 2021). The forthcoming European AI Act, which is still under legislative process after a political agreement in December 2023, is just one of them (Council of the European Union, 2023). However, the AI Act will likely have far-reaching implications in other jurisdictions worldwide, as Europe is often the global rule-setter (Bradford, 2020). The proposed text includes specific provisions concerning GenAI and high-impact general-purpose AI (GPAI) models, identified as posing systematic risks. According to the latest officially available information, developers of such models must disclose to users that content is AI-generated, design the model to prevent the generation of illegal content and publish summaries of copyrighted data used for training. High-risk GPAI, which might only apply to OpenAI GPT-4, is required to conduct impact assessments of risks and report them to the European Commission (European Parliament, 2023). The latter announced in January 2024 a dedicated AI office within the Commission, tasked with coordinating AI policy at the EU level and overseeing the AI Act (European Commission, 2024a).

These regulatory developments significantly impact competition. Firstly, certain models classified as high-risk GPAI face more extensive regulatory compliance requirements than models that potentially pose similar risks. The question of whether this regulatory burden will place the former at a competitive disadvantage compared to the latter merits closer scrutiny. As of January 2024, European legislators have not disclosed any impact assessment of the provisions affecting high-risk GPAI models on competition. This is particularly concerning as legislative debates have indicated a desire to promote European models such as the French Mistal AI and German Aleph Alpha by excluding them from regulatory burdens (Hartmann, 2023). In other words, the provision might be driven

14 See https://platform.openai.com/docs/gptbot.

15 See also, GPDP (2024).

by a desire to achieve an industrial policy goal of promoting European firms rather than protecting users from all AI risks, irrespective of the model size. Secondly, the proliferation of regulatory initiatives may result in regulatory inconsistency, leading to increased compliance costs and regulatory burdens. Consequently, some model developers might encounter challenges in scaling and competing, especially when compared to developers with greater compliance resources and the ability to benefit from economies of scale in regulatory compliance.

Competition

As GenAI is an emerging technology, firms vigorously compete along all the above value chains, from computing resources and models to data. Yet, some competition authorities have already voiced concerns that GenAI might be concentrated in the hands of a few large online platforms with access to computing resources, models and data (for the US, see Federal Trade Commission, 2023b). Moreover, they outline that some business practices, such as tying, bundling, exclusive dealing and self-preferencing, might give rise to potential competitive concerns (Bundeskartellamt, 2023a). Competition authorities also closely monitor partnerships between large cloud providers and model developers. In Germany,[16] the UK,[17] and Europe,[18] competition authorities investigate whether the partnership between Microsoft and OpenAI requires an obligation to review the transaction under their national merger control laws. If Microsoft/OpenAI undergoes a merger review, competition authorities could potentially accept or block the transaction or impose behavioural and structural conditions on how Microsoft should operate with OpenAI products and services. In the US, the Federal Trade Commission even launched a sector inquiry into these partnerships, requesting detailed information from Alphabet, Amazon, Anthropic Microsoft and OpenAI on the rationale and impact of the partnerships on competition (Federal Trade Commission, 2024a).

Besides, GenAI spurs innovation in several sectors, potentially disrupting current markets and creating new ones, such as answer engines replacing search engines (Carugati, 2023a). As of January 2024, competition authorities have not yet launched market studies into GenAI and its impact on specific markets, such as advertising or cloud computing. However, as noted earlier, they announced sector inquiries into GenAI and competition.

16 Bundeskartellamt (2023b).
17 Competition and Markets Authority (2023b).
18 European Commission (2024b).

These regulatory initiatives will inform how competition in GenAI works. They are not formal investigations into non-compliance with national competition laws or specific digital markets regulations, like the European Digital Markets Act. However, the findings will likely influence GenAI developments in delivering positive outcomes on competition. Competition authorities have already warned that they will intervene with formal enforcement powers where necessary (Competition and Markets Authority, 2023a).

Policy recommendations

The paper finds that GenAI leads to emerging markets and technologies in the context of regulatory instabilities in various jurisdictions and legal regimes. Against this background, competition authorities worldwide should follow the below policy recommendations.

First, competition authorities should cooperate in an international forum to ensure international coherence. They should do joint studies in a forum like the European Competition Network or International Competition Network to foster experience-sharing without resource duplication, given the borderless nature of the issues posed by GenAI.

Second, competition authorities should undertake in-depth studies of some critical elements of the value chain and markets. They should do priority inquiries into graphic cards and cloud computing sectors as GenAI developments depend on them. Market characteristics and business practices in these sectors might impact competition in the long term. Competition authorities should also closely monitor how GenAI impacts competition in several important markets, including search engines and online advertising given their importance to content creators.

Thirdly, competition regulators should collaborate with relevant competent authorities to examine the impact of various legal regimes on competition. Considering the interactions between competition and other legal frameworks, they should ideally produce joint studies or, at the very least, joint statements addressing data protection, intellectual property rights, AI governance and regulations in digital markets. The outcomes of these collaborations should contribute to greater regulatory stability, providing market actors with the assurance that GenAI can deliver its full benefits responsibly.

Last but not least, competition authorities should exercise formal enforcement powers and potentially update competition tools only when necessary and justified. They

should do so only after evidence of enforcement gaps is found following market studies. They should resist the call for quick intervention to avoid critics of underenforcement in digital markets.

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The Impact of Artificial Intelligence on Productivity and Employment – How Can We Assess It and What Can We Observe?

Technological optimists have been predicting the artificial intelligence (AI) revolution since the beginning of the past decade. This expectation contrasts with low productivity growth in many countries. The commercial release of ChatGPT in late 2022 has lead to rising expectations about a dramatic shift at least equivalent to the one associated with the commercial introduction of the Internet. But what is AI from an economic point of view? How can we observe the diffusion of AI in the economy and assess its effects in order to the draw conclusions for economic policy?

This article starts from a bird's eye view, detailing how automation and AI are modelled in economic theory and how their productivity and employment effects are currently measured. In the framework of national accounting, many AI systems can be considered bundles of different categories of investment. This makes them hard to measure. Much preliminary evidence on economic effects of the diffusion of AI is thus based on measures of AI exposure or AI skill demand rather than its use. First evidence suggests that AI-using firms may experience positive productivity and non-negative employment effects while aggregate effects are still too small to detect.

What is artificial intelligence?

Among the many definitions of AI, we focus on some taken from economic research. In the introduction to *The Economics of Artificial Intelligence: An Agenda*, the editors Agrawal et al. (2019, 3) write:

> The Oxford English Dictionary defines artificial intelligence as 'the theory and development of computer systems able to perform tasks normally requiring human intelligence.' This definition is both broad and fluid. There is an old joke among computer scientists that artificial intelligence defines what machines cannot yet do.

According to this logic, AI would be a concept with a concrete meaning that varies over time, since it once included, for example, early chess computers, but does not include them anymore because beating professional chess players is no longer an insurmountable challenge for computers. Still, earlier waves of computer technology that diffused within the economy were not commonly associated with the term "artificial intelligence". With regard to commercially viable applications, the term has been mainly employed since around 2012 for machine learning (a set of methods from computations statistics) as a prediction technology (Agrawal et al., 2019). The OECD (2019, 15) defines an AI system as a "machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments.... AI systems are designed to operate with varying levels of autonomy".[1]

The AI Act of the EU, which was approved by the Council of the EU's Committee of Permanent Representatives on 2 February this year, is an important policy framework for the use of AI in the economy. It defines AI systems in a similar way. Simpler software systems that are "based on the rules defined solely by natural persons to automatically execute operations" (Proposal for a Regulation 2021/0106 (COD), 2024, paragraph 6)[2] are not considered AI systems. AI systems are designed to operate with varying levels of autonomy, meaning that they have some degree of independence of actions from human involvement and

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1 See Barrufaldi et al. (2020, 11).

2 The version of 21.1.2024 has been released by individual parliament members and by journalists and is made available online by the non-profit Future of Life Institute.

of capabilities to operate without human intervention. The adaptiveness that an AI system can exhibit after deployment refers to self-learning capabilities, allowing the system to change while operating to attain the explicit or implicit objectives specified for it (Proposal for a Regulation 2021/0106 (COD), 2024, paragraph 6). In view of relating the definition of AI systems in a legal context to an economic context (such as, for example, the set of definitions underlying the international System of National Accounts, SNA), the following statement is worth considering:

> AI systems can be used on a stand-alone basis or as a component of a product, irrespective of whether the system is physically integrated into the product (embedded) or serve the functionality of the product without being integrated therein (non-embedded) (Proposal for a Regulation 2021/0106 (COD), 2024, paragraph 6).

AI as a factor of production

The perspective taken here focuses in a relatively abstract way on the modelling of AI as an input to a firm-level or macroeconomic production function. This does not consider the role AI can play in concrete economic prediction and decision-making tasks.

In a highly stylised way, Growiec (2022) describes four stages of substitution of labour by capital. In the first, pre-AI, phase of mechanisation, capital is only capable of substituting for physical human labour. The second phase is automation (which may or may not be counted as using AI, depending on the definition of AI), with software substitution for some cognitive human labour, in particular in factory automation through robotics. The third phase represents the use of machine learning, mainly for prediction, which replaces cognitive human labour rather than automation, since software can now be self-improving. In the future, some researchers envision economies will enter a fourth phase, the phase of superintelligence, in which computers will be capable of a general intelligence that exceeds human intelligence in all respects. All physical tasks then become programmable and all human cognitive labour can be substituted by artificial intelligence. This state is also called singularity.

All macroeconomic models about automation and about AI have at the core some simple production theoretic models that make assumptions about functions or tasks that technology can perform. If the technology performs the same function as some category of human labour, both are perfect substitutes. If it does not perform the same function, both are imperfect substitutes, unless their functions themselves can be substituted by one another in the production process. Macroeconomic models usually defined AI based on simple assumptions of substitution. Their complexity then comes from how these substitution properties interact with other features of the model. Whether technology eventually substitutes for human labour depends on relative prices and other firm and market conditions.

Different ways have been proposed to model substitution between technology and labour. Sometimes, the technology input is called “automation capital”, whereas the terminology “AI capital” or “AI systems” as a category of capital is not used. This may reflect the uncertainty about the empirical counterpart of what we conceptualise as AI in macroeconomic models. The prototypical production-theoretic conceptualisations are the following:

In one variant, within a macroeconomic production function with capital and labour as production factors, automation capital has a substitution parameter with labour that is different from its substitution parameter with other capital. Some models assume substitution between automation capital is perfect (Berg et al., 2018; Gasteiger and Prettner, 2022).

A second variant represents macroeconomic production technology as a set of tasks. Progress in automation and artificial intelligence increases the fraction of tasks that can be performed by machines instead of humans (Aghion et al., 2019).

In a third variant, this set of tasks itself expands and there is a task-specific productivity (Acemoglu and Restrepo, 2018).

If model implications are to be tested, empirical measures that match the way automation or AI is conceptualised have to be found. In the following, we give a brief overview of empirical measurements and results. The aim is to show the challenges associated with measuring the diffusion of AI systems throughout the economy and with observing its effects on productivity and labour substitution.

The public debate often focuses on the job losses resulting from automation. Empirical evidence to date, however, does not point to any aggregate job losses (Autor, 2015). Productivity effects from the diffusion of computer technology have been visible, in particular between 1995 and 2005 (Cardona et al., 2013). They are high when considering the small share of ICT capi-

tal in total capital but not spectacular when considering overall economic growth in rich economies in the 20th century. Whether the current wave of technological progress based on machine learning technologies has different effects is yet to be seen.

Investment in new and better capital goods is expected to have positive aggregate effects on labour productivity in the medium run. Without these effects, there would be no plausible reason for large-scale capital investment in economies. In the short run, the diffusion of new technologies may be initially too small, and adaptation costs may be too high to observe positive aggregate productivity effects.

Different kinds of negative employment effects of automation and AI are possible for individual firms: investment in automation or AI may directly substitute workers. Also, firms that lag behind in investment in automation and AI may lose market shares and thus reduce employment. On the other hand, firms that are leaders in investment in automation and AI may capture market shares through cost reduction or product innovation and increase employment. Moreover, investment in automation and AI may increase productivity and thus real incomes, which may positively affect product demand and employment. The sectoral and aggregate employment effects depend on the price elasticity of product demand.

Measuring automation and AI technologies

Assessing the employment and productivity effects of the diffusion of AI systems requires measuring their use in firms empirically. In the system of national accounting, immaterial inputs and those with rapid quality change over time are much more difficult to measure than material inputs and those with moderate quality change. Capital inputs are those non-human inputs that last longer than a year in the production process. Material capital inputs include:

- building and structures
- vehicles
- non-IT machinery and equipment and weapon systems
- ICT equipment (computer hardware and communications equipment).

These categories are all included in the current international standards of national accounting (SNA 2008). Immaterial capital inputs include:

- computerised information: software and databases
- innovative property: research and development (R&D), mineral exploration, artistic originals, design
- economic competencies: firm-specific training, market research and branding, business process re-engineering.

Software has been included since SNA 1993, and measurement was implemented in developed countries by 2000. Issues with quality measurement continue to be substantial. In principle, since SNA 1993 databases were also to be measured, but this has considerable intricacies both at the conceptual and at the practical level, thus implementation is uneven. R&D has been thought of as an investment only since SNA 2008. Previously, it was considered an intermediate expenditure on the same account as materials or energy. R&D investment is measured mostly by expenditure on R&D personnel.

In the European Union, the inclusion of R&D investment in national accounts began in 2014. Economic competencies are to date not considered investment in national accounting. Measurements of the amount of investment in this category have been created in research projects such as the INTAN-Invest Database (Corrado et al., 2021). Regarding the measurement of AI in national accounts, Corrado et al. (2021, 473) "think of AI as using a combination of tangible assets (hardware) with measured intangibles (software) and unmeasured intangibles (databases)".

For research projects in economics, the most widely used measure of automation is the number or the capital value of industrial robots. The availability of data on industrial robots worldwide in the database of the International Federation of Robotics (IFR) has sparked a lot of empirical research in recent years (Jurkat et al., 2022). An industrial robot is an "automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment" (ISO standard 8373:2012 (§ 2.9) reported in Jurkat et al., 2022, 671). In national accounting, industrial robots and similar, less well-measured automation technologies, are part of non-IT machinery. They may be bundled with software components, which are in turn part of computerised information. Based on investment data for nine manufacturing industries in ten countries for the period 1993-2007, we find that quality-adjusted robot investment has an average share be-

low 1% of total investment.[3] Automation capital measured as robot capital represents thus a very small fraction of total investment. Only few studies are capable of observing a broader set of automation machinery and equipment (Aghion et al., 2023).

Over time, progress in industrial robotics leads to the emergence of robots with an increasing degree of autonomy. In particular, the algorithms controlling them have been moving from deterministic to probabilistic algorithms (IFR, 2022), which according to the definitions used by OECD and EU can be seen as the threshold for belonging to AI systems rather than non-AI automation technology. Research with available data since the early 1990s will, however, mostly likely capture the effects of the pre-AI era.

As with computer hardware, and more importantly computer software, amounts of investment into industrial robots need to be quality adjusted when added up to a capital stock. While the IFR provides some information on how to quality adjust robot prices, measurement error is likely to remain substantial.

In order to capture a broader set of automation technologies, some studies link information on automation-related patents to information on workers' tasks or on industries for which the content of these patents is particularly relevant (see survey by Aghion et al., 2023).

To date, only few data directly and comprehensively measure the use of AI systems in firms in a way that distinguishes them from pre-AI software. As with standard ICT investment, binary measures of adoption of AI technologies may be easier to collect from firms and may yield a more nuanced picture of the technological level of the investment than monetary measures of hardware and software investment in line with national accounting. In one of the few studies with direct and comprehensive measures of AI use within firms, Czarnitzki et al. (2023) can observe the use of four broad AI methods in five different areas of the firm's activity. Data from 2018 come from the German part of the European Community Innovation Survey. Out of the nearly 6,000 firms observed in the sample, 7% report any kind of use of AI methods. Most current economic research until now uses narrower AI measures related only to certain areas of the firm's activity or indirect measures of AI diffusion based on bibliographic data from scientific publications, patent data (Barrufaldi et al., 2020) and job-related descriptions, for example, in job advertisements (Acemoglu et al., 2022).

Evidence on productivity and labour market effects of automation and AI

Effects of industrial robot use on labour productivity and total factor productivity (TFP) at the industry level appear to be mostly positive (Graetz and Michaels, 2018; Jungmittag and Pesole, 2019; Kromann et al., 2019) and in some cases surprisingly large given the small share of robot equipment in overall capital.

A survey by Aghion et al. (2023) finds mixed effects of industrial robot use on employment at the country or industry level. In most empirical research, robot use is measured at the industry level or extrapolated to the local level using industry-level data. Depending on the country observed and the research design, one robot is found to replace between 0 and 10 workers. Studies using text analysis or patent data find similarly mixed results. Firm-level studies find positive employment effects of industrial robot use. Automating firms have between 2% and 10% higher employment. The positive elasticity of employment to robot investment lies between 0.2% and 2%. Aghion et al. (2023) argue that industry-level evidence shows only the net result of effects in automating and non-automating firms. Firm-level evidence suggests that negative employment effects may be experienced by non-automating firms, which are less competitive.

In a meta-analysis of 53 studies, Jurkat et al. (2023) find an overall wage effect of industrial robot use that is close to zero. Effects tend to be more negative in estimations for manufacturing industries as well as at the country level compared to more disaggregated levels.

In their study applying data on the use of AI methods in firms, drawing on one of the most comprehensive measurements currently available, Czarnitzki et al. (2023) find a positive and significant association between AI use and firm productivity based on a variety of different measures. Surveying a small number of studies published between 2017 and 2021, Calvino and Fontanelli (2023) find the evidence on AI and firm productivity inconclusive. From their own analysis based on harmonised microdata from the OECD diffuse project, they find productivity advantages of AI users, which seem to be related to complementary assets such as ICT skills and digital infrastructure.

Identifying AI-exposed establishments through online vacancies, Acemoglu et al. (2022) find that they in-

3 Own calculations using data from the International Federation of Robotics (IFR) and EUKLEMS from ongoing research with Anne Jurkat and Julian Salg.

crease hiring in AI-related jobs. At the same time, firms decrease hiring in jobs not directly related to AI and change the skills demanded for these jobs. According to their analysis, aggregate effects on employment and wages are currently too small to be detectable. Babina et al. (2024) find evidence for higher employment growth in AI investing firms coming through the channel of product innovation.

Overall, both research on robot and AI diffusion point to positive productivity and employment effects at the firm level, while employment effects at the industry-level are less clear-cut. It may also be too early to observe aggregate productivity effects of AI.

Conclusion

While policies such as the EU AI Act, which aims at establishing a regulation for AI applications that may represent high risks and intransparencies for citizens, begin to develop a clear definition of the technologies to which this concept refers, AI as an economic input is hard to measure. This becomes evident when looking at the diffusion of those automation technologies that emerged prior to current AI but continue to develop with enhanced software capabilities. The most commonly used empirical measure of these automation technologies is industrial robot use, quantified as the number of robots or real value of robot capital stock. This measure may not fully capture the value of software and databases created and used in association with the robots.

AI systems more generally may, in terms of categories of national accounting, be considered bundles of computer hardware, software and database investment, in some cases also associated with investment in machinery that is not counted as computer hardware or investment in R&D. This implies that the overall economic value of AI systems is already to a large extent included in gross domestic product, with the exception of the value of databases, which is poorly measured. But national accounts and similarly built databases currently do not allow for the identification of AI systems as a separate category. Therefore, firm und industry-level research concerning the productivity effects of AI currently relies on other indicators. Some of them, such as data from job advertisements, do not allow the direct observation of the level of AI use in firms but rather measure AI exposure. Given the high importance of observing the future opportunities and risks associated with the diffusion of AI, the further development of firm-level measurement seems warranted.

To date, there is no evidence of massive overall job losses caused by AI that some observers tend to anticipate based on studies (such as, e.g. Frey and Osborne, 2017) that assess only the technological substitution potential of current jobs. It remains to be seen how far the previous experience of computer diffusion since the 1970s, which changed job tasks and affected various skill groups differently, but did not lead to higher aggregate unemployment, will be repeated with the further diffusion of AI technologies.

While there seems to be a large potential for AI productivity effects that lead some observers to see the possibility of a "singularity" of explosive economic growth in the more distant future, aggregate productivity effects may still take some years to be measurable.

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Designing EU Supply Chain Regulation

The EU Directive on Corporate Sustainable Due Diligence has sparked fierce debate about the regulation of supply chains. The directive's objectives are aligned with European values. However, it raises concerns that the compliance costs of social and environmental regulations may be privatised in complex supply networks, particularly in third countries with weak enforcement mechanisms. This paper suggests options to make the directive more effective and efficient. It suggests excluding countries with sufficient regulatory systems and focusing only on supplier-buyer relationships instead of the entire network. Public agencies should set harmonised regulatory standards, interpret the regulations and organise a private certification scheme in which certification companies assume liabilities. The proposed system resembles the market for financial auditors.

The integration of emerging and developing countries into the global production networks of industrialised countries has brought great progress to hundreds of millions of people around the world. For instance, World Bank data suggest that the number of people living in absolute poverty has fallen from around 2 billion in 1990 to less than 650 million in 2019, even as the world's population has grown from 5.3 billion to 7.8 billion. Other social welfare indicators paint, on average, a similar picture. From a somewhat narrow, economic perspective, the literature provides evidence on the average growth-enhancing effects of trade integration (see, e.g. Felbermayr and Gröschl, 2013; or Feyrer, 2019, 2021). However, trade integration also has its downsides. Growth can increase economic inequality in rich and poor countries (see the review by Helpman, 2021), and its impact on environmental outcomes is ambiguous, to say the least (for a review, see Cherniwchan et al., 2017). These developments are in part the result of the relocation of production processes from developed to less developed countries, where labour costs are typically lower, and social and environmental standards are either absent or poorly enforced. This has had unintended and undesirable consequences, with concerns raised about negative effects on longer-term productivity growth (Windrum et al., 2009). At the societal level, there has been criticism about human rights abuses, including forced labour and environmental degradation.

These issues are far from new, and the global community has reacted. It has developed and ratified a significant number of legal texts that implement the provisions of the 1948 Universal Declaration of Human Rights, such as those prohibiting the worst forms of child labour. Similarly, there are various environmental conventions, the 2015 Paris Agreement on climate change being a prominent and almost universally accepted example. Although these norms are desirable, they are often in breach. The risk of such events has increased with the recent rise of autocratic or illiberal governments around the world. According to the V-Dem Institute (2023), 72% of the world's population lived in autocracies in 2022, the highest level since 1986. Similarly, according to the World Bank's Carbon Pricing Dashboard, only 23% of global CO_2 emissions occur in countries with some form of carbon pricing, signalling the uneven level of government commitment to

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tackling climate change. Supply chain regulations seek to effectively promote compliance with such initiatives. One such regulation is the EU Directive on Corporate Sustainability Due Diligence. This article aims to discuss this directive and suggests practical steps to improve its effectiveness and efficiency.

The EU Directive on Corporate Sustainability Due Diligence

In 2022, the European Commission first proposed the Corporate Sustainability Due Diligence Directive (CSDDD). On 14 December 2023, the Council and the European Parliament reached a provisional deal (Council of the EU, 2023). The directive aims to improve corporate governance practices to mitigate globally adverse human rights and environmental impacts, to remedy adverse effects and to promote sustainable and responsible business practices throughout the global value chain. Firms operating in the EU will have to ensure that they meet high ethical, environmental and labour standards throughout their operations. The CSDDD requires companies to integrate due diligence into policies and management systems to identify risks. Companies would have to implement risk management systems and a grievance mechanism. They would have to produce an annual report describing due diligence efforts and objectives and monitoring the effectiveness of due diligence measures.

The EU directive will apply to all large companies operating in the EU, i.e. companies with more than 500 employees and a global annual turnover of more than €150 million. In addition, the CSDDD will apply to EU-based firms with more than 250 employees and a turnover of more than €20 million generated in "high-impact sectors". These thresholds were the result of a lengthy discussion process. While the EU Council favoured a higher threshold in terms of the number of employees and turnover, i.e. fewer directly affected companies, the EU Parliament proposed lower thresholds, encompassing companies with over 250 employees or an annual worldwide turnover of more than €150 million. In addition, the CSDDD will apply to non-EU companies and parent companies with over €150 million net turnover generated in the EU, three years from the entry into force of the directive. The Commission will have to publish a list of non-EU companies that fall under the scope of the directive.

There is a particular focus on companies operating in "high-impact sectors". These are sectors identified by the EU as having a high risk of negative impacts on the EU and a high potential for violations of human rights and environmental standards. They include wholesale trade of textiles, clothing and footwear, wholesale trade of agricultural raw materials, live animals, wood, food and beverages, agriculture, forestry, fisheries, extraction of mineral resources, manufacturing of food products and beverages, manufacturing of textiles, leather and related products and manufacturing of basic metal products, other non-metallic mineral products and fabricated metal products. Financial services are temporarily excluded from the directive. However, a review clause is envisaged to allow for the future inclusion of the downstream financial sector, based on a sufficient impact assessment. The agreement stipulates that compliance could be a criterion for awarding public contracts and concessions.

The CSDDD will introduce duties for directors and senior managers to establish and oversee the implementation of due diligence processes and to integrate due diligence into the company's strategy. Directors and management will have to consider the impact of their decisions on human rights, climate change and the environment in fulfilling their duty to act in the best interests of the company. Companies, including those in the financial sector, will also need to adapt and implement climate change transition plans to ensure that their business models are consistent with efforts to limit global warming to 1.5 degrees Celsius.

Companies found to be in breach of the new regulation will be subject to sanctions, including fines and compliance orders, and victims of violations will be compensated. Failure to comply with the CSDDD can lead to reputational costs for the importer, loss of access to EU public procurement and/or financial consequences. The latter can be significant, even if the risk is low, as fines are substantial: up to 5% of net turnover.

The CSDDD closely follows the Corporate Sustainability Reporting Directive (CSRD), which entered into force in early 2023. It is part of a wider trend to shift responsibility for enforcing international law beyond governments to individuals and businesses. Examples of recent EU legislation aimed at promoting sustainable practices along European supply chains include the EU regulation on deforestation, the EU Timber Regulation, the regulation on conflict minerals and the draft regulation banning products made with forced labour. Yet, the CSDDD is different from previous supply chain legislation in a number of ways. First, it is one of the few legal acts to cover both human rights and environmental impacts of value chains. Second, it covers direct and indirect suppliers, upstream and partially downstream in the value chain, such as distribution or recycling. Third, it goes a step further than previous reporting guidelines by requiring companies to disclose their risk mitigation strategies. Furthermore, it will close regulatory gaps. Even though trade regulations

apply to many value chain transactions, this is not always the case. Hence, CSDDD has a residual effect. In the absence of equivalent agreements, it fills a gap and provides a regulatory baseline.

The provisional agreement reached with the European Parliament has been subject to fierce debate and now needs to be endorsed and formally adopted by both institutions. Once this occurs, member states will have two to three years to transpose it into national law. This means that countries that do not have any supply chain-related due diligence laws, such as Austria, would have to create a national supply chain law. Countries that already have legislation in place, e.g. Germany, France and the Netherlands, would have to ensure that their laws do not fall short of the standards set by the EU directive.

A general appraisal

The EU is founded on a set of social and economic values. Environmental and social sustainability are part of these values and are part of the supply chain regulations. This is backed by the public. There appears to be a strong preference among EU citizens for goods and services produced abroad that do not violate these standards. EU member states are under an obligation to have appropriate frameworks in place for such engagement. While the national regulatory frameworks are supposed to ensure compliance with these values within the EU, the question arises of how these can be implemented outside of the EU. The EU CSDDD is a vehicle supporting these policy objectives under the assumption that public enforcement is poor or lacking in third countries.

A first question concerns how supply chain issues should be approached. Certainly, these could be effectively promoted if embedded in trade regulations. There are human rights conventions, international environmental treaties and agreements setting labour standards, which are provisions of international law. They must in principle be enforced by the states or by the international community. Yet, international enforcement mechanisms are absent. The UN agreed on "Guiding Principles on Business and Human Rights" in 2011, in which private companies are empowered to act as agents of society at large in the enforcement of human rights (see Jacob et al., 2022). Recently, Western governments have involved the private sector, i.e. private companies are being obliged to monitor compliance and address non-compliance in their supply networks. In a number of countries, due diligence laws to regulate the supply chain have been enacted. This is particularly the case in France (*Loi de vigilance*, effective 2017) and Germany (*Lieferkettensorgfaltspflichtengesetz*, effective 2023). The CSDDD in 2022 could be interpreted as a means to avoid a fragmentation of due diligence requirements across the EU.

The rationale for the CSDDD is that voluntary agreements have failed and that international agreements cannot be enforced abroad by foreign governments. As a result, the burden of responsibility will fall on companies doing business internationally. This means that the monitoring and enforcement of public regulations will be delegated to private companies. Private companies are certainly key to compliance. However, they do not have the mandate to enforce the rules in the wider economy and lack the legal means to monitor third parties. Hence, the CSDDD broadens the base of enforcing agents. Yet, private companies cannot fully substitute the public enforcement of compliance with rules and regulations.

Some private companies that source internationally have already taken voluntary steps to eliminate misconduct in their supply chains. However, only a small fraction of all firms have done so. For example, a survey of Austrian firms shows that many have already implemented responsible corporate governance concepts, but the systematic integration and monitoring required for reporting and documenting supply chain due diligence has so far been limited (Meyer and Reinstaller, 2022). Small and medium-sized enterprises in particular are less likely to have already implemented the necessary measures. From a cost-benefit perspective, this is not surprising. Stricter sourcing standards by individual importers, even large ones, are unlikely to have any measurable marginal impact on the human rights situation or environmental pollution in developing countries while inevitably increasing their sourcing costs. The incentives for companies to act autonomously are therefore weak. To solve this variant of the "tragedy of the commons", government action is justified.

An *ex ante* assessment

International economic effects

The implementation of the CSDDD imposes due diligence obligations that will result in increased implementation and transition costs for firms. If costs become too high, there is the risk of withdrawal of EU importers from certain source countries. According to simulations of the effect of the CSDDD on welfare and trade using a general equilibrium global economy and trade model by Wolfmayr et al. (2023), a significant reduction in international trade between the EU and countries with a high probability of due diligence violations, including China, can be expected. If EU firms were to withdraw from key high-risk trading partners, imports from sectors with a high risk of human rights and environmental violations, such as clothing, textiles

and minerals, would see their international trade fall by more than 26%. This decline in trade could have a negative impact on the degree of diversification of EU imports, undermining efforts to strengthen the EU's resilience and posing a challenge to the EU's sustainability goals, as many products vulnerable to human rights violations serve as essential inputs for the green transition. In addition, EU companies may have to replace their imports of goods vulnerable to due diligence violations with imports from other sources that comply with the CSDDD. This will increase transition costs and import prices, thereby reducing the EU's competitiveness, particularly in relation to other geo-economic powers such as the US and China (Wolfmayr et al., 2023).

Trade diversion from high-risk countries to high-income countries could hinder the integration of developing countries into international markets and the economic development of poor third countries that lose access to the EU export market. According to Wolfmayr et al. (2023), high-risk countries could experience significant welfare losses. The withdrawal of EU imports could lead to trade diversion, with importers from other countries, such as China, filling the gap. Moreover, since exporters are necessarily formal firms, CSDDD could push employment in developing countries into the informal sector, where the situation regarding human rights, labour standards and environmental pollution is much worse.

However, there are no comprehensive econometric evaluation studies of existing due diligence laws. Preliminary evidence from the French law shows that French importers have withdrawn from small and risky countries (Kolev and Neligan, 2021). This is consistent with evidence that news of adverse events in the supply chain has a particularly negative impact on the economic value (i.e. share price) of companies (Hendricks and Singhal 2003, 2005a, 2005b).

Relationships that need to be monitored

Assessing the effects of supply chain regulations suffers from poor data availability. Supply chain data at the firm level, let alone breaches of regulations within supply networks, is not available. In a recent paper published by the Supply Chain Intelligence Institute Austria (ASCII), this issue was overcome by a synthetic dataset of EU firms, which allows for the quantification of the likelihood of links to firms potentially involved in human rights abuses in their supply chain (Hurt et al., 2023). The network model shows that virtually every company in Europe is vulnerable to supply chain risk when considering indirect relationships. This is because supply networks are extremely dense: on average, there are 30-50 suppliers per company. Large companies have up to 10,000 suppliers and up to 100,000 customers.

The exposure is particularly high for small open economies. In Austria, for instance, the probability of an importer being exposed to a risky product/country combination is almost 100% from the second link in the supply chain onwards. Yet, even companies in the larger and/or less open EU countries are almost fully exposed from the third (or higher) link in the supply chain. Depending on the precise definition of high-risk sectors, the estimates show that the CSDDD directly applies to approximately 20,000 EU-based companies. These companies are estimated to have 8.9 million supply relationships with 4.8 million companies, all of which would need to be monitored. In addition, these companies will need to monitor their own supply chains. ASCII estimates that 30 million EU companies and virtually all global companies importing into the EU are no more than three levels away in the supply network from the original 20,000 companies, amounting to approximately 894 million supply relationships that would need to be monitored under CSDDD (Hurt et al., 2023). ASCII further estimates that there are approximately 600,000 such supply links from European to non-European companies.

Fixed costs of suppliers

The CSDDD increases the fixed costs of trade per supplier due to importers' efforts to fulfil the obligations set out in the directive. Additional expenditures include the identification of key suppliers and regularly reviewing their business practices to ensure compliance or developing contingency plans. Given the design of the scheme, it is inevitable that public regulatory costs will be privatised.

To assess the likely impact of the CSDDD, one can draw on a growing body of research on the effects of trade costs on firm behaviour. Starting with Melitz (2003), theoretical and empirical work has shown how firms of different sizes react to changes in the trade cost environment. If the fixed cost of sourcing from a particular foreign supplier rises, low-volume relationships will be abandoned because the operating profits they generate will no longer cover the fixed costs of the key account. In general equilibrium, this allows larger suppliers to gain market share at the expense of smaller suppliers, thereby reducing the number of suppliers and the degree of diversification. Helpman et al. (2008) extend this result to a multi-country setting and show that higher fixed trade costs stop trade between countries altogether unless there is a firm-level relationship in which the achievable operating surplus exceeds the fixed costs of maintaining the relationship. The law intends that European firms should improve local

conditions in third countries rather than withdraw. However, there are no legal means of enforcing such behaviour if firms' operations are not profitable.

For example, the German Parliament provides a legislative impact assessment of its supply chain act. It gives estimates of the direct administrative costs associated with the implementation of the due diligence obligations. However, this calculation remains incomplete, because European importers are not in a position to judge *ex ante* whether a particular supplier is compliant. As a result, companies invest in costly monitoring activities. Increased monitoring will reduce the likelihood of human rights abuses or environmental crimes, but it will not eliminate the likelihood of a foreign supplier shirking its responsibilities. Even when a supply chain risk management and monitoring system is effectively implemented, many firms do not have a complete picture of their entire supply chain due to data protection and privacy concerns.

The effective relationship-specific fixed costs are the sum of direct (bureaucratic) costs plus the probability of failure times the probability of detection times the sum of fines and reputational costs. This means that companies will withdraw from foreign countries if they perceive a high risk of damage. Terminating business relationships with non-compliant suppliers is a possible result of the CSDDD. However, this is likely to increase market concentration towards fewer suppliers. This runs counter to efforts to diversify the EU's supply base. It may also lead to the withdrawal of EU importers from high-risk countries, with possible developmental and geopolitical implications.

It also means that information asymmetries are at work. Even compliant foreign suppliers will lose business in Europe because they cannot be distinguished from rogue firms. This "lemon problem" means that a CSDDD that increases the effective cost of large customers for European importers may end up penalising the wrong foreign companies. The problem is compounded by legal ambiguities that plague the CSDDD provisions. For example, it is difficult to determine *ex ante* how much effort a company will have to expend to comply with the due diligence requirements. Over time, this will be determined by best practice routines and by the courts. However, the risk remains that a firm will be accused, with or without justification, of failing in its due diligence obligations after a risk has materialised.

Towards an effective, cost-efficient regulatory design

The policy should be designed to ensure that the directive is effectively implemented so that human rights and environmental standards are respected along the value chain. While compliance imposes additional costs on companies, it must be done in a cost-effective manner so as to minimise disruption to compliant operations and company profitability.

Scope of application

The starting point is to limit the increase of fixed costs at the company level. These should not reach an extent to which unwanted firm reactions become likely. A straightforward way to do this is to ensure that the overall cost efficiency of the monitoring system is maximised. Consider a network of M buyers in the EU and N sellers abroad. To achieve efficiency, it is obviously preferable to monitor the N potential sellers rather than the MxN potential bilateral relationships. In a global network where each of the K firms is potentially a buyer and a seller to every other firm, focusing on firms rather than relationships reduces the monitoring activities from Kx(K-1) to K. For the importer in the EU, focusing on the nodes of the networks rather than on the links significantly reduces total costs. Lower costs imply that fewer EU importers withdraw from risky countries or concentrate their sourcing on fewer suppliers within the same country. From a non-compliant supplier perspective, the firm risks losing all M buyers in the EU rather than just one. In other words, the negative consequences of non-compliance would be much greater due to single market-related multiplier effects. This greatly increases the effectiveness of the regulation.

Companies are being obliged to consider adverse impacts on human rights and the environment in relation to their own activities, as well as the activities of their subsidiaries and of companies in the value chain. The latter is a direct or indirect business relationship that is consistent in intensity or duration and does not represent an insignificant or merely subordinate part of the value chain (Article 3(f) of the CSDDD). Altogether, this implies that both suppliers and buyers are subject to the EU CSDDD. Restricting the regulation to upstream relationships, i.e. only to suppliers, would immediately lead to a significant cost degression. Given the cash flows from buyers to suppliers, this limitation of the scope is also more practical from a transactional perspective.

The geographical scope of the regulation should be limited to reduce the bureaucratic burden. The CSDDD has been designed on the assumption that public enforcement in third countries is poor or non-existent. In turn, this implies that the directive should not apply to transactions with trading partners in countries with sufficient *de jure* and *de facto* enforcement of European values. Companies located in geographical areas with a suffi-

cient rule of law should therefore be exempted, because they are assumed to be able to sufficiently enforce social and environmental standards. These should include, but not be limited to, EU member states, EFTA countries, the USA, Canada, Australia, New Zealand, Japan and South Korea.

A certification and blacklisting system

While direct monitoring can be costly for companies and not monitoring bears the risks of including a non-compliant company in the supply chain, a market solution can reduce both the costs incurred and the risk of dealing with a non-compliant company. In principle, such certification can take place at the country or company level and can be carried out by public authorities or specialised private companies. Given the budgetary constraints of the public sector and the complexity of the real business environment, a market solution seems more efficient than a government solution. This could be similar to the market for financial audits.

Specialised and regulated certification firms could take on risk. Private firms would take on both public oversight responsibilities and liabilities. The certifying firms would have to be contracted by a public authority to carry out due diligence and would be authorised to issue a certificate for a certain period of time, thereby exempting the foreign company's EU trading partner from carrying out bilateral due diligence. Such specialised companies would charge a fee for their services. Crucially, they would assume liability for their due diligence, so that the EU importers themselves would be completely relieved of liability. A certification approach can be interpreted as a "positive list", i.e. a list of companies that comply with the CSDDD.

There are significant advantages to the supplier-based certification approach:

Firstly, by effectively pooling the costs of due diligence, a positive list approach significantly increases the efficiency of the monitoring system as a whole. It also increases effectiveness because non-compliance by a single supplier leads to the delisting of that supplier for the entire EU market. This multiplies the incentives for compliance. As a result, focusing on the manufacturer results in a system that is both more efficient and effective compared to a system that focuses on the bilateral relationship.

Secondly, once a supplier has been approved and certified, the European label can be used by importers anywhere in the world. Suppliers therefore have an interest in being certified and listed. This gives the EU measure much more clout, creating a desired "Brussels effect" (Bradford, 2020). Without this mechanism, the CSDDD strictly covers only those foreign exporters who sell to the EU.

Thirdly, a CSDDD that allows companies to outsource liability to specialised certification firms would create a European supply chain certification industry that could set global standards and pursue opportunities in many economies and jurisdictions. The existing structure of comparative advantages puts the EU in a good starting position.

Similarly, negative lists can be drawn up and maintained by public authorities. These would – temporarily – blacklist firms that do not comply with the CSDDD. The negative listing of a country, region or foreign company by a public authority would undoubtedly provoke political opposition abroad and likely be accompanied by retaliation measures. This is not necessarily a disadvantage, as such possibilities require an analysis of the trade-offs involved. Leaving the decision whether to import from a particular country to EU importers, or to EU courts interpreting or ruling on the CSDDD, removes geopolitical considerations from the debate, whereas it may be in the European interest to include them. For example, it may be politically desirable to continue sourcing from a high-risk country if decoupling would cause the foreign government to change its allegiance. Different actors, from trade unions, business associations and non-governmental organisations to private individuals, should be allowed to provide information to the authorities responsible for maintaining and amending the positive and negative lists. The CSDDD, as presently envisaged, should apply in cases where a supplier is not included in either positive or negative lists.

Conclusions

In a nutshell, the Corporate Sustainable Due Diligence Directive requires companies to conduct due diligence on their own behaviour and that of their direct and indirect suppliers. They would have to identify and prevent, end or mitigate any actual or potential adverse impacts on human rights and the environment in their own operations, in their subsidiaries and in the value chain. This paper proposes a certification scheme to move monitoring from the bilateral, transactional to the supplier level. As in the market for financial auditors, certifying companies would take responsibility for compliant suppliers. The certifier would be publicly approved by an authority within the EU. At the same time, blacklists exclude certain countries or suppliers from supply chains involving EU companies. There are no due diligence requirements for companies that are blacklisted or certified. This approach is based on the integrity of the EU's single market, which is more effective

when implemented within a single framework rather than many, possibly incompatible, national rules.

This system would reduce the overall cost of the regulation for EU importers and the likelihood of unwanted side effects. It would also be more effective because non-compliance by a foreign supplier would lead to delisting across the EU, rather than affecting a single supplier-buyer relationship. The market solution would also reduce legal uncertainty. Overall, the system offers an option to extend the scope of the regulation, and thus EU values, beyond EU-based production networks. Certainly, if other countries, such as the United States, were to implement a similar system that is in line with the approach adopted by the EU, such an initiative would be more effective.

A certification scheme can shift liabilities and, if designed in a cost-effective manner, reduce the burden on companies and effectively improve local production conditions. However, residual risks remain, and these can be significant, for example, if upstream market structures for critical inputs are highly concentrated, with no alternative suppliers available. This is likely to be the case in supply chains where raw materials are required. In the worst case, European suppliers would be at a competitive disadvantage in an otherwise desirable initiative.

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Christian Pfister*

Issuing a Wholesale Central Bank Digital Currency: Why and How

Although there are currently four retail central bank digital currencies in circulation, no central bank has yet issued the wholesale form of a central bank digital currency. There are good reasons to do so, however, and central banks have already conducted projects in this area. A wholesale central bank digital currency could be issued in different ways. This article presents two "polar" scenarios, with a restrained and an extensive use of the possibilities offered by recourse to distributed ledger technology. Their consequences for monetary policy are discussed, and some precautions for central banks that intend to launch a wholesale central bank digital currency are underlined.

A wholesale central bank digital currency (wCBDC) would be a form of central bank money that would be perfectly fungible with reserves, accessible only to a limited set of economic agents (at least those who currently have access to reserves, i.e. banks), and available in a distributed ledger technology (DLT) environment. These features distinguish wCBDC both from retail central bank digital currency (rCBDC),[1] which is accessible to the general public and is not necessarily supported by DLT, and from reserves, which are accessible only to banks, but not supported by DLT. The possibility of issuing a wCBDC has seldom been envisaged in the academic literature (however, see Pfister, 2019) and no wCBDC has yet been launched. Still, wCBDC has often been discussed by central bankers, especially in the recent past (see, e.g. Bowman, 2023; Jones 2023; Panetta 2021, 2022; Villeroy de Galhau, 2023), and central banks have conducted projects on wCBDC.

1 Currently, rCBDCs circulate in the Bahamas, the Eastern Caribbean, Jamaica and Nigeria (Kosse and Mattei, 2023). Regarding the distinction between rCBDC and wCBDC, one can refer to Pfister (2019).

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Why issue a wCBDC?

This section first presents and discusses arguments against and in favour of wCBDC, before reviewing central banks' projects related to wCBDC and the main lessons drawn from them.

Arguments against

A common argument against wCBDC is that it already exists, since reserves are central bank money in digital form that is available to banks for wholesale transactions, and therefore it would not need to be created (Bowman, 2023; Durfee et al., 2023; Panetta, 2021). However, central bankers who have positively envisaged the idea of issuing a wCBDC, as Jones (2023) and Villeroy de Galhau (2023), must have reasons to think that another form of reserves might need to be made available.

Another argument against wCBDC is that a bridge could be created between DLT platforms and central bank infrastructure, which would allow for settling the cash leg of transactions in central bank money without the need to launch a wCBDC. Two proposals in that direction have been made. They are both discussed in the framework of the New Technologies for Wholesale settlement – Contact Group (NTW-CG) established by the ECB (ECB, 2023), together with the Banque de France "full DLT" proposal (ECB-NTW-CG, 2023). The first proposal that avoids creating a wCBDC is the "trigger solution", which was put forward by the Deutsche Bundesbank. It would be based on a technological bridge or interface between a conventional payment system and a DLT-based application. The second proposal has been suggested by the Banca d'Italia. It would use the existing Target Instant Payment

Settlement (TIPS) system and hashed timelock contracts (HTLC)[2] to synchronise the asset leg and the cash leg of transactions in tokenised assets. However, a coordination problem could arise if issuers and investors view the central bank's initiative to create a "bridge" as too timid, since this decision could easily be reversed. If this were the case, wCBDC might be essential for tokenisation to take hold, contrary to the view expressed by Durfee et al. (2023).

A further argument against is that the use of DLT would create risks and complexities for the central bank "because a shared ledger might allow central bank money to circulate on a platform that is not owned and operated by the central bank" (Bowman, 2023). However, this would not have to be the case (i.e. wCBDC could be designed to prevent such circulation). Furthermore, the project Helvetia Phase II demonstrated that it was both technically and, under Swiss law, legally feasible to issue wCBDC on a DLT platform operated and owned by a third party and even to delegate tasks related to wCBDC to the operator, provided that the central bank retains necessary wCBDC control and monitoring functions (BIS-SNB-SIX Group, 2022).

Arguments in favour

The main reason to issue a wCBDC would be to provide a perfectly safe and liquid settlement instrument that would be directly available in a DLT environment, thus preserving the anchoring role of central bank money (i.e. enabling the maintenance of parity between the different forms of money) in this environment (Pfister, 2019; Villeroy de Galhau, 2023). This would have two consequences:

First, it would increase financial stability, since other settlement instruments that are already available on DLT, such as stablecoins, bear credit and liquidity risk (Melachrinos and Pfister, 2021).[3]

Second, it would support the digitalisation of assets by allowing the straight-through processing of transactions in a DLT environment and explicitly demonstrating the central bank's support.

Other reasons to issue a wCBDC relate to "disintermediation" and "weaponisation".

Disintermediation

The fact that wCBDC would not cause a loss of bank deposits, a so-called disintermediation, whereas rCBDC could (Pfister, 2019, 2022), while helping achieve objectives partly similar to those of rCBDC is one reason to consider issuing a wCBDC. This would notably be the case for cross-border payments, where interoperability between CBDCs could be arranged within different models (BIS-CPMI-IMF-WBG, 2022).

In particular, wCBDC could offer two major advantages for emerging and developing economies. The first one would be to remedy the drawbacks of correspondent banking by increasing the speed and lowering the cost of remittances, although other solutions such as the interlinking of fast payments systems could offer a similar result. The second advantage is that capital flow measures could be made more efficient (He et al., 2023). This could be achieved thanks to the automation of controls through recourse to smart contracts and to the organisation of these controls at the level of the CBDC architecture or that of the cross-border platform that connects the wCBDC rails.

Weaponisation

Another reason to issue a wCBDC relates to the weaponisation of money, or rather that of payment infrastructures, in particular the Swift messaging system. In the wake of war in Ukraine and the financial sanctions directed against Russia, more and more central banks are now envisaging a possible launch of a wCBDC in the coming years (Demertzis and Lipsky, 2023; Kosse and Mattei, 2023). This tends to show that issuing a wCBDC and making it interoperable with those of "friendly" economies is possibly envisaged in some countries as a way of evading potential sanctions.

Central banks' projects and main lessons drawn

Central banks have launched projects on the applicability of wCBDC for domestic payments, capital markets and cross-border payments (de Sèze, 2023).

Domestic payments have first been investigated.[4] The idea was to assess the potential benefits of DLT technology to increase the efficiency of real-time gross settlement

2 A HTLC requires the beneficiary of a payment to acknowledge its receipt before a predetermined time or a preset deadline.

3 Stablecoins regulated, supervised, well-managed, and fully backed by central bank reserves would come very close to wCBDC, but it is doubtful that central banks would allow them, since they are likely to view such arrangements as tantamount to outsourcing the production of central bank money (Bindseil, 2023).

4 Examples of early projects are: Project Stella by the ECB and the Bank of Japan in 2016, Project Jasper by the Bank of Canada in 2017, Project Ubin Phase 1 and Phase 2 by the Monetary Authority of Singapore in 2017, Project Khokha by the South Africa Reserve Bank (SARB) in 2018, and Project Inthanon Phase 1 by the Bank of Thailand in 2019.

(RTGS) systems widely used by central banks (BIS, 1997). Overall, the projects showed that it would be challenging for a DLT-based system to process domestic payments more efficiently than existing RTGS systems. However, wCBDC could increase financial system efficiency as a result of integration with the broader financial market infrastructure.

Regarding *capital market applications*, the results of projects were generally positive.[5] However, a significant expansion of the scope of coverage of the ledger to include additional assets and the full trade and post-trade life cycle may be required to realise efficiency improvements. Also, instant gross settlement requires prefunding of the asset leg and the cash leg, which could require significant amounts of liquidity for settlement. On the other hand, the higher velocity of money allowed by DLT may reduce the need for liquidity, as well as counterparty, operational and market risks. Furthermore, as is already the case for RTGS systems, queuing arrangements could reduce the need for liquidity, although this would imply rejecting settlement risk at the periphery of the wCBDC platform, thus partly foregoing the potential security benefits of using central bank money for the final settlement of transactions.

The possibility of using wCBDC for *cross-border payments* is the area that has been most explored in recent years.[6] It seems very promising, provided that central banks coordinate at the international level.

Central banks have so far mostly explored existing markets for which investments in proofs of concept were rather light. However, Jones (2023) notes that, other types of markets that stand to benefit from tokenisation are "greenfield markets that could develop rapidly by leveraging programmability and better informational transparency". Examples he gives are those of nature-based markets like biodiversity or carbon credits, where underlying exposures are diverse, and data needs to be verifiable in real time to enhance trust. This could apply to "environmental, social and governance" (ESG) bonds, for which smart contracts could provide real-time information on the performances of the issuers on ESG grounds. This would allow both to adjust the yields and to help the market become more mature as investors could more easily compare performances. Of course, the DLT protocols that would enable such functionalities would have to be "environment-friendly".

5 Early examples are Project Jasper Phase 3 by the Bank of Canada in 2018, Project Inthanon Phase 2 by the Bank of Thailand in 2019. See also Banque de France (2021).

6 Early examples are presented in Annex 6 of BIS-CPMI-IMF-WBG (2022).

How to issue a wCBDC?

The potential perimeter of the use of wCBDC, the consequences for monetary policy and precautions central banks should take are discussed in turn.

Perimeter

Should wCBDC circulate on a ledger (or several interconnected ledgers), together with other tokenised assets (deposits, securities and possibly also foreign currencies) or should it be used in all large-value transactions, instead of using deposited tokens or stablecoins?

The first possibility was initially formulated by McLaughlin (2021) and has been supported by a group of large U.S.-based financial corporations under the heading of the "Regulated Liabilities Network" (RLN), with the aim of enabling a financial system that is compliant with existing laws and regulations (The RLN, 2022). Applying this approach at a European level has also been supported by Villeroy de Galhau (2023). It would allow making settlements in different payment instruments, including wCBDC, when transacting in tokenised assets that are regulated.

By contrast, although this is not explicitly mentioned by the Bank for International Settlements, it seems that in the proposal that is put forward in its 2023 Annual Report (BIS, 2023), all transactions on the "unified ledger" would be settled in wCBDC. This would eliminate settlement risk, thus supporting financial stability, and eliminate any risk of "fragmentation" of the monetary system. However, if could also lead to a sharp increase in the demand for central bank money in the form of wCBDC, as clearing operations would disappear. On the other hand, the role of central bank money as the final means of settlement might be in question if participants in the unified ledger have the choice between using central bank money or not. From an operational perspective, it might also lead to higher volatility in demand for CBDC, thereby complicating the management of the monetary base by the central bank. However, monetary policy could still be implemented, in principle even in the extreme case in which there would be no demand for central bank money, although the central bank would then lose its seigniorage revenue and thus have to find alternative resources to cover its operating costs (Woodford, 2001).

Monetary policy consequences

The consequences of issuing wCBDC for the conduct of monetary policy are likely to be minimal as far as the monetary policy objective (price stability) and its trans-

mission mechanism are concerned. At most, by supporting tokenisation, wCBDC could contribute to slightly higher economic growth and productivity in the medium to long run, with positive effects on demand and consequences for inflation that are hard to predict, due to the opposite influences of demand and productivity on inflation (Pfister, 2023). However, the consequences for the monetary policy implementation framework could be more substantial. They are discussed below, in the context of two highly differentiated models, referred to as "reserves-on-ledger" and "central-bank-on-ledger", with a restrained or an extensive use of the possibilities offered by recourse to DLT, respectively.

Consequences for the monetary policy implementation framework

Common features of both implementation models include the central bank and potentially all financial institutions participating on the wCBDC platform, and having an account with the central bank as a precondition for participation. Transactions would take place on a payment-versus-payment (PvP) basis, be validated through a consensus mechanism in which the central bank would not necessarily participate, although it would in all cases be entitled to block a transaction, and be settled "atomically", thus eliminating settlement risk. Transfers between reserve accounts and wCBDC holdings would be immediate and could be free of charge, in order to eliminate any frictions and maintain the fungibility of the monetary base (cash plus reserves plus CBDC). The wCBDC could appear as an aggregate item in the balance sheet of the central bank.

The "reserves-on-ledger" model keeps the monetary policy instruments and procedures basically unchanged, using wCBDC mainly for "notary" purposes. The wCBDC platform, which would be fully owned and operated by the central banks, would thus appear as a mere extension of the existing central bank payment infrastructure (i.e. its RTGS system). In this model, wCBDC could only be created by transferring reserves onto the wCBDC platform and destroyed by converting wCBDC back to the reserve accounts. The wCBDC platform would operate only during central bank working hours. At the end of the day, there would be two possibilities: either wCBDC would remain "frozen" in the wCBDC platform, or it would be converted back into reserves. In the first case, wCBDC would have to be accounted for in the computation of reserve requirements if a required reserves system is in place. In the second case, either the central bank would automatically "sweep" all wCBDC onto central bank accounts (and the aggregate item "wCBDC" in the balance sheet of the central bank would be systematically void or would not even appear), or the holders, who would be incentivised (e.g. if the wCBDC bears a zero-interest rate – see below), would realise the transfer.

The "central-bank-on-ledger" model aims to draw as much as possible on the offerings of the DLT, even if this might imply some amendments to the monetary policy instruments and procedures. In this model, wCBDC could be created directly by the central bank on the wCBDC platform, for instance by purchasing assets or by conducting refinancing operations on it. The wCBDC platform itself could be either operated and owned by the central bank or shared by the central bank and other stakeholders. Institutions (e.g., Fintechs or non-residents) could participate in the wCBDC platform, possibly without having an account with the central bank. In case a reserve requirement system is in place, wCBDC held by institutions that are subject to it could be considered as required reserves by priority and as excess reserves for the rest (Pfister, 2020a). The wCBDC platform would operate on a 24/7 basis. Possible consequences could be that an explicit market for intraday wCBDC might appear and that liquidity crises might occur when the central bank is closed. At some point, this could put pressure on the central bank to also operate 24/7.[7] To the extent that reserves are remunerated at a non-zero interest rate, interest would then have to be paid at the same rate and same time as the payment of interest on reserves, in order to keep parity between wCBDC and reserves.

Of course, there could be many variants in between the "reserves-on-ledger" and the "central-bank-on-ledger" models. For instance, access could be enlarged and operating hours extended, starting from the "reserves-on-ledger" model.

The choice of the issuance model would have implications for the wCBDC remuneration. In the "reserves-on-ledger" model, wCBDC would not have to be remunerated, even if reserves are. This could obviously be the case if the central bank automatically "swept" wCBDC into banks' accounts at the end of the day. In case it did not and reserves (including excess reserves) are remunerated, the lack of remuneration of wCBDC would give banks an incentive to convert their wCBDC back into reserves at any moment before the end of the day. However, for this incentive to work, interest rates on required and excess reserves would have to be positive or banks would have to need the reserves to fulfil their reserve requirement (assuming, which is reasonable, that the penalty for missing the reserve requirement is itself positive). This shows that,

7 For more on the possibility and the consequences of implementing a "real-time" monetary policy, see Pfister (2018).

in the "reserves-on-ledger" model, automatic "sweeping" by the central bank would most likely have to prevail when interest rates are negative. This notwithstanding, within the same model and to the extent that reserves are remunerated, interest could also be paid on wCBDC, through programmability, in case wCBDC would be "frozen" in the wCBDC platform at the end of the day, along the same modalities as in the "central-bank-on-ledger" model.

Finally, if both wCBDC and rCBDC are issued, and the central bank wishes to keep their circulations distinct, the remuneration of rCBDC and its possible individual holding limit would depend on the remuneration of wCBDC. In particular, in order to avoid that monetary policy counterparties hold rCBDC instead of wCBDC, if rCBDC bears a zero-interest rate, its individual holding would have to be limited when the policy rate is negative. For the same reason, the remuneration of rCBDC should be set below or equal to that of wCBDC when the policy rate is strictly positive.[8] Of course, there could also be only one form of CBDC serving both as a rCBDC and wCBDC, but the risks of disintermediation by rCBDC would be higher, since wCBDC would have to bear the same interest rate as reserves to keep parity with them and interest rates are most of the time strictly positive (Pfister, 2019).

Precautions

Resilience refers to the ability to identify, protect against and recover from adverse shocks and other disruptive events. Due to their systemic role and to the reputation risk involved, wCBDC ecosystems should be secure (e.g. resist cyberattacks and fraud) and resilient to operational risks, such as loss of network communication, electrical outage, and natural disasters. In the case of cross-border transactions, resilience would also depend on arrangements used for interlinking CBDCs. The installation of a unified or regulated liabilities network or that of a "bridge" or the sharing of a common infrastructure at the international level could create concentration and a single point of failure risk.

The central bank's reputation could also be seriously hurt in case of breaches of confidentiality. As exemplified in the projects carried out by the Banque de France, two main techniques, where transactions can be pseudonymous and the central bank has more visibility over transactions, can be implemented separately or in combination (Banque de France, 2021). The first technique is data encryption, where specific cryptographic keys are distributed in order to determine which participants can access which data and are required to decrypt and read these data. The second technique is data segregation, which implies that data is located on specific nodes of the blockchain. As a result, the transactions are stored only in relevant databases and made accessible to specific node owners, for instance the parties to a transaction. Overall, on the basis of the Banque de France experiments, it would appear that the use of data encryption on a public blockchain could ensure more confidentiality, while keeping traceability, albeit at a higher cost than using data segregation on a private blockchain or on a standard system.

Jurisdictions participating in a project to make cross-border payments using wCBDCs should at least agree on common standards making their wCBDC systems compatible.[9] Provided governance issues are overcome, a higher degree of integration between wCBDC systems could be achieved by interlinking them through a common infrastructure, or even by creating a single wCBDC system where cross-border payments are settled by participating jurisdictions and multiple currencies are exchanged (BIS-CPMI-IMF-WBG, 2022). In all cases, coordination should preferably take place at an early stage, as making existing payment infrastructures compatible or interlinking them is costly and takes time, to the point that building entirely new infrastructures for that goal can be more economical and expeditious. At the same time, coordinating can be ambiguous since it can unwillingly serve the interests of a foreign country which has taken a technological lead. For instance, the People's Bank of China (PBoC) has been actively exploring the possibilities of a cross-border use of CBDCs in recent years (BIS Innovation Hub, 2022). The PBoC has also been partnering in the work of the G20 on CBDC interoperability for cross-border payments (FSB, 2023). Through its participation in international projects and groups, China could play a disproportionate role, in comparison with the one played by its currency on the international stage, in the definition of international standards for CBDC (Pfister and de Sèze, 2023).

8 On the remuneration of rCBDC and its consequences for monetary policy, see Pfister (2020b, 2023).

9 Compatibility is the minimal form of interoperability that presupposes the use of common standards for interacting, without the need for a common or a shared infrastructure.

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Relationship Between CO_2 Emissions and Trade: The Case of the EU

Understanding the relationship between international trade and CO_2 emissions is crucial for designing appropriate measures to address climate change. This article focuses on CO_2 emissions as one of the trade flow determinants of the EU countries, along with other factors including remoteness, labour productivity, real effective exchange rates, and research and development expenditures. The authors conclude that EU exports and imports are growing to or from those partner countries whose CO_2 emissions are rising. Furthermore, the growing similarity between the emissions of the EU and partner countries supports mainly the growth of EU exports and points to the slowdown in the growth of partners' emissions intensity. The existence of a relationship between CO_2 emissions and EU trade is important for the expected effects of the Carbon Border Adjustment Mechanism to materialise. Thus, this study confirms the assumption that emissions can be reduced in EU partner countries through trade and trade measures.

Due to intensifying negative effects of the climate crisis, the relationship between international trade and CO_2 emissions gained attention not only in academia but also among policymakers. Understanding this relationship is important in designing appropriate measures for addressing climate change.

The effect of trade on CO_2 emissions seems ambiguous. On the one hand, trade allows for lower-emission goods, services and technologies to be distributed worldwide, which leads to lowering global emissions. An additional positive effect of trade on global CO_2 emissions is the pressure that trade openness puts on firms to increase their efficiency, including energy efficiency. On the other hand, however, trade contributes to the growth of CO_2 emissions through the environmental costs of transportation, mainly shipping. It also allows the production of emission-intensive goods to be moved from countries with high environmental standards to countries with lower CO_2 emission costs for producers. This, in turn, leads to higher global CO_2 emissions compared to situations without production shifting and subsequent trade, i.e. import of products to countries pursuing climate protection policies. This phenomenon is referred to as carbon leakage.

For countries pursuing CO_2 emission reduction policies, the implications of their policies on trade are particularly important. As Sato and Burke (2021, 1) explain:

> Attempts by governments to extract revenue from industry sectors with climate policies invariably will be met by opposition. Yet when faced by claims that climate policy will drive away jobs at the expense of domestic workers while having little impact on emissions anyway, policymakers and politicians must be able to explain the underlying causes.

The EU is considered to be the global leader in environmental and climate issues (Wurzel and Connelly, 2011). To prevent emission reduction measures in the EU from being accompanied by carbon leakage and an increase in the import of emissions-intensive goods, the EU has

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launched the Carbon Border Adjustment Mechanism (CBAM), as of 1 October 2023. During the transition period, which will run until the end of 2025, importers of several emissions-intensive goods will be required to report direct and indirect greenhouse gas (GHG) emissions contained in their imports without any payments. The new mechanism has initiated a great deal research focusing on its expected effects.

This article focuses on CO_2 emissions as one of the factors influencing trade flows of the EU countries along with other factors including remoteness, labour productivity, real effective exchange rates (REER), and research and development (R&D) expenditures as a share of GDP. Verification of the relationship between CO_2 emissions and EU trade is significant with regard to the adoption of CBAM.

Literature review

Several authors have empirically studied the relationship between international trade and CO_2 emissions. For EU countries, Shpak et al. (2022) investigated the dependence of CO_2 emissions on macroeconomic indicators including exports and imports between 1990 and 2020. They concluded that with increases in EU exports, its CO_2 emissions decreased while with increases in EU imports, CO_2 emissions increased.

The relationship between the rise of exports and the decrease in CO_2 emissions can be explained by the Porter hypothesis, according to which policy measures aimed at reducing CO_2 emissions stimulate innovation, productivity and reorientation towards fossil energy-sparing technologies and products (Porter, 1991). Porter's hypothesis has been verified by several empirical studies. Based on the evidence from firm-level data for Germany, Richter and Schiersch (2017) found a negative relationship between the export intensity of a company and its emission intensity indicating that exporting firms are less CO_2 emission-intensive than non-exporting ones. The same relationship was identified by Barrows and Ollivier (2021) in the case of manufacturing firms in India. Although the export growth led to growth in CO_2 emissions of these firms due to the output growth, it had a negative impact on CO_2 intensity growth.

As far as the relationship between import and CO_2 emissions increases is concerned, Fanelli and Ortis (2020, 141), in contrast to Shpak et al. (2022), argue that "replacement of European products with emerging countries' imports has led to an apparent decrease in EU's emissions". This was also found by Valodka et al. (2020), who investigated the impact of international trade on the EU clothing industry's carbon emissions. According to their results, along with production outsourcing, the EU has also outsourced CO_2 emissions. Ding et al. (2018) confirmed that China, as one of the major destinations for outsourcing, produced a high level of CO_2 emissions in the form of exports to other countries. From 2000 to 2014, CO_2 emissions embodied in Chinese exports to 38 countries including all EU countries increased significantly. After 2011, however, the CO_2 emission export intensity declined and was expected to decrease further. Similarly, Hu and Xu (2022) revealed that from 2002 to 2017, the expansion of the export trade scale improved the energy environmental efficiency and thus the CO_2 emissions efficiency in China. Han et al. (2022, 1253) explain that it is the upgrade of the industrial structure that plays a "significant mediating role in the export composition improvement for carbon reduction".

In order to reduce emissions and implement climate action, the EU has acted against carbon leakage by imposing CBAM on selected commodities with the highest emissions such as electricity, cement, aluminium, fertilisers, iron and steel products. It is also considering adding more types of plastic. Importing these commodities into the EU creates a new obligation to report the total quantity of goods imported in the period under review, including the amount of emissions tied to the production of the goods, together with the price already paid by the producer for carbon emissions in the country of production. In the future, a fee will by imposed on imports from areas with lower emission prices. The fee amount will be based on emissions from the production of the goods concerned (Overland and Huda, 2022). The idea that a carbon tax could become an effective tool in competition or a means of generating additional revenue for the importing country at the expense of the exporting country had to rise to the level of political decision-making sooner or later since companies producing emissions-intensive products such as steel and aluminium would have no incentive to introduce low-carbon production because of strong competitive pressures (Roginko, 2022). According to Lim et al. (2021), low-carbon industries will develop in the EU, which is expected to reduce import demand in the EU energy sectors.

Among the sectors subject to CBAM tariffs are the products that the EU imports the most: steel and aluminium. Overland and Sabyrbekov (2022) used open coding in the Atlast.ti machine learning programme to perform quantitative analysis of the content published by five EU aluminium companies in their financial reports and created a composite index. The analysis concluded that the countries' response to the CBAM will depend on their innovation capacity to cope with higher GHG costs. Clora and Yu (2022) underline the need to coordinate measures to decarbonise demand and supply across sectors in order to achieve ambitious emission reductions in Europe. Given the likely divergent changes in Europe's external trade between

sectors and trading partners, appropriate domestic policies should be put in place to facilitate these changes. Authors of the study also point to a positive link between the progressive reduction of European GHG emissions and increasing carbon leakage, as well as between a worsening trade balance and increasing carbon leakage, which requires the EU, the UK and Switzerland to engage the rest of the world in global decarbonisation efforts.

The CBAM is likely to change the price dynamics of some countries, reduce incentives for firms to outsource their carbon emissions and support a more general transition to a low-carbon economy. Fairness concerns could be addressed by recovering revenues from carbon import adjustments and using them for technology transfer and international climate finance (Magacho et al., 2022). Zachmann and McWilliams (2020) argue that a carbon tariff should not be a fundamental element of the European Commission's climate policy. They claim that there is no evidence that the increase in the carbon price leads to the displacement of emissions-intensive production. The authors draw attention to the fact that introducing a carbon duty may reduce steel imports from countries with lower environmental requirements into the EU, and at the same time it may support imports of products that are made of steel. This may lead to so-called cascading protectionism, i.e. customs duties being extended to other products in the value chain (Jenčová, 2020).

Methodology

The aim of this study is to examine CO_2 emissions as one of the determinants of exports and imports of EU27 member countries using the Poisson pseudo-maximum likelihood gravity modelling with fixed effects (Anderson, 1979; Silva and Tenreyro, 2006; Bubáková, 2013; Fally, 2015). Models were primarily estimated in RStudio (R Core Team, 2022) with the Gravity 1.0 package (Wölwer et al., 2018; Wölwer et al., 2022) and with the econometric software GRETL (Adkins et al., 2015; Cottrell and Lucchetti, 2021). The estimators were verified using robust standard errors (Zeileis et al., 2020; Zeileis and Hothorn, 2002; Zeileis, 2004, 2021). Multilateral resistance terms were covered, adding fixed effects to our specifications (Adam and Cobham, 2007; Cheong et al., 2014; Hsiao, 2014; Yotov et al., 2016; König, 2021). For simpler calculations, fixed effects were added manually and only for exporters and importers, but the latest literature recommends using exporter-time, importer-time and exporter-importer fixed effects (Breinlich et al., 2021). We recommend this for further research.

We expanded our specifications of gravity models with an alternative approach of similarity between countries, inspired by Linder's (1961) work. The similarity between pairs of countries is measured by the similarity term, which is calculated as the absolute value of the difference between the decadical logarithms of the investigated variable of two partner countries (literature uses natural logarithms; Jošić and Basic, 2019; Kitenge, 2021). A negative coefficient estimation on the similarity term is interpreted as an increase in similarity.

Gravity modelling is based on the classic regression analysis of panel data with fixed ($\alpha_{i,j,s}$) and time effects (λ_t), where Y represents the dependent variable and X individual regressors (general regression equation; own processing by Lukáčiková, 2013; Lu and Su, 2020; ECB and Frohm, 2021; Fišera, 2022):

$$Y_{i,j,s,t} = \alpha_i + \alpha_j + \alpha_s + \lambda_t + \beta_1 X_{1_{i,j,s,t}} + \beta_2 X_{2_{i,j,s,t}}$$

$$+ \beta_{n-1} X_{n-1_{i,j,s,t}} + \beta_n X_{n_{i,j,s,t}} + u_{i,j,s,t}.$$

Table 1 presents the variables used in the study.

Table 1
Description of variables

Variable	Description
Export_EU_jst	Export of EU27 member states (i) to all available (not EU27) partner countries (j), divided down by 10 SITC product groups (s) from 2011 to 2019 (t). Missing values were replaced with zero (UNCTADStat, 2022-2023).
Import_EU_jst	Import of EU27 member states (i) from all available (not EU27) partner countries (j), divided down by 10 SITC product groups (s) from 2011 to 2019 (t). Missing values were replaced with zero (UNCTADStat, 2022-2023).
ln_Remot_jt	Natural logarithm of the partner country's (j) remoteness from the EU that was determined as the product of distance and the partners' share of global GDP (Mayer and Zignago, 2012; CEPII, 2011; WBG, 2022; LU Department of Econometrics, 2021). Because of fixed effects, remoteness should be interpreted as a change in the partner's share of global GDP over time.
Sim_GDP_ppe	Labour productivity as a share of GDP per employee in the form of similarity term (WBG, 2022).
Sim_REER	Real effective exchange rate as index in the form of similarity term (WBG, 2023). REER captures changes in exchange rates and price levels of partners (e.g. Pavelka et al., 2021).
Sim_RandD	R&D expenditures as share of GDP in the form of a similarity term (WBG, 2022).
Sim_CO_2	Carbon-dioxide emissions in the form of a similarity term (WBG, 2022).
ln_CO_2_kt_jt	Natural logarithm of the partner country's (j) CO_2 emissions in kilotonnes (WBG, 2022).

Source: Authors.

Table 2
Results of gravity models

	Export_EU_jst				Import_EU_jst			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
const	20.49 ***	8.49 **	21.39 ***	16.29 ***	17.98 ***	12.93 **	19.15 ***	7.69 ***
ln_Remot_jt	-0.91 ***	-0.94 ***	-1.03 ***	-1.04 ***	-0.66 ***	-0.69 ***	-0.84 ***	-0.88 ***
Sim_GDP_ppe	-1.58 ***	-1.42 ***	-1.59 ***	-1.54 ***	-2.28 ***	-2.19 ***	-2.50 ***	-2.31 ***
Sim_REER	2.10 ***	2.05 ***			2.05 ***	2.06 ***		
Sim_RandD	-0.14	-0.20 **			-0.50 ***	-0.51 ***		
Sim_CO_2_kt	-0.27 ***		-0.22 ***		-0.10 *		-0.01	
ln_CO_2_kt_jt		0.76 ***		0.31 ***		0.32		0.76 ***
n (t 2011-2019)	66,480		341,550		66,480		341,550	
PPML	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects i	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects j	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Confidence levels: *** 99%; ** 95%; * 90%.

Source: Authors' estimation.

Results and discussion

Table 2 contains the results. Models 1 to 4 are specified with the variable export of 27 EU member states to all countries with available data for the years 2011 to 2019. Models 5 to 8 work with the values of imports of 27 EU member states coming from all partners. From the set of partner countries, the EU27 countries were omitted in all models.

The number of observations (n) was determined by the chosen specifications of the gravity models and the availability of individual variables in the source databases. The analysed time series and its length were influenced by the availability of data for CO_2 emissions.

The partner remoteness variable has an estimated coefficient with the same sign and similar values. We can confirm that with the growing remoteness of the partner, we expect a decrease in both EU27 exports and imports. However, it should be emphasised that due to the inclusion of fixed effects in the specifications of the equations, it is not possible to estimate variables that do not evolve over time. For this reason, we can only interpret the change in the share of the partner's GDP in the global GDP for the partner's remoteness variable. Hence, EU27 countries trade more intensively with partners whose share of global GDP is decreasing. The share of advanced economies in world GDP is declining in favour of emerging economies. Our results are consistent with the results of studies by Steinhauser and Boros (2022) and Kittová et al. (2022). Although these studies analyse only one EU country, namely the Slovak Republic, with its high trade openness, it represents a suitable benchmark among the EU27 countries.

In the case of the labour productivity variable in the form of a similarity term, all estimated parameters are negative. This means that due to the increasing similarity of labour productivity of partners, we can expect higher EU27 exports to partners, as well as EU27 imports from partners.

The REER parameter in the form of a similarity term was included only in models 1, 2, 5 and 6. The reason is that REER data were available only for some (mostly developed) partner countries and the inclusion of this parameter in the specification substantially reduces the number of observations. The results for the REER parameter are particularly interesting considering the import and export values. Thus, our models confirm the classic theoretical assumptions according to which the increasing difference in REER increases the value of exports and imports of EU27 to and from its partners. In the case of depreciation or devaluation of the currency of the exporting country against the currency of the partner, the price competitiveness of exports increases. Currency appreciation or revaluation against the partner's currency supports imports from the partner country. The negative effect of an overvalued currency on the trade balance was confirmed by Fišera and Horváth (2022). However, globalisation and global value chains reduce the influence of exchange rate fluctuations on the domestic economy. Moreover, countries that have given up control over their own currency

affect price competitiveness mainly by setting the tax wedge or the price of labour, not by influencing exchange rates (Turner and Van´t Dack, 1993; Baranová, 2013; Albu et al., 2022).

Like the REER variable, R&D expenditures were used only in some model specifications. Results of models 2, 5 and 6 show that the value of EU27 imports and exports is growing with the increasing similarity in R&D expenditures of partners. The estimated parameter in the specification of model 1 is, however, statistically insignificant, and therefore we cannot confirm the impact of the variable on EU27 exports.

Finally, we evaluate two variables expressing CO_2 emissions, which from the point of view of this research are the most important in our specifications. The results presented in Table 2 for the ln_CO_2_kt_jt variable show that EU27 exports are increasing to those partner countries whose CO_2 emissions are increasing. We explain this by the growing export of high-tech and environmental goods[1] from EU countries triggered by the production and consumption demand of partner countries (see e.g. Huiling et al., 2022 or Kerle et al., 2021). The growing demand, i.e. the import of partner countries, results from the growth of their industrial production, which is reflected in the growth of CO_2 emissions. The detailed statistics derived from the BACI database (Gaulier and Zignago, 2010; CEPII, 2023) and calculated using the dplyr package of the RStudio environment (Wickham et al., 2023) supports this conclusion. It shows that bilateral trade flows of environmental goods (IMF, 2021) from the 27 EU members to third countries increased from approximately US $221 billion in 2017 to almost US $285 billion in 2021. This time series showed stagnation only between 2019 and 2020 due to the pandemic.

Furthermore, based on the estimated coefficient of the variable ln_CO_2_kt_jt in model 8, we can assume that EU27 imports from partner countries with growing CO_2 emissions are also increasing (in the period from 2011 to 2019 they included, for example, China, India, Vietnam, Malaysia and Thailand). We interpret this finding in line with Fanelli and Ortis (2020) or Valodka et al. (2020) as a consequence of the rising costs of CO_2 emissions in the EU, which lead to the reduction of CO_2-intensive production in the EU and its transfer to countries with lower costs of CO_2 emissions. Subsequently, the EU imports the CO_2-intensive production of these countries. This interpretation also tracks with the findings of studies on introducing CBAM in the EU (Lim et al., 2021; Clora and Yu, 2022), which point to the fact that Europe's GHG emission reductions are offset by increased emissions elsewhere, and production is dispersed in several countries because of the global value chains.

The negative coefficient estimation on the similarity term for CO_2 emissions expresses that with an increase in the similarity of CO_2 emissions between the EU and partner countries, EU27 exports to partner countries increase (models 1 and 3). The influence of the similarity of emissions on EU27 imports was confirmed only marginally in model 5. Based on the results, we reject the null hypothesis of insignificance of the estimate of this variable with 90% probability. The growing similarity of CO_2 emissions of the EU and partner countries (such as China and India) is explained by the so-called closing of the gap in the development of CO_2 emissions, i.e., slowing down the growth of these countries' emissions, which corresponds to the findings of Hu and Xu (2022) or Han et al. (2022).

It is important to note that there is no single so-called global methodology for calculating CO_2 that is comparable among all countries in the world. This gives companies a choice of several calculation methodologies (e.g. under the GHG Protocol), which implies that the comparability and reporting of CO_2 when importing certain commodities into the EU may be distorted. Based on evidence, we expect a rather negative attitude of other countries towards CBAM in the short term. CBAM is expected to reduce imports of the commodities concerned. This, in turn, may lead to cascading protectionism. In the longer term, however, we assume that introducing a carbon tariff in the EU will contribute to reducing global emissions by changing the composition of production within and between countries. However, this requires climate policy synergies of the world's strongest economies (EU, US, China) and help from developed countries to developing countries. Based on studies focused on CBAM in the EU and its impact on changing trade patterns, we can summarise several policy recommendations:

- coordinate measures aimed at decarbonising not only demand but also supply in all sectors in Europe, which requires the implementation of appropriate domestic policies;
- involve the rest of the world, mainly China and the US, in global decarbonisation efforts (Clora and Yu, 2022);
- assess which countries are most likely to become the biggest opponents of the CBAM (Overland and Sabyrbekov, 2022), mitigating the impact of CBAMs in these

1 Environmental goods include both goods connected to environmental protection like those related to pollution management and resource management, and goods that have been specifically modified to be more environmentally friendly (IMF, 2023).

countries and offering support for their decarbonisation, for example through technology transfers;

- use the CBAM revenues for financing climate protection and technology transfer (Magacho et al, 2022).

Conclusions

Our research confirmed the existence of a relationship between CO_2 emissions and EU27 trade. We conclude that EU exports and imports are growing to or from those partner countries whose CO_2 emissions are rising. We explain these results in the case of EU exports by the growth of demand from partners with increasing CO_2 emissions for high-tech and environmental goods. In the case of EU imports, this is a consequence of moving CO_2-intensive production from the EU to partner countries and importing it to the EU. The growing similarity between the emissions of the EU and partner countries mainly supports the growth of EU exports and points to the slowdown in the growth of partners' emissions intensity. However, in drawing these conclusions, it is important to point out the limitations of the research arising from the fact that the CO_2 emission indicator used does not reflect the determinants of emissions such as sectoral composition of the economy, transport, energy efficiency, etc. We therefore recommend that future research should take these determinants into account. Another limitation of our study results from the availability of individual variables in the source databases, the time series analysed and its length. Therefore, we recommend the verification of results presented in this study using data for the coming years.

The existence of a relationship between CO_2 emissions and EU trade is important for the expected effects of the CBAM to materialise. This mechanism is expected to support environmental goods production in the EU, decrease unit costs of such production, and increase its affordability and its wider use in other countries leading to growing EU exports of environmental goods. CBAM is also expected to limit CO_2-intensive imports to the EU and thus promote the introduction of climate policies aimed at reducing CO_2 emissions in partner countries. A significant limitation of this assumption can be seen in the mismatch of countries' CO_2 calculations. Therefore, the adoption of a single methodology for CO_2 measurement is recommended. Moreover, measures to mitigate climate change should be based on the adoption of a global carbon price for GHG emissions based on the place of production. It is also important to avoid cascading protectionism and use government revenues from the carbon tax to promote more efficient production – not only of raw materials but also of all links in the supply chain – with the common goal of reducing the carbon footprint. This requires a change in the composition of production in the coming years.

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Budgetary Framework Reform in Green Transition in the EU and Germany

The proposal to amend Council Directive 2011/85/EU on the EU budgetary framework may result in changes in the role of environmental sustainability and explicitly the role of green budgeting in decision-making processes. While this topic is still in its infancy in Germany compared to other EU countries, there are some examples that show how green budgeting elements can be integrated in present budget procedures. The few German initiatives at the municipal level refer to very broad sustainability goals, rarely take comprehensive account of ecological impacts and are only extended to parts of the budget on a pilot basis: a genuine green budgeting concept has not been developed. With the focus on green budgeting, the EU is starting to push the climate policy agenda further. However, all international green budgeting practices show that it takes a considerable amount of time to implement a mature approach. Accordingly, time and effort will be needed for member states to adapt, conceptualise and expand approaches in the future.

The European Commission's initiative for a fundamental change in European governance laid the groundwork for a reform that began in the wake of the COVID-19 pandemic. After a public participation process initiated by the Commission and the publication of a subsequent communication in 2022, legislative proposals were published in April 2023 (European Commission, 2023c). The Council formally agreed on the proposed reform in December 2023, resulting in an adapted proposal (Council of the European Union, 2023). The reform proposals on fiscal rules (European Commission 2023a; 2023b) received considerable media and academic interest (Gauret, 2023), while the reform proposals on the EU budgetary framework of Council Directive 2011/85/EU (European Commission, 2023c) drew less attention.

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Substantial changes that could result from this Commission's proposal concern Independent Fiscal Institutions (IFIs), as the authors have recently commented in this journal (Bender et al., 2023). The present article discusses another important side element related to the nature and structure of governance in the EU: the changes concerning the role of (environmental) sustainability issues in the budgetary framework and explicitly the suggestions on the role of green budgeting in the budgetary decision-making processes in the EU and its member states. The proposed changes aiming at incorporating aspects of sustainability into the budgeting process – summarised under the term "green budgeting" in the following – may affect the way budgetary and fiscal policies are designed, monitored and evaluated in the future.

The Organisation for Economic Co-operation and Development (OECD) and the European Commission, among others, are gradually subsuming budgetary resources and climate policy or environmental protection under the term green budgeting and have cast it into an initial definitional framework: green budgeting examines the positive, neutral and negative effects of all budgetary, regulatory and tax policy measures and processes in the public sector. Both financial aspects (input assessment) and assessments of the results dimension (impact assessment) can

Table 1
EU budgetary framework: European Commission's proposal to amend Council Directive 2011/85/EU

	Implementation and reporting	Data reporting demands on budget planning	Governance and implementation in the budget process
Proposal of the Commission	IFIs/medium-term budgetary frameworks: proposed Article 9(2) points (c) and (d)	• Data and descriptive information on expenditure, tax expenditure and revenue items • Evaluation of the budget in terms of favourable and unfavourable green priorities	• Becomes relevant upon adoption of the proposal • Authors' recommendation is to use the established EU institutions and coordination mechanisms, e.g. incorporation in the European Semester
Implementation status in the EU	• No legal obligations at the EU level • Reports are usually prepared on the basis of budget laws • Mostly reporting in annual budget plans, sometimes in execution reports or multi-annual budget plans • Tagging is usually conducted with a set of environmental objectives (e.g. EU Taxonomy)	• Partly issuance of sovereign green/ sustainable bonds • Coverage of the public sector is mostly limited to the central government	• Usually central budget authority is leading the process, closely involving relevant ministries • Information is often provided to the parliament along with the budget documents • Structured dialogue with civil society bodies, independent climate councils, etc.
Implementation status in Germany	• No (legal) anchors for green budgeting • Only target formulations in the coalition agreement at the federal level • Recommendations for a legal anchoring, e.g. in the Federal Budget Code (BHO)	• No genuine green budgeting concept at the federal or state level • Only reports that are related to the topic (e.g., spending reviews, reports on environmentally harmful subsidies) • Pilot initiatives at subnational level	Central players at the federal level (e.g. in the Spending Review) currently appear to be: • Ministry of Finance • Ministry of the Environment • Ministry of Economic Affairs

Sources: Authors' own illustration; for the EU, see European Commission (2023d) and Botta et al. (2023); for Germany, see Bär et al. (2023) and Bär and Bitomsky (2022).

be examined (Battersby et al., 2021; OECD, 2022). Green budgeting can include both *ex post* evaluations and *ex ante* impact assessments. The core instrument of the assessment is usually green budget tagging, a method used for classifying budget items according to their environmental impact and thus directly linking the financial and environmental effects of public services on a rather input-oriented basis (Larch, 2023).

In a higher stage of development, green budgeting is a form of output-oriented or priority-based budgeting that aims to align fiscal and budgetary policies with environmental goals, especially climate goals (Bova, 2021). It aims to provide policymakers and planners with a clear and systematic understanding of the environmental or climate impacts of budgetary decisions, which enables them to prioritise effective measures to achieve environmental policy goals. Therefore, it forms a cornerstone for the systematic and fundamental incorporation of environmental costs, risks and impact assessments into the field of public finance.

This article first clusters the ideas of the proposal to link public finances with climate and environment, then briefly discusses the current role of green budgeting in the EU and subsequently reviews the current state of affairs in Germany. Finally, the article assesses the possible impacts of the proposal on the national budgets and on EU governance in general.

Clustering the proposal's important side element

The latest version of the proposal (Council of the European Union, 2023) refers, among other things, to the Commission's communication on the European Green Deal (European Commission, 2019), which calls for "a greater use of green budgeting tools ... to redirect public investment, consumption and taxation to green priorities and away from harmful subsidies". It cites as an impetus the Commission's communication on the new EU strategy on adaptation to climate change (European Commission, 2021), which points to "the macro-fiscal relevance of climate change and highlighted the need to increase Union's resilience to the impacts of climate change" (Council of the European Union, 2023). The proposal also emphasises that budgetary planning should focus more on "macrofiscal risks from climate change, including its environmental and distributional impacts" (Council of the European Union, 2023). It emphasises that one key of national strategies to address the risk arising from climate change is to understand the channels through which climate-related shocks affect public finances.

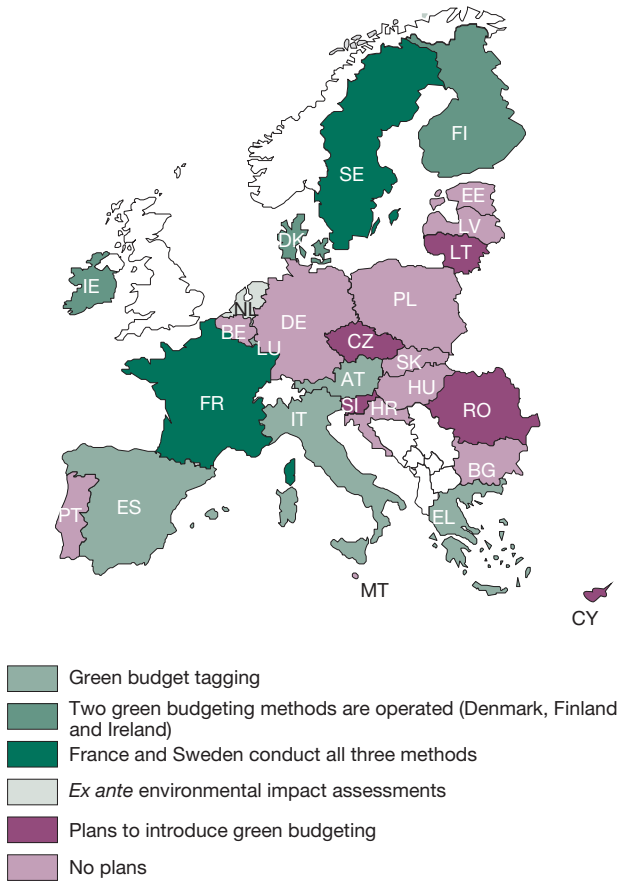
Specific proposals on sustainable growth and finance as well as green budgeting are made in Article 9. Member states are required to establish a national medium-term budgetary framework "with an impact on general government finances and sustainable and inclusive growth,

broken down by major revenue and expenditure item" (European Commission, 2023c, 17). The frameworks shall include an assessment of how the envisaged policies will affect the sustainability of the public finances and sustainable and inclusive growth, taking into account the macrofiscal risks from climate change and its impacts.

Table 1 provides a brief analysis of the proposal and the state of implementation in the EU on green budgeting, with a special focus on Germany. It clusters data reporting requirements by (legal) implementation as well as the governance and the implementation in the budget processes – and thus provides an overview of the content of the subsequent sections.

It is worth noting that the original Council Directive 2011/85/EU did not contain any mention of (environmental) sustainability and climate. Apparently, the political environment has changed since the directive was adopted in 2011, which the Commission itself explains with the decisions and strategies described above (European Commission, 2019, 2021). The reasons given in the proposal for amending the directive are, in particular, the advantages of green budgeting and the assessment the obligations and risks for public finances resulting from natural disasters and climate-related events. The proposal explicitly argues that "Green budgeting tools can help redirect public revenue and expenditure to green priorities" (Council of the European Union, 2023). Before discussing the implications of this proposal, we turn to the current state of green budgeting in Europe.

Figure 1
Green budgeting practices in the EU



Source: European Commission (2023d); authors' illustration.

A new budgetary instrument for the EU

Due to the growing need for financial efficiency, combined with the increasing pressure to act quickly in the face of worsening climate and biodiversity crises, the concept of green budgeting is gaining importance within the EU: prominent and more advanced examples are Austria, Denmark, France, Ireland, Italy, Sweden as well as the EU budget itself (Bär et al, 2022; OECE et al., 2021; OECD, 2022). In addition to the central government approaches, there are numerous subnational approaches, e.g. in Sardinia (Italy), Andalusia and Catalonia (Spain), and Brittany, Grand Est and Occitania (France) (OECD, 2022). Some cases include social security (e.g. Spain and France) or state-owned enterprises (France) (European Commission, 2023d). While some approaches focus more on climate-related budget titles, only on expenditures, or only on environmentally positive budgets, others go well beyond this scope.

Almost two-thirds of member states have introduced or plan to introduce green budgeting approaches (Figure 1). Twelve EU countries are practicing green budgeting, and five are planning to introduce such practices in the future. Ten countries use tagging as a method, six conduct *ex ante* environmental impact assessments and three carry out *ex post* environmental evaluations. In particular, France and Sweden stand out for practicing all three methods. Denmark also applies both, *ex ante* environmental impact assessments and *ex post* environmental assessments, Finland and Ireland operate through tagging and *ex ante* environmental impact assessments. Germany, Belgium, Portugal and most of the Eastern European countries are lagging behind.

In principle, the data reporting requirements for budget planning vary greatly among the EU countries. Most countries provide information in their annual budgets, while France, Ireland, Italy and the Netherlands do so in their budget implementation reports, and Finland, Ireland, Italy and Luxembourg in their multi-annual plans. Austria, France and Italy publish detailed statements on

green budgeting separately from the budget. In addition, Austria, Greece, Finland, France, Ireland and Sweden capture the negative impact of budget items. The analysis of expenditure measures is the most common practice whereas Ireland and Finland are also tagging revenue measures. Furthermore, Austria, Spain, France and Italy have implemented a scaled approach to tagging.

There is also a great variety in terms of governance and implementation in the budget process. In Austria, Spain, France and Portugal, a working group develops and coordinates the process, while supervision is shared with the central budget authority or is integrated within the Ministry of finance. In Denmark and Sweden, the Ministry of the Environment prepares annual evaluation reports in cooperation with relevant agencies (e.g. energy or environmental protection agency) and in Denmark, the Minister for Climate must present parliament with a report on the effects of the government climate policy and answer any questions at an interpellation debate in the parliament. Denmark, Greece, France, Ireland, Luxembourg, Portugal and Sweden, in particular, revise their methodology regularly (European Commission, 2023d).

The French approach is one of the most sophisticated in terms of methodology and content, showing a wide range of results and is also considered an international showcase (Bär et al., 2022). And there are numerous subnational green budgeting initiatives in France, with different regions and municipalities using a methodology based on that used at the national level (OECD, 2022). The French model was initially proposed in 2017 as part of the OECD Paris Collaborative on Green Budgeting, further developed in 2019 by a French interministerial working group and first applied in 2020 for the 2021 budget. In the French model, the government submits the green budgeting report to Parliament as an annex to the Finance Act (Gouvernement de la République française, 2022). Involved institutions are in particular a Sustainable Development Commission, the Ministry for Ecological and Inclusive Transition and the Ministry for the Economy, Finance and the Recovery. The example of France also shows that the EU taxonomy can serve as an orientation and a set of rules for sustainable budgets. In the French system, the budget is assessed by means of six categories for sustainable finances, also defined in the EU taxonomy (climate change mitigation, adaption, water, waste, pollution and biodiversity).

Fundamentally, the impacts of climate change create new challenges for fiscal policy and, correspondingly, for IFIs. In particular, the number of climate advisory bodies in the EU is increasing and, at the same time, many IFIs may be tasked with simulating basic macroeconomic and budgetary impacts of climate change. The reform proposal includes an expansion of the mandatory tasks of IFIs (Bender et al., 2023), which is why one of the main questions for the future is whether the respective IFIs are prepared for their new responsibilities – also in the context of climate policy and green budgeting. In practice, there are already some promising approaches: IFIs in six member states are assessing environmental and climate transition measures as part of cost evaluations. Some IFIs stand out so far. For example, in the Netherlands, the IFI is completing a model-based assessment of the Dutch Climate Agreement, and in Sweden, views on the interaction between climate change and the domestic regulatory framework are summarised in a report (Larch, 2023).

There is still potential for expansion in green budgeting concepts. For example, no comprehensive *ex post* evaluation of green budgeting approaches has yet been completed. Currently, only Austria reports that it is developing such an instrument. However, there are early indications of positive impacts from green budgeting, e.g. in Austria, Denmark, Greece, Ireland, Luxembourg, Spain and Sweden. These impacts are probably mainly due to the fact that sustainability considerations are becoming more prominent in budget planning and deliberations. And in some cases, impact assessments have to be conducted. As a result, policymakers are becoming more aware of the environmental impacts of budget measures. Commission surveys show that EU member states would generally welcome support from the Commission to further develop their green budgeting approaches (European Commission, 2022b; 2023d). In addition to ongoing support, some member states would like to be further supported by the Commission in a number of areas: in evaluating the (national) approach to green budgeting, its effectiveness and impact; in establishing a permanent help desk for green budgeting at EU level; and in extending training to more officials. The country-specific technical assistance already taking place has been generally well received, and some countries may wish to further deepen this cooperation.

Generally, it is advisable to use the established EU institutions and their coordination mechanisms, like the European Semester, which since 2011 has been a cycle of macroeconomic, budgetary and structural policy coordination supporting the implementation of agreed common priorities. It provides a common timetable for EU policy governance, including the publication of country-specific recommendations by the European Commission, which may well have the potential to incentivise structural reforms towards the implementation of green budgeting tools. Thus, the European Semester could act as a hinge between member states and the EU to exchange, pool,

and process information on green budgeting progress (Green Budget Europe, 2023).

The state of green budgeting in Germany

Germany is far behind in green budgeting practices (European Commission, 2022b; 2023d). First pilot projects on green budgeting have been initiated – especially under the label of sustainability budgeting and at the municipal level. The state level is not yet intensively involved, acting merely as an advisory institution for the municipalities (e.g. Keilmann and Gnädinger, 2022; Arbeitsgruppe Produktbuch, 2023; Keilmann et al., 2023).

The city of Freiburg im Breisgau was the first municipality to link its sustainability target system to the city budget (Schuster et al., 2021). Other German municipalities have gradually followed this example, with concepts initially being tested and implemented primarily on a pilot basis (Botta et al., 2023). Despite many commitments to a greater coherence between environmental policy goals and budgetary policy, the status quo still shows great inconsistencies between these two policy areas (Bär et al., 2023; OECD, 2023). At the federal level, apart from a few initial approaches that show some connection to the topic, there is no considerable green budgeting concept (see e.g. BMF, 2017, 2021, 2022; Burger and Bretschneider, 2021; Federal Court of Audit, 2022).[1] However, these are rather cursory reports on individual topics; a genuine green budgeting concept has not been developed.

On the one hand, public finances in Germany show high levels of environmentally friendly expenditure in departmental plans (Bär et al., 2023; Destatis, 2023). On the other, there are extensive environmentally harmful subsidies, which is why a green budgeting approach with a systematic analysis of the revenue and expenditure side would contribute to a stronger impact orientation in this mixed burden (Bär and Bitomsky, 2022, 29). The current agreement at the federal level has committed to a stronger target- and impact-oriented budget management and to the reduction of redundant, ineffective and environmentally damaging subsidies and expenditures (SPD, Bündnis 90/Die Grünen and FDP, 2021). In addition, the Federal Court of Auditors explicitly recommends the development of a "climate tracking" (Bundesrechnungshof, 2022), comparable to existing tagging approaches, in order to classify budget items according to their climate impacts (Bär and Bitomsky, 2022). Nevertheless, there are no binding (legal) anchors for green budgeting yet.

At present, there are very few approaches being pursued that are comparable with international green budgeting approaches, especially in terms of methodological maturity. In addition to a broad landscape of sustainability concepts, target descriptions and voluntary commitments (some with statutory status), a close link to the public budget has only been established in isolated cases (Botta et al., 2023). The main approach is to use sustainability budgeting, referring to rather broad sustainability goals and only rarely taking ecological impacts into account comprehensively. In most cases, budgeted amounts for specific municipal products are indicated, especially those with which a positive sustainability impact is associated. Meanwhile, consideration of the negative impacts of either municipal expenditures (energy consumption, construction activity, procurement, etc.) or the revenue side are still very limited. Trade-offs due to environmentally harmful financial flows are also hardly taken into account, whereby just the intent to be "environmentally friendly" is often considered sufficient to classify a financial flow as such (Bär and Bitomsky, 2022). In addition, various initiatives on impact-oriented budgeting, e.g. gender budgeting,[2] are also related to (environmental) sustainability budgeting.

In the German use cases of green budgeting, only selective aspects and a few key budget products are linked to sustainability targets and key performance indicators (Botta et al., 2023). Overall, the existing approaches in Germany fall short of a systemic inclusion of the climate impact of budgets (Bär and Bitomsky, 2022). An integrated approach that encompasses all areas of the budget, all levels of the federal system and captures climate effectiveness according to a comparable scheme is still largely open. German budget planning – which is primarily input-oriented – shows a rather low impact or outcome orientation at all federal levels in an international comparison. And one of the main reasons why there still is no uniform green budgeting strategy in Germany is the lack of a methodological and conceptual basis (OECD, 2021). Experiences from budgeting considering broader sustainability aspects also show that estimating the impact of expenditures is fraught with greater methodological difficulties (Martens, 2017; Mulholland and Berger, 2019). In general, the extent to which the ecological impacts of budget systems have so far been considered, and the methods used to do so, vary greatly from one local administration to another. Due to the methodological diversity, it can be assumed that a standardisation of one green budgeting

1 A scientific project is currently supervising a possible approach to green budgeting, with a project duration from 2022 to 2025 (FU Berlin, 2022; FiFo, 2022).

2 Gender budgeting describes the application of gender mainstreaming in the budget process and involves a gender analysis of budgets that integrates a gender equality perspective in the budget process and redistributes revenues and expenditures to promote gender equality (Council of Europe, 2005).

concept would be beneficial in the medium term for successful nationwide scaling.

Concluding assessment on green budgeting

The implementation of green budgeting comprises a long and complex path. While international comparisons are difficult due to different governmental and administrative structures, all best practices (including the domestic ones) show that a mature green budgeting approach takes years to implement. In addition, there is an evident need for continual adaptation and expansion of concepts, as well as a range of stakeholders and institutions involved.

The Commission's proposal to amend Council Directive 2011/85/EU represents a milestone for the reform of European governance, not only in general or for IFIs (Bender et al., 2023), but also for approaches to climate and environmental public finance. With the focus on green budgeting, it is clear that the Commission is starting to further advance the climate policy agenda. Simultaneously, the implementation of the proposal might lead to an increase in administrative capacity and could be accompanied by a rapid expansion and strengthening of the governance system. This must always be seen against the background of the national implementation strategy. Keeping that in mind, the proposal could demonstrate how effective governance can help to foster good governance in the sense of enhanced political advisory work.

However, some provisions of the proposed regulation remain subject to special and therefore national interpretation. While proposals may be well intentioned, their implementation depends on factors to be negotiated at the national level (Bender et al., 2023). Consequently, even if adopted, it will not automatically provide the resources needed to develop a fully comprehensive green budgeting toolkit for member states. Although the proposal remains relatively vague in terms of concrete implementation measures, it could bring momentum to the green budgeting implementation processes. In order to align resources, political commitment and a framework for green budgeting adapted to the national context are needed.

In Germany, a more legally binding European anchoring of green budgeting initiatives will probably push this process in the political agenda. Policymakers would likely have to act quickly if the proposal was adopted, in order to create Germany's own legal and institutional foundations. However, green budgeting also requires considerable resources (e.g. personnel, know-how) and a substantial monitoring effort. As the implementation of green budgeting in Germany is not very advanced, the adoption of the proposal could also mean that all levels of government would have to invest in their own administrative infrastructure. This raises the fundamental question of whether green budgeting should be initiated top-down, from the EU level down to the member states, or rather bottom-up, from the member states – or even at subnational levels. This questions may be answered differently in the various member states.

Green budgeting concepts require political settings that are aware of their importance and explicitly provide appropriate resources. This would be equally supportable from a policy perspective, as a detailed and comprehensive analysis of impact-oriented budgeting and taxation must also be in the interest of policymakers themselves. Green budgeting generates considerable data in the public sector and thus supports better informed policy decisions. With green budgeting at different levels of government, regionalised policy decisions on climate could also be made, which could have a positive impact on, e.g. planning law, building permits or facility management. Better informed policy decisions would in particular aim at a better estimation of the costs and benefits of specific measures. Sectoral targets can be underpinned by sub-targets, the data basis of which can also be determined using fiscal policy indicators. This can be further enhanced if the data collection process can be integrated into the European Semester. A standardised European database on green budgeting could be helpful in assessing national efforts to implement eco-friendly policies with regard to fiscal policies. At the same time, however, the instrument does not solve political problems by itself: it is a (technical) instrument that is only useful if it is supported by strong political will and is part of a system of budget decisions and other planning instruments – a tool to accompany change, but not a panacea to achieve it (Postic, 2021; Bär and Bitomsky, 2022).

Despite numerous examples of practical application, green budgeting – in the form of a systematic consideration of the environmental impacts of public revenues and expenditures – is still a relatively new concept in both the international and the European frameworks, with core questions still being answered in different ways. In principle, legislative initiatives such as the proposal to amend Council Directive 2011/85/EU can provide a breath of fresh air for the expansion and establishment of approaches throughout Europe.

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Strategic Climate Cooperation and Greenhouse Gas Price Coordination

Over the past year, policymakers, academics and non-governmental organizations on both sides of the Atlantic have begun talking about how to coordinate policies to reduce methane emissions from the oil and gas sector. While this may seem like an obscure, technical topic, moving forward with this initiative is critical, as the implications for climate cooperation – not just for the US and EU, but for the global community – are profound. In this article, we explore the reasons behind this assertion.

Climate change poses a global incentive problem: while individual nations bear the full costs of their climate policies – including the costs of energy transitions and the impact of higher energy prices on their competitive industries – most of the benefits of such policies accrue to the global community. As a result, self-interest too often leads to inadequate action.

Current international climate agreements, based on collective targets and nationally determined contributions, do not adequately address the free-rider challenge, which reduces their effectiveness. In contrast, common price agreements offer several advantages: ease of measurement, continuous monitoring, comparability, flexible implementation, and enforceability through mechanisms such as Carbon Border Adjustment Mechanisms and the conditional use of international climate funds. The reciprocity inherent in such a common price agreement is essential for climate cooperation, and reciprocity has been a helpful factor in the success of other international agreements – from minimum corporate taxes to trade to disarmament (Cramton et al., 2017). Reciprocity protects cooperators from potential exploitation and fosters an environment conducive to cooperation, even for self-interested parties (Ostrom, 1990; Schmidt and Ockenfels, 2021).

A climate club provides an opportunity to initiate a common pricing agreement (Nordhaus, 2015; Snower, 2022), although it is important to recognize that cooperation and enforcement mechanisms evolve incrementally. The value of a multilateral or bilateral agreement should be judged not on its immediate impact but on its potential to dynamically change the landscape of cooperation in an area of inadequate, fragmented and asymmetric climate policies. A global, ambitious carbon price may take time to become feasible, but striving to improve cooperation is beneficial, imperative and possible.

There are a number of key strategies:

Start with bilateral engagement. Effective climate cooperation requires that the US and the EU coordinate on a carbon price floor and ultimately use their collective sanctioning and rewarding power to motivate and enforce cooperation from reluctant governments (Farrokhi and Lashkaripour, 2022). Getting the US on board is currently difficult, but its climate policy remains in flux, and the 2025 overhaul of the tax code will require new sources of revenue. Carbon pricing revenues are a plausible candidate (Clausing and Sarin, 2023). Moreover, a carbon price and a carbon border adjustment would support green technologies and other US industries, such as steel, because of the lower carbon intensity of their production compared to competitors. Carbon pricing is also essential for efficient abatement, and the US is unlikely to meet its climate goals without it.

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Start with a flexible and modest price floor. An initial minimum price agreement can be only modestly ambitious because it can be implemented on top of all existing and planned national and international climate policies, making it more palatable. Once coordination is established, the price can be adjusted. Negotiation flexibility includes targeting specific industries or sectors, such as electricity, for which implementation is straightforward and reliable. It also includes setting an average minimum price that allows participants to exempt some sectors at the expense of others.

Start with a methane agreement. There is currently a unique window of opportunity for a transatlantic methane agreement, which could be a critical step toward kick-starting climate cooperation. Reducing methane emissions is essential to limiting the rise of global temperatures to unacceptable levels, and the oil and gas sector has the most significant low-cost abatement potential. Under the Inflation Reduction Act (IRA), the US has introduced a methane emissions fee as a backstop to new methane regulations in the oil and gas sector. In a parallel, uncoordinated process, the EU is implementing new methane regulations for fossil fuels, including a proposal to sanction imports from countries that fail to meet specific regulatory standards.

Coordinating these transatlantic efforts with similar goals and scope would encourage oil and gas exporters to adopt regulations comparable to those in the US and the EU or face a border adjustment fee on exports to both jurisdictions (Böhringer et al., 2016). The climate impact would be significant, and if broadened to include other key importers, its impact would be comparable to the overall effect of the recent IRA. Still, the impact on energy prices would be small because of the low abatement costs and the ability of importers to substitute relatively clean supply sources (Rystad, 2023). Most importantly, a coordinated methane policy would help build climate cooperation, defuse recent friction over divergent policy approaches and pave the way for alignment in other sectors, which could ultimately motivate further coordinated climate policy action globally (Clausing et al., 2023; Clausing and Wolfram, 2023).

In light of the above, coordination on greenhouse gas pricing should be pursued by focusing first on the US and the EU, tailoring initial proposals to minimize political and economic barriers to agreement, and building on existing parallel developments. This approach can significantly strengthen the critical process of international climate cooperation. It is hard to overstate the potential benefits of this path to climate cooperation for the US, the EU and the world.

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